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Essays on monetary policy, credit and housing.

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To Katerina, Dimitra and Spyros.

Declaration

I declare that the content presented in this PhD thesis constitutes my own original work, except where explicitly acknowledged. I have diligently recognized all the sources of information utilized in the creation of this dissertation.

Aristotelis Margaris
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Abstract

The present thesis consists of two independent chapters. The contribution of the thesis lies in the field of monetary policy, particularly in the conjunction of monetary policy with credit and housing. The first chapter contributes to the literature by shedding light on the interaction of monetary policy with Government Sponsored Enterprises (GSEs) in the U.S. and revealing their crucial role in the transmission of monetary policy through financial intermediaries. The analysis suggests that GSEs expand their share in the mortgage market after a monetary policy tightening. We discuss three reasons behind this result and then focus on its implication on the transmission mechanism of monetary policy shocks. We conduct a counterfactual experiment to measure the effects of a monetary tightening on the economy when GSEs' future market share is constrained not to respond to this shock. We document a sizable difference between the standard and the counterfactual impulse responses. Under the counterfactual, monetary policy is more effective in contracting real activity, prices and increasing credit cost. Thus GSEs' share expansion after a monetary tightening erodes the effects of the latter on the economy. We link those findings with the bank-lending channel of monetary policy. We argue that GSEs mitigate the increase in the cost of financing for financial intermediaries after a monetary tightening. As the bank-lending channel predicts, a relatively lower cost of liquid funds implies a smaller increase in external finance premium

and, therefore, a lower impact of a monetary tightening on the economy.

The second chapter constitutes the first body of research to provide estimates of the dynamic effects of monetary policy on regional house prices in the U.K. and reveal heterogeneity in the responses of regional house prices to monetary policy shocks. The existing literature dedicates much attention to differences in local housing supply to interpret the heterogenous response of regional house prices to economic shocks. The chapter contributes to this debate by showing that heterogeneous regional house price developments after a monetary policy shock relate to borrowing constraints and the household balance sheet compositions in the region. To the best of our knowledge, this thesis is the first which adds this dimension to regional house price heterogeneity. After a monetary expansion, in regions with low loan-to-income ratios, households exploit lower mortgage rates and increase regional housing demand via intertemporal substitution. On the contrary, in regions with low housing affordability, a large share of households are constrained to borrowing and cannot increase housing demand. Consequently, house prices appreciate relatively less after a monetary policy expansion.

Contents

Chapter 1

Government-sponsored intermediation and the bank-lending channel of monetary policy.

Abstract

We examine the response of Government Sponsored Enterprises to monetary policy shocks and investigate their role in the transmission mechanism of monetary policy. We use VAR models and external instruments to show that GSEs expand their market share in response to monetary tightenings. A counterfactual analysis suggests that GSEs mitigate the effects of monetary policy shock on economic activity, prices and cost of credit. Conceptually we link our analysis with the bank-lending channel of monetary policy. In the event of a monetary contraction, depositors give up deposits and seek higher returns in the financial markets. Financial intermediaries seek liquidity via costly debt issuance to accommodate the deposit loss. The increase in the cost of funds contracts loan supply and amplifies the effects of monetary policy. Our findings suggest that GSEs alter the effects of the bank-lending channel. GSEs expand their market share by purchasing banks' illiquid assets (mortgages). Hence, banks can substitute illiq-

uid assets for liquid via GSEs, which allows them to keep the cost of liquid funds at relatively lower levels in at least two ways. First, via lowering the demand for funds in the funds market and second, by reducing the term structure of GSEs' debt. As a result, they cut the supply of loans proportionally less. This disrupts the amplification mechanism of monetary policy through bank lending.

1.1 Introduction

Government Sponsored Enterprises (GSEs)[1] have been actively involved in the mortgage market by holding a large share of total mortgage debt for most of the post-war period.[2] The idea behind the foundation of GSEs was to maintain stability in the housing market and promote homeownership in the country. To fulfil their role towards the Federal government, they operate in the secondary mortgage market by purchasing mortgages from financial intermediaries. This mechanism provides banks with liquidity and allows them to expand mortgage credit. At the same time, GSEs have been privately owned for most of their recent history, implying that their market activity should also be profitable and deliver dividends to the shareholders.

Given the importance of housing-related credit and house prices for the macroeconomy (Iacoviello, 2005; Leamer, 2007; Mian and Sufi, 2009; Di Maggio and Kermani, 2017), one would expect that GSEs' operations are effective in shaping mortgage credit and economic activity. However, the findings of the existing literature on this topic are mixed. Some early attempts suggest a positive effect of GSE activity on residential mortgage

[1] In this chapter we consider the two largest GSEs, Freddie Mac and Fannie Mae.

[2] As noted in Fieldhouse et al. (2018) Freddie's and Fannie's share accounted for 40% to 50% of total originations in the period 1980-2006.

debt, construction activity and mortgage spreads (Smith et al., 1988; Jaffee and Rosen, 1978; Hendershott and Villani, 1980; Hendershott and Shilling, 1989), while others show no effect of GSE activity on residential investment or the homeownership rate (Arcelus and Meltzer, 1973; Meltzer, 1974). A common shortcoming of the aforementioned studies is that they are based on reduced form estimates and thus lack a thorough identification approach. In a more recent work, Lehnert et al. (2008) utilize VARs with recursive ordering to examine the impact of GSEs' purchases on mortgage spreads, finding no significant influence on the cost of residential credit. In the same spirit but with arguably more rigorous identification Fieldhouse et al. (2018) provide estimates of the dynamic effects of GSEs' purchasing activity on cost-of-credit, housing and economic activity indicators. Their estimates advocate the crucial role of GSEs in the housing and credit market in the U.S. They show that expansions in GSEs' purchase activity decrease the cost of credit and increase house prices and homeownership. Notably, these effects are beyond the mortgage and housing market as they document a significant decrease in corporate and treasury spreads. We interpret these findings as of major interest for monetary policy, especially with respect to its effects through credit.

Surprisingly, the literature is silent regarding the interaction of monetary policy with the GSEs. This chapter fills this gap and investigates the interaction of monetary policy with GSEs and their role in the transmission mechanism of monetary policy. Fieldhouse et al. (2018) briefly discusses the interaction of monetary policy shocks with credit supply shocks, i.e., the interaction of monetary policy with cyclically and non-cyclically motivated interventions of the Federal government in the operational rules of GSEs. Instead, we focus on the effects of monetary policy on the systematic operation of GSEs. Using structural VARs, we show that GSEs expand their market share after a monetary contraction. A counterfactual experiment to assess the role of GSEs in the transmission mechanism of monetary policy. The results suggest that monetary policy has greater effects on economic activity, prices and cost of credit after shutting down the GSE channel.

Considering the role of GSEs as housing market stabilizers, the fact that they increase their market share and thus credit supply in response to monetary tightenings is not surprising. When they observe an increase in the interest rates by the Fed, they expect housing demand to decrease due to the higher cost of credit. Thus, they act to prevent a decrease in house prices. Considering their profitability goal, their response to a monetary tightening is not expected to be different from market share expansion because of profit opportunities that GSEs may have in the event of an interest rate increase. Being backed by the Federal government endowed GSEs with benefits such as the ability to issue bonds with yields close to treasury yields, the right to borrow directly from the treasury and issuing bonds eligible for open market operation by the Fed (Fieldhouse and Mertens, 2017). Consequently, any increase in interest rates is expected to increase the spreads on GSEs bonds relatively less than the mortgage spreads. This creates profit opportunities for GSEs as they can use low-cost funding to finance the purchase of relatively higher-return mortgages.

A key question arises from GSEs expanding the credit supply in response to monetary tightening. What role, if any, does the expansion of GSEs' market share play in the transmission mechanism of monetary policy? A large strand of literature describes the transmission of monetary policy through credit cost and the banking system known as the credit channel of monetary policy (Bernanke and Blinder, 1988; Bernanke and Gertler, 1989; Bernanke and Blinder, 1992; Bernanke and Gertler, 1995; Bernanke et al., 1999; Kashyap and Stein, 2000; Drechsler et al., 2017). These studies usually depart from the standard textbook view, where the central bank has leverage over the real interest rate and thus over expectations about the future path of the real rate due to sticky prices. Instead, they introduce the role of financial intermediation as an amplification mechanism of the transmission of monetary policy in the presence of financial frictions. The key idea is that, in the presence of frictions, a wedge emerges between internal and external financing, known as the external finance premium. A monetary policy tightening is expected to increase the size of the external finance premium in two ways. First, by worsening the balance sheet position of non-financial borrowers (households and firms) as it depreciates the value of total assets and decreases net cash flows. Second, by increasing the cost of funds for financial intermediaries and cutting the supply of loans.

Regarding the involvement of GSEs in the transmission of monetary policy, we would rather focus on the intermediaries side of the credit channel or on what is known as the *bank-lending channel* of monetary policy. In the traditional view of the bank-lending channel, as monetary policy tightens, deposits, which can be considered a primary source of funding for banks, flow out of the system. Responding to this event, banks can either raise the deposit rate to prevent drainage or turn to financial markets to finance their lending activity. Under all scenarios, the cost of funds increases, the supply of loans shifts inwards, and the external finance premium increases (Bernanke and Blinder, 1988, 1992; Kashyap and Stein, 2000). It follows that the power of the mechanism depends on the relative cost of financing via financial markets against deposits. In the extreme case where demand for intermediaries' debt is perfectly elastic, banks can substitute financing from deposits to financing from financial markets without affecting the supply of loans. Although, as argued in Drechsler et al. (2017); Hanson et al. (2015); Stein (1998), deposit funds cannot be replaced at zero cost. Financial market investors and depositors can substitute banking debt and deposits for higher-return assets, and this increases the cost of funding for banks. Hence banks are expected to cut the supply of loans proportionally to the cost of substituting deposit funds for non-deposit funds.

In contrast to depositors and financial market investors, GSEs supply funds in exchange for mortgages. When monetary policy tightens, instead of being relied on costly external funding and deposits, banks can substitute illiquid (mortgages) for liquid (cash) assets by selling mortgages to GSEs. This will provide them with the funds to keep their lending activity and reduce their dependence (demand) on financial markets. This reduces the cost of funds for financial intermediaries and keeps the supply of loans in the economy relatively high. In favour of this narrative, Drechsler et al. (2022) reports a large drop in deposits and expansion of private-label securitization after the monetary tightening in 2003. This episode was a prominent example of banks substituting mortgages for liquidity and maintaining their lending supply.

To examine the response of GSEs to monetary policy and their role in the transmission mechanism, we model the dynamics of the economy in a Bayesian-VAR using monthly macro aggregates, interest rates and a measurement of the GSEs' market share. To identify the monetary policy shock, we follow Stock and Watson (2012) and Mertens and Ravn (2013) and utilize a proxy for the latent structural shocks as an external instrument.

In our baseline estimations, we use the instrument of Degasperi and Ricco (2021), which extends the instrument of Miranda-Agrippino and Ricco (2021). Following an extended strand of literature (Cochrane and Piazzesi, 2002; Kuttner, 2001; Gürkaynak et al., 2005; Gertler and Karadi, 2015; Nakamura and Steinsson, 2018; Swanson, 2021) they construct the instrument using high-frequency movements of various federal fund futures around FOMC announcements. The main idea is that in a short window of 30 minutes, 10 minutes before and 20 minutes after the FOMC announcement, the monetary policy shock is a major shock that hits the economy. Before the FOMC announcements, market participants assess the economic outlook and put a price on the Fed fund futures according to their expectations about the future path of the Fed fund rate. During the announcements, they revise their expectations due to unexpected changes in the Fed fund rate and revise the price of the Fed fund futures accordingly. Thus the price difference of the Fed fund futures before and after the announcements measures the exogenous and unanticipated change in monetary policy.

Without further refinement, the constructed measurement captures surprises regarding the present level and the future path of the Fed fund rate, i.e., pure monetary policy and forward guidance shocks. This is true assuming that the market participants and the monetary authority observe the same information set (Miranda-Agrippino and Ricco, 2021). Usually, they do not (Blinder et al., 2008). In such cases, the instrument also conveys information about the central bank's present and future economic outlook assessment. The literature describes that as delphic forward guidance (Campbell et al., 2012) or information shocks (Nakamura and Steinsson, 2018; Jarociński and Karadi, 2020). To "clean" the instrument from information effects, Miranda-Agrippino and Ricco (2021) isolate the residual component of a regression of the Fed fund futures surprises on the market participant's and the central bank's economic projections. Then they regress the refined instrument on its lags to wipe out any anticipation due to the slow absorption of information. Hence, the resulting instrument captures pure monetary and forward guidance shocks free of information and anticipation effects.

We define a contractionary monetary policy shock as a shock which increases the monetary policy indicator (1-year Treasury bond) by one percentage point on impact. The impulse response analysis indicates a strong expansion of GSEs' future market share by seven percentage points on impact and convergence to its trend in a 6-month horizon. At the same time, privately held mortgages decline persistently across the forecast horizon. This result corroborates the mechanism discussed above, where banks substitute mortgages for cash using government-sponsored securitization. The responses of standard macro and credit variables align with the macroeconomic literature without any puzzles to appear. The results are robust to a large set of instruments and various model specifications.

To investigate the role of GSEs in the transmission mechanism of monetary policy, we conduct a counterfactual experiment in the spirit of Bernanke et al. (1997); Sims and Zha (2006); Bachmann and Sims (2012). Using our estimated VAR model, we compare impulse responses from the baseline proxy-VAR with impulse responses from a VAR where any effects through GSEs have been shut down. To impose the counterfactual condition, we generate a sequence of shocks to the GSE market share such that the impulse responses to monetary policy shocks are zero across the forecast horizon. Under the counterfactual condition, monetary policy exhibits greater effects on real activity, prices and credit costs. These results lead us to conclude that the systematic operation of GSEs weakens the effectiveness of monetary policy shocks on the economy.

The remainder of the chapter is organized as follows. Section 2 describes the econometric framework, Section 3 presents the data and discusses the results, Section 4 presents robustness checks, and Section 5 concludes.

1.2 Econometric Framework

Consider an $n \times 1$ vector y_t to collect the variables of interest. The dynamics of y_t can be described by a system of linear simultaneous equations,

$$A_0 y_t = A_1 y_{t-1} + A_2 y_{t-2} + \cdots + A_p y_{t-p} + \varepsilon_t \tag{1.1}$$

where $\varepsilon_t \sim \mathcal{WN}(0, \Omega)$ is a vector of structural shocks with Ω diagonal,i.e, the elements of ε_t are mutually orthogonal, and A_j, $j = \{0, 1, \ldots, p\}$, are $n \times n$ matrices of coefficients. Constant terms have been omitted for simplicity. The dynamics in (1.1) can be described by a reduced form VAR,

$$y_t = B_1 y_{t-1} + B_2 y_{t-2} + \cdots + B_p y_{t-p} + u_t, \tag{1.2}$$

with $u_t \sim \mathcal{N}(0, \Sigma)$ be a Gaussian white noise vector of reduced form residuals and $B_1, \ldots, B_p$ are coefficient matrices. Let the matrix $S = A_0^{-1}$, using S we link the reduced form errors u_t with the structural shocks ε_t via

$$u_t = S\varepsilon_t. \tag{1.3}$$

It is straightforward that $B_i = SA_i$, $i = \{1, 2, \ldots, p\}$. Under stability, the model of Equation (1.2) admits a moving average representation,

$$y_t = Iu_t + \Psi_1 u_{t-1} + \Psi_2 u_{t-2} + \ldots \tag{1.4}$$

Since S is a square matrix, we can rewrite the equation above as

$$y_t = SS^{-1}u_t + \Psi_1 SS^{-1}u_{t-1} + \Psi_2 SS^{-1}u_{t-2} + \ldots$$

using relationship (1.3), we can obtain the impulse response functions of the structural VAR in Equation (1.1) as

$$y_t = S\varepsilon_t + \Psi_1 S\varepsilon_{t-1} + \Psi_2 S\varepsilon_{t-2} + \ldots$$

or

$$y_t = \sum_{i=0}^{\infty} \Phi_i \varepsilon_{t-i} \tag{1.5}$$

with $\Phi_0 \equiv S$ and $\Phi_i \equiv \Psi_i S$, for $i = 1, 2, \ldots$ Each column of matrices Φ contains the impulse responses of the endogenous variables to the corresponding shock in the respective horizon. Let the monetary policy indicator be the first variable in the model. Thus, the first column of matrices Φ_{h1}, $h = 0, 1, 2, \ldots$, contains the impulse responses to a monetary policy shock across the forecast horizon. It is straightforward that in order to obtain Φ_{h1}, we need to estimate the dynamics of the variables and define the first column of S.

To estimate B and Σ we rewrite the VAR in Equation (1.2) in compact matrix form:

$$Y_t = X_t B + u_t \tag{1.6}$$

with Y_t an $1 \times n$ matrix of endogeneous variables, $X_t = [Y_{t-1}, \ldots, Y_{t-p}, 1]$ a $(np + 1) \times 1$ matrix of regressors in each equation and B the $(np + 1) \times n$ matrix of VAR coefficients. $p = \{1, 2, \ldots, p\}$ denotes the selected lag length, since we deal with monthly observations, we set $p = 12$. Last, u_t is the vector of the reduced form residuals defined in (1.2). We estimate the model parameters via Bayesian methods. We impose the standard natural conjugate priors for the linear VAR parameters with tightness to be defined optimally as in Giannone et al. (2015). Appendix A.1 provides details for the model estimation.

Following Stock and Watson (2012) and Mertens and Ravn (2013), we utilize a proxy series m_t as an instrument for the latent monetary policy shocks ε_t^m to impose covariance restrictions and obtain S_1. First, let m_t satisfy

$$\mathbb{E}\left(m_t \varepsilon_t^{mp}\right) = \alpha \tag{1.7}$$

and

$$\mathbb{E}\left(m_t \varepsilon_t^{-mp}\right) = 0. \tag{1.8}$$

Equation (1.7) describes the relevance condition where z_t needs to be correlated with the shock of interest (ε_t^{mp}), and Equation (1.8) describes the exogeneity condition, which requires m_t to be orthogonal to all the remaining shocks (ε_t^{-mp}). Under partial invertibility, we also consider the lead-lag orthogonality between the instrument and the reduced form residuals (Miranda-Agrippino and Ricco, 2023). Then, we can identify the impact vector S_1 up to a scale as:

$$\mathbb{E}\left(u_t^{mp} m_t\right)^{-1} \mathbb{E}\left(u_t^{-mp} m_t\right) = S_{11}^{-1} S_{12}, \tag{1.9}$$

where S_{11} coresponds to the element of the column vector S_1 related to the shock of interest and S_{12} all its remaining elements. Combining S_1 and the estimates of the reduced form model, we can obtain the impulse response functions of the endogenous variables to a monetary policy shock.

1.2.1 The Couterfactual

One of the main focuses of this chapter is to assess the role of GSEs in the transmission mechanism of monetary policy shocks. To achieve that, we design a counterfactual experiment to isolate the effects of monetary policy on the economy through GSEs. This class of counterfactuals within the VAR setup assume a sequence of shocks that cancel out the response of selected variable across the forecast horizon (Bernanke et al., 1997; Sims and Zha, 2006; Kilian and Lewis, 2011; Bachmann and Sims, 2012). Then, we compare impulse responses to a standard monetary shock against impulse responses of the same economy to a monetary policy shock where GSEs are restricted to not respond due to the sequence of generated shocks. Crucially, we assume that the sequence of hypothetical shocks that generate our counterfactual are modest, in the sense that they do not change the structure of the economy materially (Kilian and Lewis, 2011).

Assume that the monetary policy indicator is the first variable in y_t and the GSE indicator the second. Following Bachmann and Sims (2012), we decompose the effects of monetary policy on the economy to direct effects, i.e., the first column vector in S, and the indirect effects of monetary policy through GSEs. The latter is given by the interaction of the direct effect of monetary policy on GSEs' market share (second row of the first column vector of S) with the direct effects of a GSE credit shock on the rest of the endogenous variables in the model ($3:n$ rows of the second column vector in S). Thus, it is straightforward that we need knowledge of the second column of S.

To identify the monetary policy shock and the GSE credit shock, i.e., the first two columns of S, we generalize the proxy-VAR identification described above for the case of two instruments for two shocks[3]. Consider a partitioning of S as follows:

$$S = \left(\begin{array}{c|c} \underset{k\times k}{s_{11}} & \underset{n\times(n-k)}{s_{21}} \\ \hline \underset{(n-k)\times k}{s_{12}} & \underset{(n-k)\times(n-k)}{s_{22}} \end{array}\right)$$

k denotes the shocks of interest, in our case, the monetary policy shock and the GSE credit shock, thus $k = 2$. The contemporaneous impact of the shocks can be identified up to scale under unity normalization of the diagonal of s_{11} as:

$$\mathbb{E}\left(u_t^{1:2} m_t\right)^{-1} \mathbb{E}\left(u_t^{3:n} m_t\right) = s_{11}^{-1} s_{12}, \tag{1.10}$$

[3] Mertens and Ravn (2013) provide analytical solutions for the case of multiple instruments to identify multiple shocks.

m_t is the 2×1 vector of instruments where the first entry corresponds to monetary policy and the second to GSE credit shock. As a final step, we impose further restrictions to identify multiple shocks (Mertens and Ravn, 2013). We impose a lower triangular structure in s_{11}. By imposing that, we assume there is no contemporaneous feedback of GSEs to monetary policy, which is plausible given the sluggish effects of GSE credit shocks on the economy (Fieldhouse et al., 2018).

Since we have identified the first two columns of S, we can implement the counterfactual as follows: Consider a companion representation of the VAR in Equation (1.2):

$$Z_t = \Lambda Z_{t-1} + u_t$$

where $Z_t = [Y_t, Y_{t-1}, \ldots, Y_{t-p-1}]$ and

$$\Lambda = \begin{pmatrix} B_1 & B_2 & \ldots & \ldots & B_p \\ I & 0 & 0 & \ldots & 0 \\ 0 & I & 0 & \ldots & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & \ldots & \ldots & I & 0 \end{pmatrix}.$$

The impulse response of variable i to shock q at horizon h is given by:

$$\Phi_{i,q,h} = v_i \Lambda^{h-1} S(q), \tag{1.11}$$

where v_i is a selection vector that takes value one in row i and zero otherwise. The counterfactual experiment holds fixed the response of GSEs to a monetary policy shock, i.e., $\widetilde{\Phi}_{2,1,h} = 0$, $h = \{0, \ldots, H\}$. To generate this condition we define a hypothetical shock $\widetilde{\varepsilon}_2$ such:

$$S(2,1) + S(2,2)\,\widetilde{\varepsilon}_{2,0} = 0 \tag{1.12}$$

or

$$\widetilde{\varepsilon}_{2,0} = -\frac{S(2,1)}{S(2,2)} \tag{1.13}$$

for $h = 0$. Then we calculate the subsequent hypothetical GSE shocks recursively:

$$\widetilde{\varepsilon}_{2,h} = \frac{\Phi_{2,1,h} + \sum_{j=1}^{h-1} v_2 \Lambda^{h-j} S(2)\, \widetilde{\varepsilon}_{2,j}}{v_2 S(2)}, \;\; h = 1, \ldots, H$$

Given the hypothetical sequence $\widetilde{\varepsilon}_2$, we can compute the counterfactual impulse responses of the system to a unity monetary policy shock as:

$$\widetilde{\Phi}_{i,1,h} = \Phi_{2,1,h} + \sum_{j=1}^{h} v_i \Lambda^{h-j} S(2)\, \widetilde{\varepsilon}_{2,j} \tag{1.14}$$

To assess the role of GSEs in the transmission of monetary policy shocks, we compare impulse responses obtained by Equation (1.14) with impulse responses estimated according to Equation (1.11). Section 1.3 discusses the results of the counterfactual exercise.

1.3 Data and Empirical Results

Our approach builds on a standard monetary policy VAR model as in Coibion, 2012; Gertler and Karadi, 2015; Miranda-Agrippino and Ricco, 2021. Our baseline specification includes industrial production and unemployment to model real activity, CPI and commodity prices as nominal measurements, and the excess bond premium as a financial market indicator. The latter captures the spread component of an index of various private sector bonds net of default and is considered a powerful indicator for economic activity (Gilchrist and Zakrajšek, 2012; Gertler and Karadi, 2015). The superiority of the excess bond premium against other financial indicators is particularly beneficial in the VAR context as it provides valuable information and, at the same time, keeps the model parsimonious. Last, we include the mortgage spread as a cost of credit indicator and the GSE expected market share to capture GSE activity.

GSE's expected market share is defined as the annualized net commitments made by GSEs in a 3-month period, over a long-run trend of mortgage originations. That is:

$$Expected\ Market\ Share = \frac{12}{3} \times \frac{\sum_{j=0}^{2} p_{t+j}}{\widetilde{Z}} \tag{1.15}$$

where p_t denotes net commitments and $\widetilde{Z}_t$ is the long-run trend in annualized mortgage originations as defined in Fieldhouse et al. (2018). GSE net portfolio commitments are the difference between commitments on mortgage purchases and commitments on mortgage sales in each time period. We choose net commitments against other measurements as the secondary mortgage market operates through advanced announcements. GSEs demand mortgages in the secondary market by making advanced commitments to mortgage originators. Then mortgage originators use eligible loans from their portfolio or originate new loans which comply with GSEs standards and deliver them to GSEs.

Originally, Fieldhouse et al. (2018) use annualized commitments over an 8-month period, although they show that shorter or longer periods deliver similar results. Apart from that, our motivation to study changes in expected GSE market share over a shorter horizon is the nature of the shock itself. Fieldhouse et al. (2018) study GSE credit supply shocks and instrument the shocks using historical records of government interventions on GSEs'operational rules. The identified shocks have gradual effects on GSEs' balance sheets and occur sparsely in time. For that reason is meaningful to

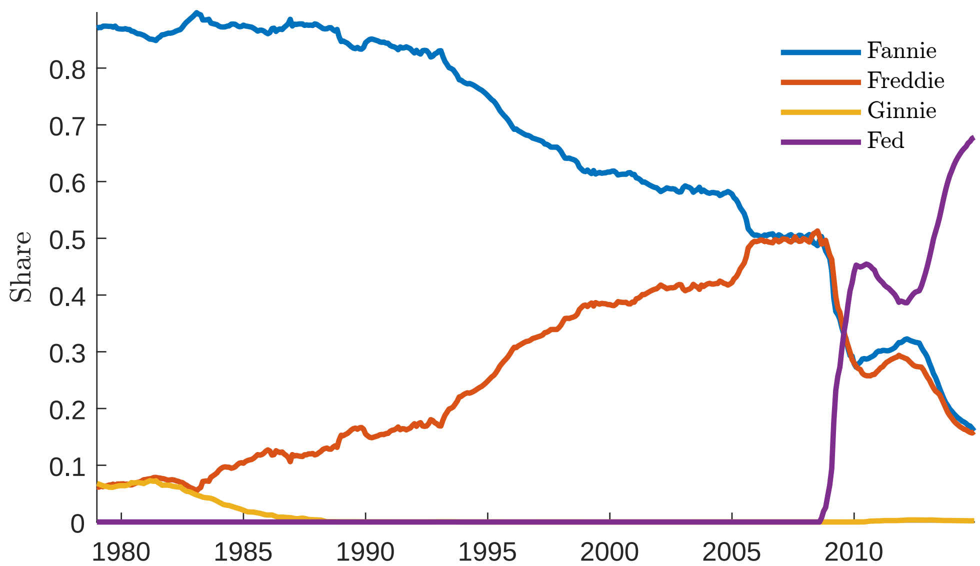

Figure 1.1: Mortgage holdings of each GSE over the total GSE holdings.

study changes in commitments over longer horizons[4]. In contrast, monetary policy shocks are known for their abrupt transitory effects, and FOMC announcements occur regularly and deliver surprises every month or two. Thus, calculating a short period of expected GSEs market share mitigates statistical noise and gives statistical power to the instrument.

We choose to discard Ginnie Mae and the Fed from the analysis and focus, instead, on Freddie Mac and Fannie Mae, as together hold by far the largest share in the secondary mortgage market for most of our sample period, see Figure 1.1.

To analyse the effects of monetary policy on GSE activity and the role of GSEs in the transmission of monetary policy, we build upon the baseline by adding relevant housing, credit and GSE indicators. Appendix A.2 provides a description of all the variables used in various model specifications, their sources and their transformations. Our estimates utilize a sample of monthly observations from 1979:01 to 2014:11. Following Miranda-

[4]In fact Fieldhouse et al. (2018) state that the 8-month horizon is chosen because it delivers the highest statistical relevance for the instrument.

Agrippino and Ricco (2021) and Gertler and Karadi (2015), we select the sample start date to coincide with the appointment of Paul Volker as chairman of the Federal Reserve because of evidence for change in monetary policy regime for the post-Volker period (Clarida et al., 2000).

The main results of the chapter are based on identified monetary policy shocks using the instrument of Degasperi and Ricco (2021), which is an extension of the instrument constructed by Miranda-Agrippino and Ricco (2021). Note that the instrument covers a shorter period of time than the endogenous variables in the model, from 1991:01 to 2014:12. Consequently, our identification period is restricted to coincide with the time length of the instrument. In Section 1.4, we consider alternative instruments for monetary policy shocks and subsample analysis for robustness. We show that the results are stable across instruments and sample periods.

The counterfactual experiment requires identifying shocks to GSE's market share. To achieve that, we utilize an instrument based on GSEs' excess stock market returns[5]. The instrument is constructed as the residual component of a regression of the log ratio of GSE stock returns over the market returns on a large set of contemporaneous (Q) and lagged controls (W):

$$\log\left(\frac{GSEs'Retuns}{MarketReturns}\right)_t = c + \Theta Q_t + \sum_{i=1}^{12} \Gamma W_{t-1} + e_t^{GSE},$$

where e_t^{GSE} is the series of interest. The appendix of Fieldhouse et al. (2018) describes the strategy and the selection of the control variables in detail. Fieldhouse et al. (2018) also provide an instrument for GSEs' credit shocks based on narrative analysis. We choose to proceed with the excess stock returns based instrument (e_t^{GSE}) instead of the narrative instrument because it is more informative in the identification period (1991:01-2014:12). As de-

[5]Originally, the idea of exploiting stock market returns to identify macroeconomic shocks introduced by Fisher and Peters (2010) in the context of government spending shocks.

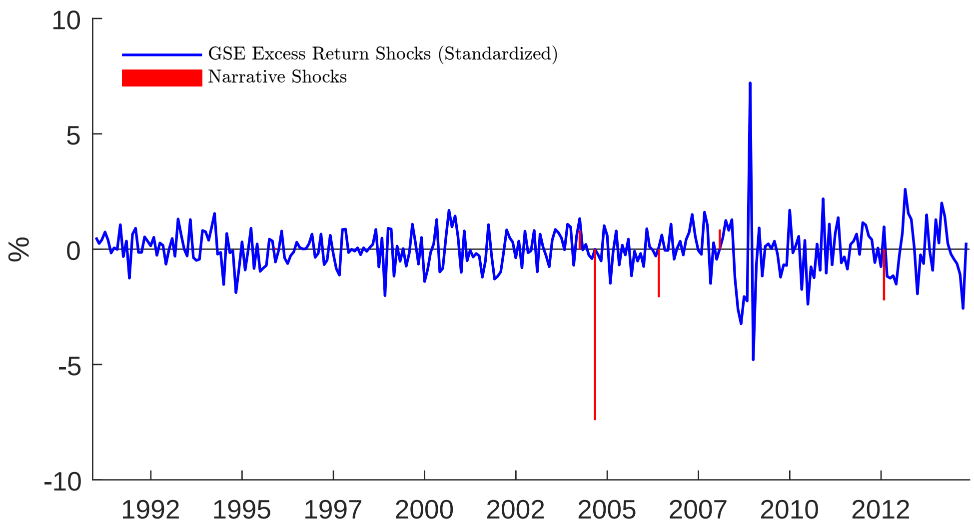

Figure 1.2: Excess market return shocks against narrative shocks.

picted in Figure 1.2, in the period 1991-2014, only 5 narrative events occur and thus observed limited variability for the narrative instrument. Conversely, GSEs' excess stock returns convey more information for the same period. As shown in the appendix section of Fieldhouse et al. (2018), both approaches to identification yield similar results.

Figure 1.3 displays the impulse responses of the benchmark model to a monetary tightening that increases the 1-year treasury rate by 1 percentage point. For GSEs' market share, we observe a strong expansion of roughly 7 percentage points on impact, a peak response of 8.5 percentage points in the month post of impact and then a convergence to the initial trend in the next five periods. Regarding economic activity, the monetary tightening is recessionary, with a decline in industrial production and an increase in unemployment. Both price indicators decrease, with commodities prices exhibiting a milder and more transitory response than the CPI. The excess bond premium increases, reflecting a tightening in the financial markets. Finally, the mortgage spread increases, reflecting an increase in the cost of credit. Generally, the results of the benchmark specification are consistent

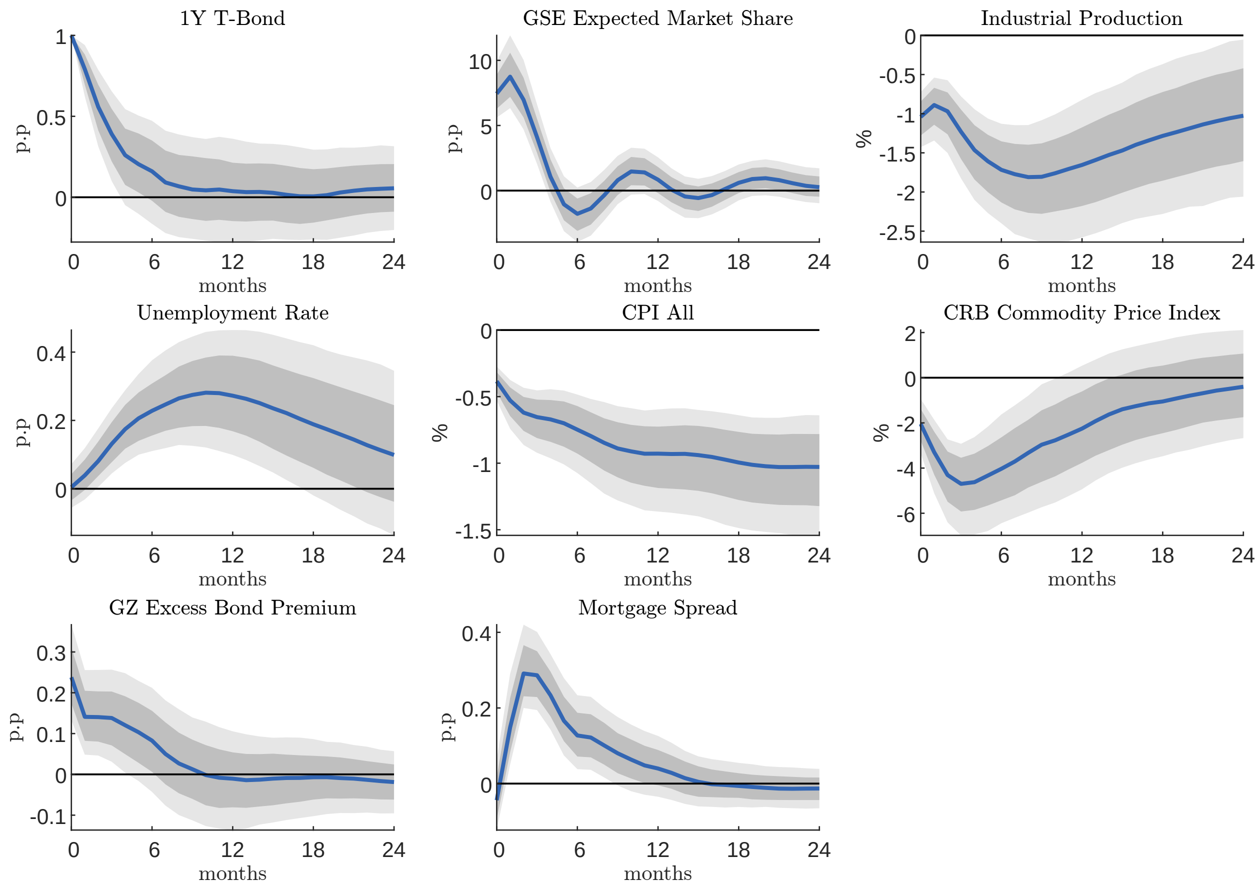

Figure 1.3: The figure shows responses to 1 percentage point increase in 1Y T-bond. Shaded areas denote 68% and 90% credible density intervals. p.p denotes percentage points and % percent.

with macro theory and do not exhibit any puzzles.

In the remaining chapter, we discuss the relationship of monetary policy with GSEs and their role in the transmission mechanism. First, we discuss the rationale behind the positive response of GSEs'market share to monetary policy tightenings. The most straightforward reason would be that in order to fulfil their mandate towards the federal government, GSEs increase their market share to prevent a slowdown of the homeownership growth rate and turmoil in the housing market.

A second reason is that GSEs may have some profit opportunities due to higher interest rates. GSEs' cost of borrowing is expected to follow closely the treasury rates due to the common perception that their debt is insured

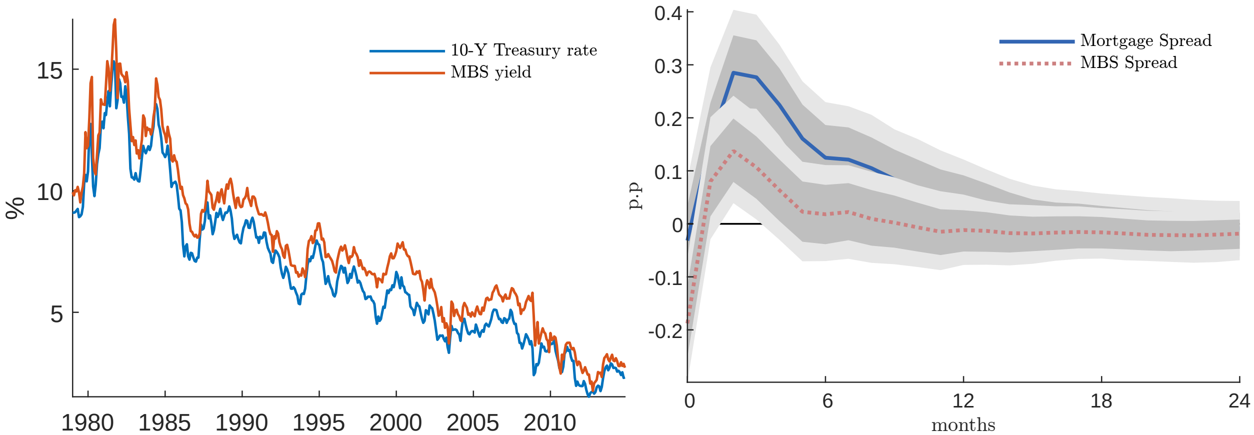

Figure 1.4: The left panel illustrates the 10-Y Treasury rate and the yield of GSE-issued MBS. The right panel shows the impulse response of the GSE-issued MBS spread against the response of the mortgage spread.

by the Federal government (Passmore, 2005). Alternative to debt, GSEs often issue mortgage-backed securities (MBS), sell them to other GSEs or investors, and finance their purchase activity. The left panel in Figure 1.4 illustrates the tight linkage of the government rates with the GSE-issued MBS yields. This is an illustrative example of the favourable finance conditions for GSEs. We use MBS yields as the GSE cost of financing indicator because GSE bond yields are unavailable. Considering the central bank to increase the interest rates, the returns on mortgage holdings appreciate via the traditional cost-of-capital channel and balance sheet effects of monetary policy on non-financial borrowers. At the same time, GSEs' cost of financing is expected to increase relatively less than the mortgage spreads due to the favourable financing conditions discussed above. The right panel of Figure 1.4 show that after a monetary tightening, mortgage spreads increase roughly by 20 basis points more than the yields of the GSE-issued MBS. This wedge between the GSE cost of finacing and mortgage returns implies that GSEs can purchase high-return mortgages by issuing relatively low-cost debt or MBS. Exploiting that, they increase profits by expanding their market share.

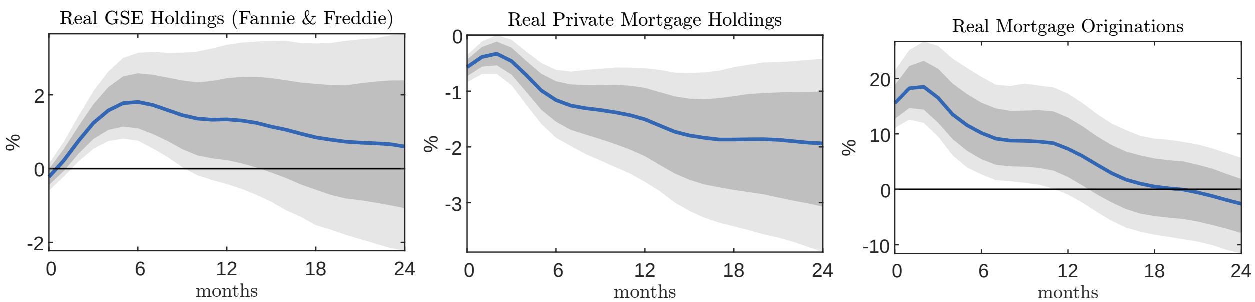

Figure 1.5: IRFs of GSE total mortgage holdings and private mortgage holdings. The shaded areas denote 68% and 90% credible density intervals.

A further reason behind the expansion of GSE market share after a monetary contraction could be the limiting regulations regarding GSE portfolio composition. The asset holdings of GSEs are restricted by Federal law to mortgage-related assets, treasury securities and cash or cash-equivalent holdings with very few deviations. In the event of a monetary tightening, the opportunity cost of holding cash or cash-equivalent assets or low-return treasury securities increases, and at the same time, GSEs cannot turn to alternative higher-return assets. That makes mortgages the most plausible asset to hedge against interest rates. The three points above could justify the GSEs' market share response to a monetary policy tightening.

The mechanics behind the GSEs' market share expansions are important to understand the involvement of GSEs in the financial intermediaries sector and discuss any implications for the transmission of monetary policy. GSEs cannot originate mortgages but can only purchase them from banks. They do so by advanced commitments. They commit to purchase a specific amount of mortgages with specific characteristics in the next few months[6]. Banks originate new mortgages or use eligible loans from their portfolio to deliver the demanded mortgages to GSEs. Therefore, a GSE market share expansion after a monetary policy tightening takes place via financial inter-

[6]GSEs can purchase only conforming loans. These are loans with value inside the limits of FHFA. The majority of mortgages are within the conforming loan limits.

mediaries who sell their retained and originate-to-sell mortgages to GSEs. This mechanism is captured in Figure 1.5, where we observe that within a 6-month horizon, GSE total mortgage holdings increase by 2% and privately owned mortgages decrease roughly by the same amount. At the same time, mortgage originations exhibit a significant increase of roughly 10% on impact capturing the originate-to-sell mechanism. Consequently, in the wake of a monetary tightening, GSEs increase their mortgage purchase activity, provide funds to banks and operate as an alternative financing tool for financial intermediaries which otherwise rely on deposits and debt. Naturally, this raises questions regarding the transmission of monetary policy through banks' cost of funding or to what is known as the bank-lending channel of monetary policy.

In the traditional bank-lending channel, as the central bank raises interest rates, depositors shift from deposits to higher-return assets and contract the availability of funds in the banking system. Then, because of reserve requirements or limits on banking sector debt, banks cut the supply of loans and increase the external finance premium (Bernanke and Blinder, 1988). This view has been challenged in the post-financial liberalization period as reserve requirements had been lifted and banks had unconstrained access to the financial markets (Romer and Romer, 1990; Woodford, 2010). Although, the bank-lending channel does not strictly require banks to hit their reserve requirements or any other constraint to be relevant. As long as they cannot substitute deposits for debt without a cost, they are expected to cut the supply of loans, increase the external finance premium and amplify monetary policy (Kashyap and Stein, 1994). Stein (1998); Hanson et al. (2015); Drechsler et al. (2017) among others, show that deposits are not perfectly replaceable by debt and debt is costly relative to deposits.

GSEs' expansion in response to a monetary tightening is particularly rel-

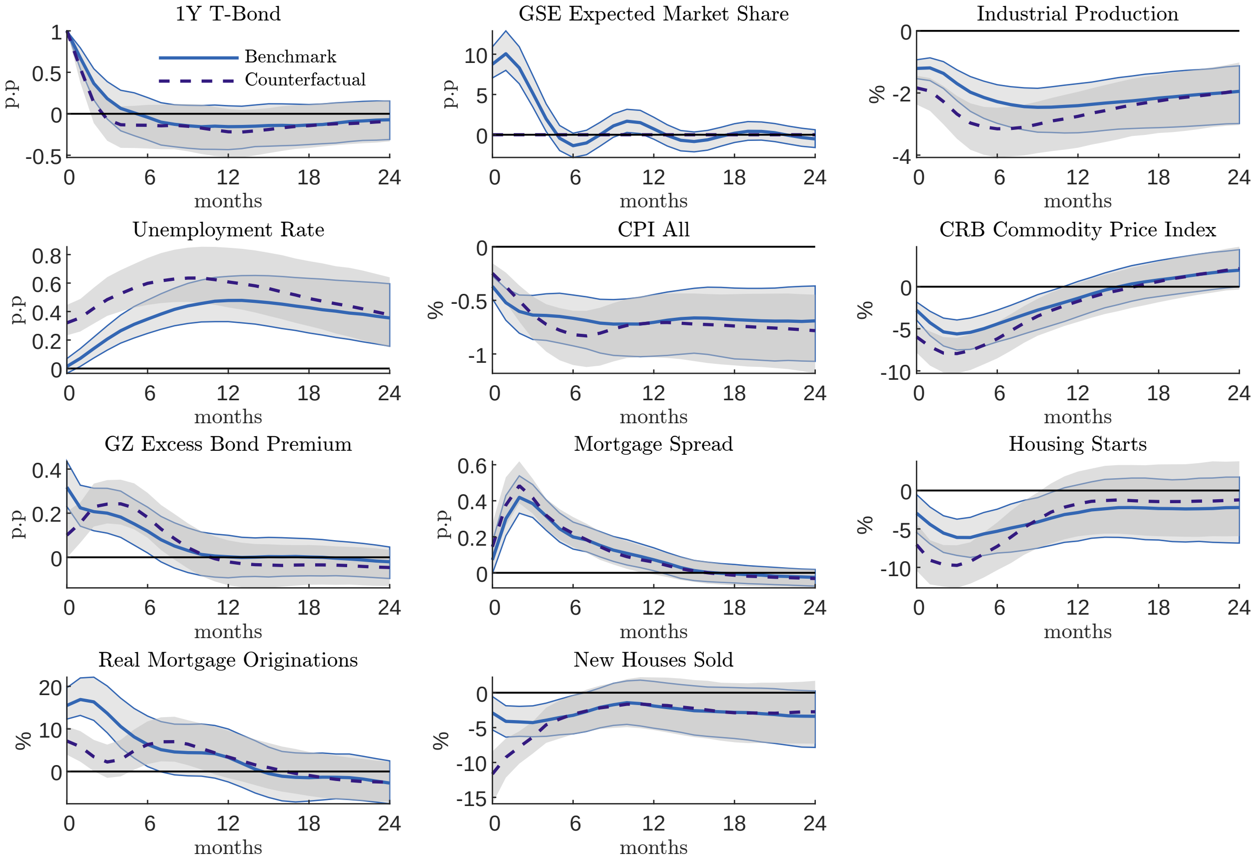

Figure 1.6: Benchmark (solid line) and counterfactual (dashed line) impulse responses to monetary policy shock. Shaded areas cover the 68% credible density intervals

evant in this mechanism as they reduce the cost of funding for financial intermediaries and therefore mitigate the cut in loan supply and consequently disrupt the amplification of monetary policy, at least in two ways. First, providing liquidity to banks in exchange for illiquid mortgages decreases banks' demand for liquidity in the funds market, decreasing the price of banking debt. To explain this point further, when debt-financed liquidity becomes expensive due to a contractionary monetary policy shock, banks sell illiquid assets to GSEs and partly substitute the financial market funding. This decreases demand for banking debt in the financial markets and decreases the price of debt. A second way to think of GSEs reducing the cost of funding for financial intermediaries is via the term structure of

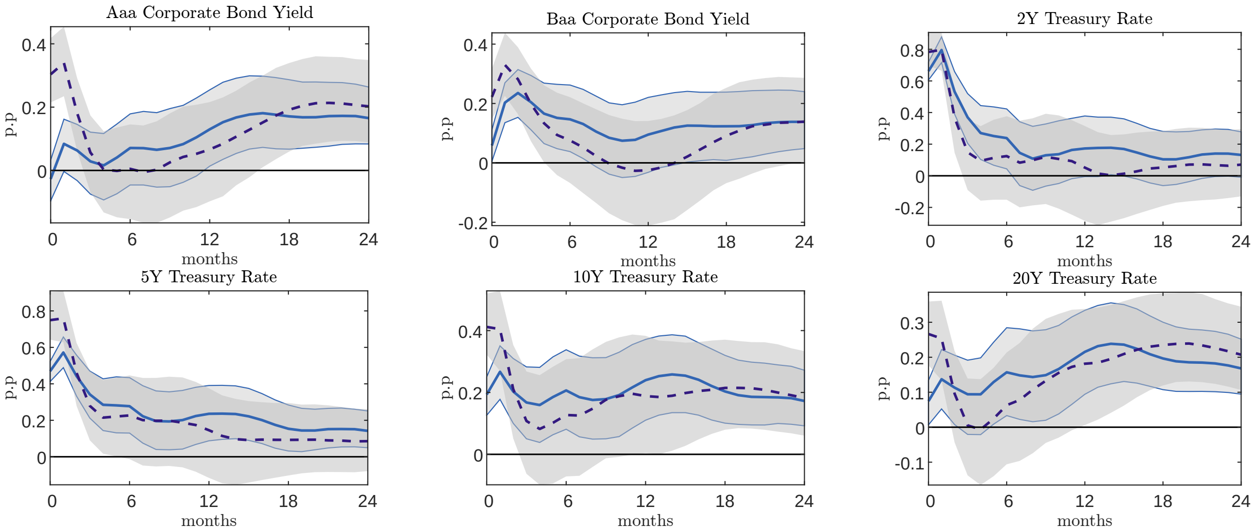

Figure 1.7: The effects of a monetary policy shock on various credit costs (solid blue line), against the counterfactual effects (dotted line), shaded areas show 68 percent posterior coverage for each model. p.p denote percentage points.

their debt. The originate-to-sell mechanism implies that banks originate mortgages and sell them to GSEs in a short period getting back the principle and some servicing spread. Since financial intermediaries do not retain the long maturity mortgages in their portfolios, they can finance them using short-maturity debt. The minimum debt maturity is the time between origination and acquisition from the GSEs. Hence, they can switch from long-maturity to short-maturity debt and face a fairly smaller term premium. In any case, the involvement of GSEs mitigates the increase in the cost of funding for financial intermediaries and erodes the increase in the external finance premium.

The results of the counterfactual analysis advocate in favour of the above narrative as they indicate that monetary policy has greater effects on economic activity, prices and cost-of-credit when we shut down the response of GSEs. Figure 1.6 shows the effects of a monetary policy tightening (solid line) against the effects of a monetary policy tightening where GSEs expected market share is restricted to not respond to the shock (dashed line). We see that monetary policy has significantly greater effects on unemployment, industrial production and commodities prices under the counterfactual scenario. Furthermore, monetary policy is more influential to various treasury rates and private sector bond yields under the counterfactual, see Figure 1.7.

We consider the stronger influence of monetary policy under the counterfactual scenario to operate mainly via housing demand and construction activity. To elaborate, under the counterfactual scenario, banks finance lending only via deposits and debt[7]. Hence, an increase in interest rates increases relatively more the cost of funds in the financial intermediary sector, which turns in an increase in the external finance premium. Households face a relatively higher cost of borrowing to purchase a house. Consequently, housing becomes more expensive, reducing housing demand and construction activity. Figure 1.6 captures this mechanism where, under the counterfactual, mortgage originations do not exhibit expansion, housing sales reduce significantly more showing a reduction in housing demand, and housing starts exhibit a sharp drop indicating a slowdown in construction activity. Notably, the housing construction sector accounts for the non-trivial 6.5% of the GDP in the sample period. Ultimately, the strong recessionary effects of monetary policy on unemployment, industrial production and commodity prices can be attributed to the contraction in housing construction activity.

The results of the impulse response analysis and the counterfactual provide a controversial but interesting finding regarding the response of the real house price index. The conventional theory advocates that monetary tightenings have cooling-off effects on house prices. As borrowing costs rise, housing demand falls, reducing house prices, see Iacoviello (2005);

[7] Private securitization could also be an alternative source of financing, Fieldhouse and Mertens (2017) and Drechsler et al. (2022) note that private labelled securitization became particularly relevant for the period 2003-2006, prior to 2000s was a small fraction of the secondary mortgage market.

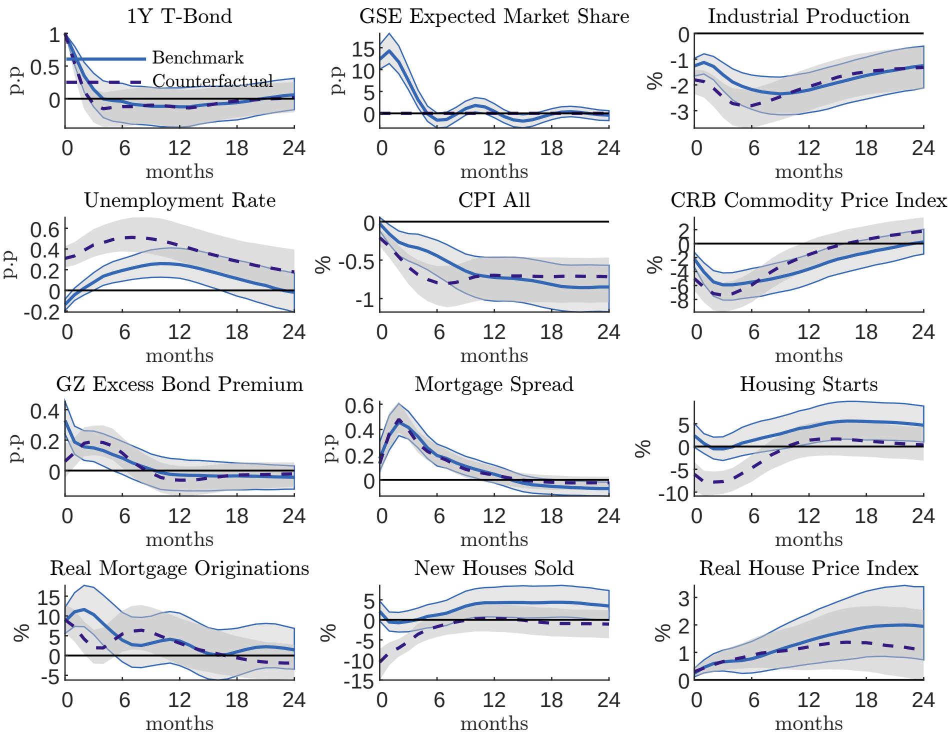

Figure 1.8: Impulse responses of a large VAR with various mortgage and housing variables. Solid lines indicate standard impulse responses, and dashed lines counterfactual impulse responses.

Iacoviello and Neri (2010); Rahal (2016); Benati (2021) among others. Surprisingly, the impulse responses to a monetary policy tightening provide puzzling results for house prices. In line with the discussion regarding the involvement of GSEs in the transmission of monetary policy, we could attribute this result to GSEs' market share expansion. However, the counterfactual responses of the real house price index do not alter significantly from the standard results. Differently from other variables, such as housing starts, housing sales and mortgage originations which clearly contract under the counterfactual scenario, house prices persist in exhibiting a puzzle.

Although, the house price puzzle might not be a completely misleading result as it could be associated with the housing boom episodes of 2003-2006. This period is characterized by the Fed's contractionary stance, which increased interest rates by 4.25% and by a decrease in mortgage spreads associated with a significant increase in privately-labelled securitization (Drechsler et al., 2022; Justiniano et al., 2022). This fuelled a significant expansion in jumbo and subprime mortgages, boosting housing demand and house prices. This phenomenon may dominate the dynamics of the VAR and produces the house price puzzle. The presence of a house price puzzle deserves more attention and deeper analysis, although this is beyond the scope of this chapter.

1.4 Robustenss

We run various robustness checks using sub-sample estimates and alternative proxies for the monetary policy shocks. First, we estimate the baseline model in the sub-sample period 1979:01-2008:08. In September 2008, the government took GSEs under conservatorship and forced Freddie and Fannie to reduce their portfolio by two-thirds (Fieldhouse and Mertens, 2017). At the same time, the Fed included GSE MBS and portfolio mortgages in the large asset price purchase programs of 2008-2009. This is also illustrated in Figure 1.1, where we observe an abrupt increase in the Feds' holdings share after the wake of the global financial crisis. Showing that the response of GSEs' expected market share does not alter significantly from the full sample estimate ensures that the results are not driven by any crisis-related dynamics. The results of the sub-sample analysis are illustrated by Figure 1.9. Moreover, we utilise alternative proxies to instrument monetary policy shocks. Figures 1.10, 1.11 and 1.12 illustrate impulse responses of the benchmark under different monetary policy instruments. The results regarding GSEs' expected market share are robust across different instruments. In Table 1.1, we demonstrate each instrument and the

Instrument	Shock		
	Fed Fund Rate	Forward Guidance	Information
Degasperi and Ricco (2021)	✓	✓	
Swanson (2021) FFR factor	✓		✓
Jarociński and Karadi (2020)	✓	✓	
Gertler and Karadi (2015)	✓	✓	✓

Table 1.1: Various monetary policy instruments utilized in the study and their sources. Checkmarks indicate the identified dimension of monetary policy.

dimension of the monetary policy that captures (pure monetary, forward guidance and information shock). Regarding the house price puzzle, we estimate the impulse responses using the series of Shiller (2015) as an alternative house price indicator to Freddie Mac HPI. The results regarding the deflated house price index are persistent in exhibiting a puzzle. Moreover, we exclude the 2003-2006 period from the estimated sample to address the role of the 2003-2006 housing boom on the observed puzzle. We cannot reach a solid conclusion because the instrument lacks relevance, and our identification is weak.

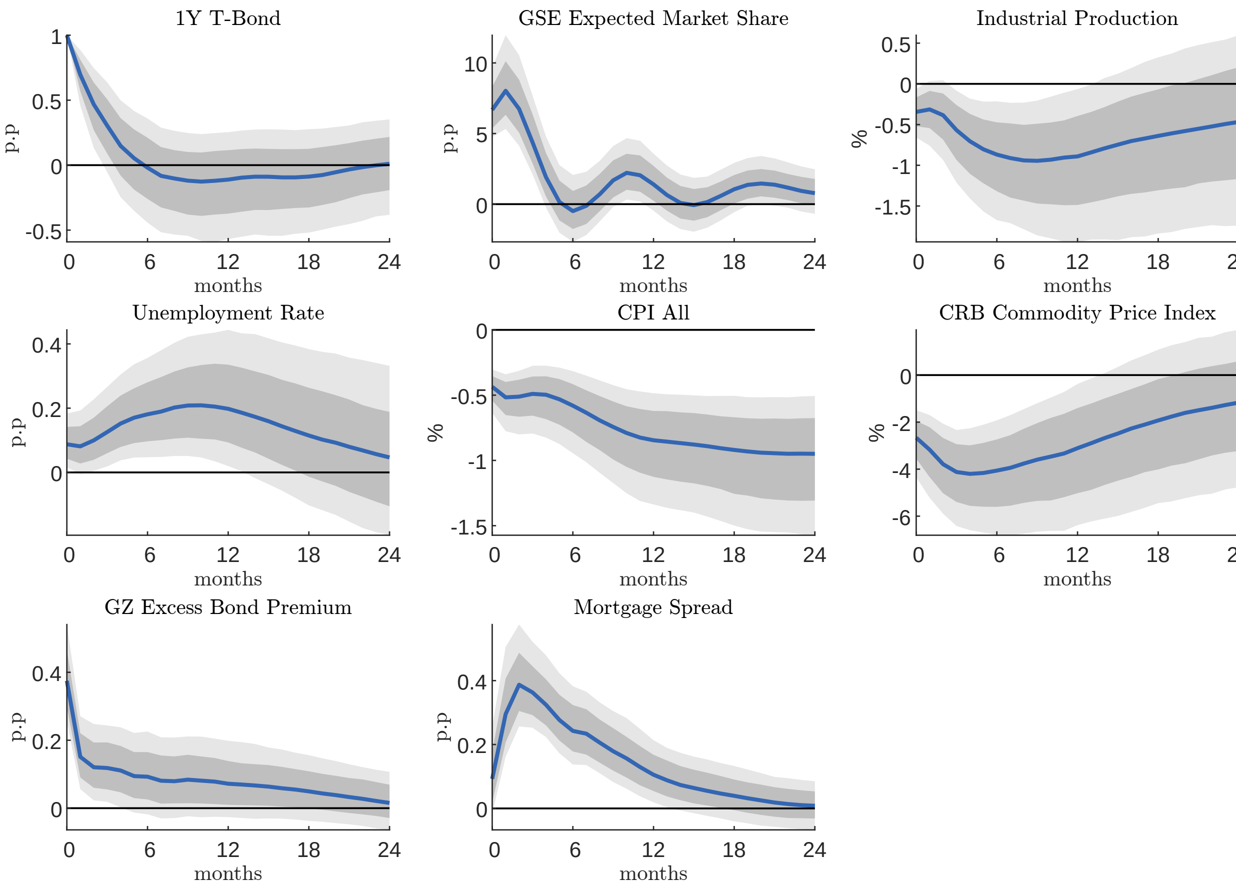

Figure 1.9: Sub-sample impulse response estimates for the period 1979:01-2008:08.

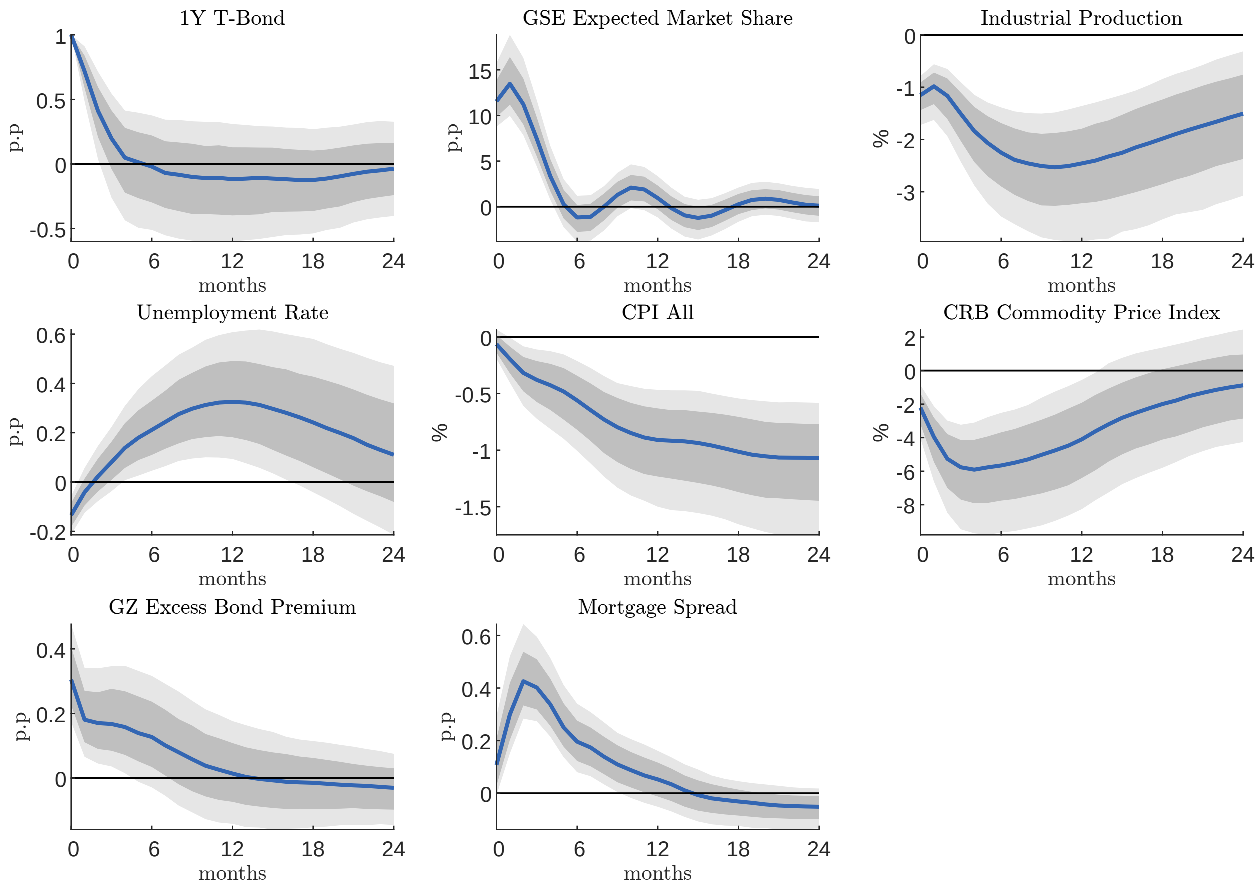

Figure 1.10: Impulse responses of the benchmark specification using the proxy of Swanson (2021) to identify monetary policy shocks.

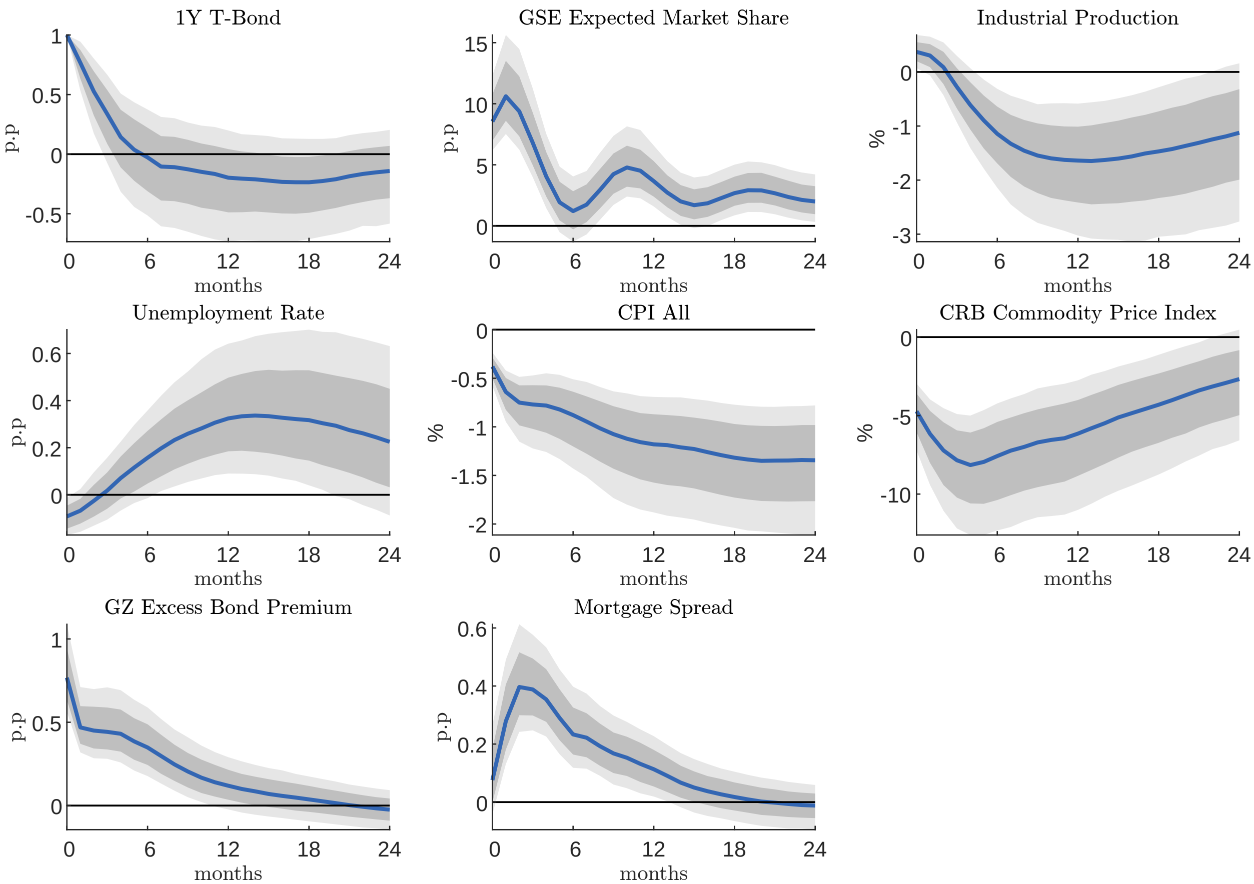

Figure 1.11: Impulse responses of the benchmark specification using the proxy of Jarociński and Karadi (2020) to identify monetary policy shocks. Particularly, we identify the monetary policy shocks using the information clean instrument provided by the authors.

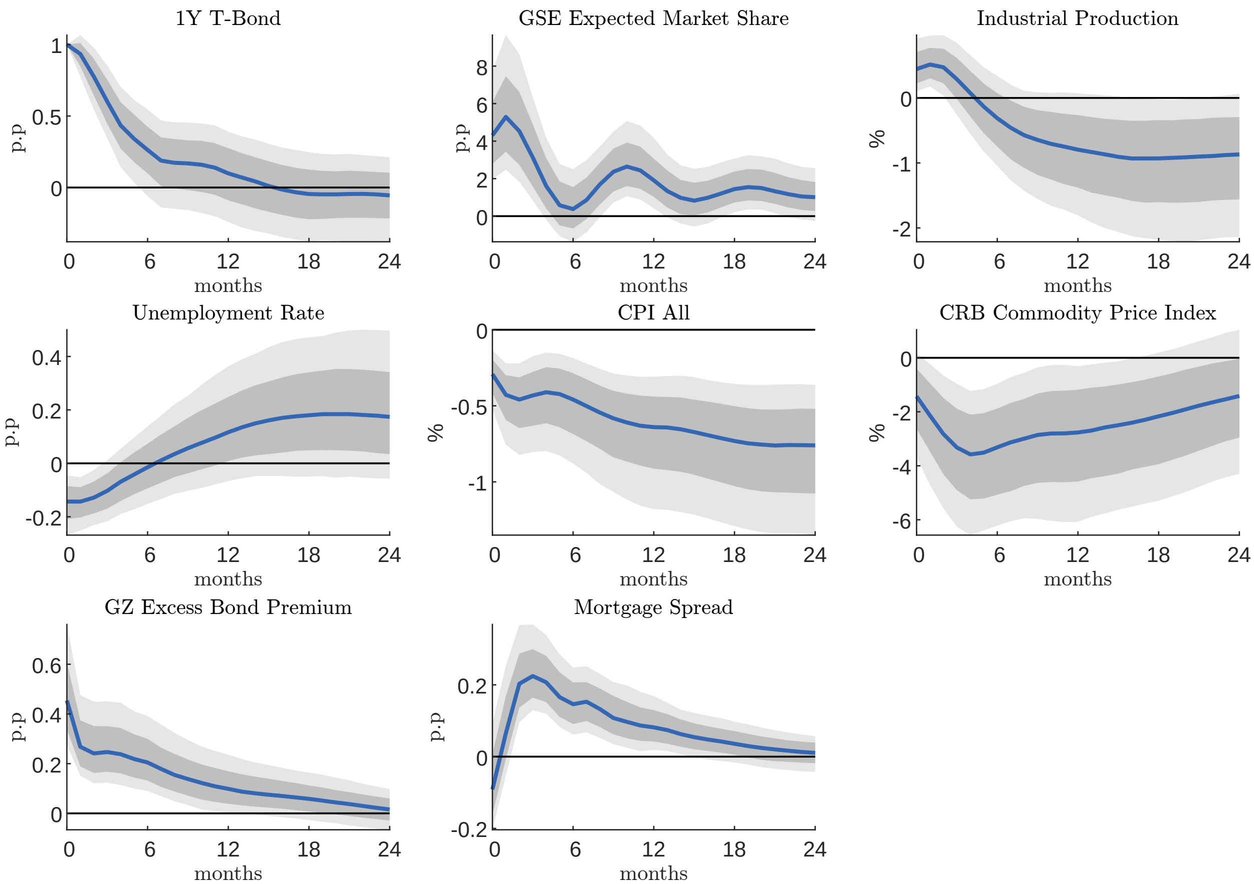

Figure 1.12: Impulse responses of the benchmark specification using the proxy of Gertler and Karadi (2015) to identify monetary policy shocks.

1.5 Conclusion

We investigated the effects of monetary policy on GSEs' market share, finding a positive relationship between monetary contractions with GSEs' market share. We justify that result considering the limitations of GSEs to substitute across assets, their housing market stabilization mandate towards the federal government, and the profitability opportunities via rising premiums between mortgage and GSEs' spreads. We conducted a counterfactual analysis where we disregard GSEs in the transmission of monetary policy shocks, and we find that monetary policy tightenings are more effective under the counterfactual. We attribute this to the cost of funding in the financial intermediaries sector and the bank-lending channel of monetary policy. The empirical evidence presented in the chapter can motivate future research on the role of GSEs and securitization on monetary policy transmission. Enriching existing theoretical frameworks on the operation of monetary policy in the presence of financial frictions as Gertler and Karadi (2011) and Drechsler et al. (2017) with GSEs could provide new insight regarding the transmission of monetary policy and new policy implications regarding the utilization of GSEs as a policy tool further from their role in the housing market.

Chapter 2

Regional house prices and the heterogeneous effects of monetary policy: Evidence from the U.K.

Abstract

We investigate the dynamic effects of monetary policy shocks on the regional housing markets of the U.K. The econometric framework incorporates a Factor Augmented VAR where monetary policy shocks are identified using a proxy internally in the model. The empirical results reveal a heterogeneous impact of monetary policy shocks on regional house prices. We link the effectiveness of monetary shocks on regional housing with the level of housing affordability and the ability of households to borrow. In regions with low housing affordability, a large fraction of households are hand-to-mouth, and monetary policy transmits via general equilibrium effects. In such cases, we find sizable effects on the economy but negligible effects on house prices. Conversely, monetary policy influences house prices considerably in regions where intertemporal substitution is more likely to take place.

2.1 Introduction

In the U.K., housing accounts for more than 1/3 of total household wealth (ONS, 2022; Banks and Tanner, 2001), and is considered the most valuable single asset that households hold. For that reason, housing booms and busts affect household wealth and the real economy. Numerous theoretical and empirical studies support this view and establish the importance of house prices for the business cycle, providing information about the linking mechanism of house prices with main macroeconomic variables such as consumption, investment and unemployment (Iacoviello, 2005; Campbell and Cocco, 2007; Mian and Sufi, 2011; Mian et al., 2013; Mian and Sufi, 2014; Bahaj et al., 2020). The linkage of housing with the macroeconomy makes it an interesting topic to study.

The outbreak of the global financial crisis and the Great Recession created new questions about the interactions of monetary policy with house prices. A vivid example is the debate regarding the actions that monetary authorities should or should not take in the presence of housing or, in general, asset booms and busts (Leamer, 2007; Mishkin, 2007; Curdia and Woodford, 2010; Gambacorta and Signoretti, 2014; Gourio et al., 2018). Answering such questions requires knowledge of the relationship between monetary policy and house prices, the underline mechanism and the magnitude of the effects of monetary policy shocks on house prices. In that spirit, numerous papers study the ties of monetary policy with housing and report a strong connection of interest rates with house prices mainly via the cost of borrowing (Iacoviello, 2005; Jarocinski and Smets, 2008; Iacoviello and Neri, 2010; Williams et al., 2015; Rahal, 2016).

The majority of this literature focuses on national house prices. By doing so, it ignores the fact that housing is a spatially segmented market with strong heterogeneity across areas (Ferreira and Gyourko, 2012). The regional representation of the housing market is further corroborated by Del Negro and Otrok (2007). They show that the bulk of house price variation is due to area-idiosyncratic components, which is in line with the view that most variation in house prices is related to local market characteristics. Moreover, they reveal that the contribution of the national component is significant and heterogeneous across areas. Hence, regional housing markets are exposed to a different degree to aggregate shocks. This heterogeneity, which national-level studies neglect, could provide useful insights for the transmission of monetary policy on house prices. Despite that, the relevant literature is relatively limited. Most of the existing studies focus on the interaction of monetary policy with sub-national housing in the U.S. (Fratantoni and Schuh, 2003; Del Negro and Otrok, 2007; Vargas-Silva, 2008; Fischer et al., 2021; Aastveit and Anundsen, 2022) and there are no previous studies on monetary policy and regional housing markets in the U.K. The first contribution of this study is to fill this gap by measuring the dynamic effects of monetary policy on the regional housing markets of the U.K.[1] We consider Aastveit and Anundsen (2022) and Fischer et al. (2021) as the closest studies to ours. Apart from the country of interest (that is the U.S.), we also deviate from them in the interpretation of regional heterogeneity. They focus their analysis on differences in regional housing supply elasticities and find that monetary expansions lead to relatively higher appreciations in regions with lower elasticities. Instead, we argue that the heterogeneity of monetary policy on regional house prices could also be demand-driven. Our analysis links the efficacy of monetary policy with the level of housing affordability in each region and with the com-

[1]We use the NUTS-1 region specification of Nomenclature of Territorial Units for Statistics, that decomposes the U.K to 12 regions. Post Brexit, NUTS classification switched to ITL, which for now is identical to NUTS.

position of households. This approach contributes to the literature with two interesting findings. First, we provide a mechanism where the heterogeneous effects of monetary policy stem from regional differences in housing affordability, and second, our analysis provides evidence that monetary policy affects house prices mainly via intertemporal substitution.

Our econometric approach employs a Factor Augmented Vector Autoressive (FAVAR) model initially introduced by Bernanke et al. (2005). In this setup, we can model regional and a large set of national variables within a single econometric framework. This is attractive because it allows us to estimate impulse responses from the same information set and, as such, it allows direct comparisons[2]. To estimate the unobserved factors, we follow a novel approach introduced by Barigozzi et al. (2021) which yields a factor representation of the level data. The advantage of this approach is that it enables the estimation of the effects of monetary policy shocks on the level of the variables of interest. In the second step, we model the dynamics of the system in a Bayesian FAVAR model.

To identify monetary policy shocks, we follow Kuttner (2001), Cochrane and Piazzesi (2002), Gürkaynak et al. (2004), Gertler and Karadi (2015), Nakamura and Steinsson (2018), Gerko and Rey (2017), Cesa-Bianchi et al. (2020). These studies exploit high-frequency movements of relevant futures in a closed window around monetary policy events to isolate the effects of an exogenous and unanticipated action of monetary policy. We employ the instrument of Gerko and Rey (2017) internally in the VAR, and we order it first. The main motivation for adopting this method of identification is the nature of the instrument itself. The instrument is constructed from high-frequency movements of the 3-month short sterling fu-

[2]In a standard VAR we would not be allowed to model regional house prices and monetary variables together due to degrees of freedom limitation. An alternative approach to ours could be a large Bayesian VAR as in Bańbura et al. (2010).

tures around inflation reports. Hence, it contains information about the future economic outlook and the future path of monetary policy. In such cases, the instrument exhibits autocorrelation and has forecasting ability on one or more endogenous variables in the model; this compromises the shock invertibility conditions (Noh, 2017). Plagborg-Møller and Wolf (2021) show that we can estimate the correct relative impulse response functions from a recursive VAR where the instrument ordered first even in the case of non-invertible shocks (e.g. forward guidance)[3].

The impulse responses reveal heterogeneous effects of monetary policy shocks on regional house prices. We define an expansionary monetary shock which increases the 5-year zero coupon by 1 percentage point. On impact, house prices in North East increase by 6.12% and by 1.4% in London. The peak response comes 3 quarters after the impact of the shock, where house prices appreciate by 8.5% and 5.5% respectively. House prices in London, South East and East of England are the least responsive to monetary policy shocks. In contrast, house prices in North East, North West and Yorkshire & the Humber are found to be the most monetary sensitive.

A number of studies link the heterogeneous response of local economies to monetary shocks with region-specific characteristics (Carlino and DeFina, 1998; Georgopoulos, 2009; Mandalinci, 2015)[4]. As such, it may well be the case that the sensitivity of regional housing markets to monetary policy could differ across regions due to different region-specific housing market characteristics. We provide a justification of the empirical results by disentangling the regional housing market and attributing the source of the heterogeneous response of regional house prices to unexpected changes in monetary policy. For this purpose, we conduct a two-sided (supply-

[3]Equivalently by controlling for past values of the instrument, this approach is equivalent to Noh (2017) and Paul (2020).
[4]An extensive review of this literature provided by the survey of Dominguez-Torres and Hierro (2019).

demand) analysis by exploiting regional data and relevant studies to analyse regional determinants of housing supply and demand and their role in the linking mechanism of regional house prices with monetary policy.

A strand of the literature suggests that differences in house price developments across regions are driven by heterogeneities in local housing supply (Banks and Tanner, 2001; Saiz, 2010; Cheshire and Sheppard, 2005; Hilber and Vermeulen, 2016; Barker, 2004, 2006). Supply constraints exist due to constraints in housing development; region-specific constraints could be natural barriers, such as uneven ground, as well as regulatory constraints, e.g., complex bureaucratic procedures which increase the cost of housing construction and create delays in the construction process. Regions with such characteristics exhibit inelastic housing supply. In this case, a homogeneous increase in housing demand due to a monetary policy shock translates to relatively higher house prices. Hilber and Vermeulen (2016) provide a measure for regulatory constraints and data for physical constraints in housing in England. Using this measure, we conclude that differences in regional housing supply elasticities alone are not sufficient to justify the empirical results.

We then turn our attention to housing demand. Monetary policy shocks do not necessarily influence housing demand homogeneously across regions. It might be the case that an unanticipated expansion of monetary policy triggers shifts of a different magnitude in each region. We argue that monetary policy affects housing demand more in regions where housing is relatively affordable. This mechanism relates to a strand of literature that studies monetary policy in the presence of households with different balance sheet positions and credit constraints (Kaplan et al., 2018; McKay et al., 2016; Bilbiie, 2020). This theoretical framework supports our analysis and justifies our empirical results. According to this class of models, intertemporal substitution is limited for hand-to-mouth households, and monetary policy is effective via its general equilibrium effects. Since hand-to-mouth households are low in income and assets, they fail to substitute consumption and investment across time. Hence in each time period, they consume their disposable income. A monetary policy expansion increases their income via general equilibrium. Any extra income flows directly to present-period consumption. Under this framework, in regions with low housing affordability, a large fraction of households behave hand-to-mouth because their income is insufficient to borrow and acquire housing, and they are expected to consume their disposable income in each time period. In such regions, monetary policy is expected to affect the regional economy mainly via general equilibrium and to have mild effects on regional housing demand due to the absence of intertemporal substitution. Regional data on housing affordability advocate this narrative, as the effects of monetary policy on house prices are found to be milder in regions where the median household faces income constraints to buy a house.

The rest of the chapter is structured as follows. Section 2 provides a description of the dataset. Section 3 describes the empirical model, the identification of monetary policy shocks and the model estimation. Section 4 interprets and discusses the empirical results and Section 5 concludes.

2.2 Data

The dataset consists of 25 national variables, regional gross value added (GVA), regional housing sales volume and the U.K. regional house price indices[5]. The data span the period from Q3-1997 to Q4-2014. The national variables are obtained from the Bank of England. The national house price

[5] Full description of the variables in Appendix B.3

index, regional house price index and regional sales volume are collected from Land Registry. The regional sales volume is available for all NUTS-1 regions of the U.K. except Scotland and Northern Ireland. Regional GVA is obtained via the economic statistics centre of excellence (ESCOE).

For the monetary policy shock identification we use the proxy of Gerko and Rey (2017). The authors provide the instrument series at a monthly frequency. Following the procedure of construction of monthly series from daily observations, we transform the data to quarterly observations. As a measurement of the stance of monetary policy, we use the 5-year zero coupon as proposed by Gerko and Rey (2017). Combining regional and national variables leads to a dataset of 60 variables. In section 2.4, we use annual regional data on housing affordability, upfront cost and income requirements to issue a mortgage from the Office of National Statistics to compare housing affordability between regions.

2.3 Empirical model

The study adopts the non-stationary factor model setting of Barigozzi et al. (2021). Consider an n-dimensional dataset of time series. Each variable $x_{i,t}$, $i = 1, ..., n$ and $t = 1...T$, can be decomposed into an unobservable common component $\chi_{i,t}$ and an unobservable idiosyncratic component ξ_{it}

$$x_{it} = \chi_{it} + \xi_{it} \tag{2.1}$$

and the common components can be expressed as linear combinations of r common factors $F_{r,t}$

$$\chi_{it} = \lambda_{i1} F_{1t} + ... + \lambda_{ir} F_{rt} = \lambda_{\mathbf{i}}^{'} \mathbf{F_t} \tag{2.2}$$

where $\lambda_{\mathbf{i}} = (\lambda_{i1}...\lambda_{ir})'$ are the factor loadings and $\mathbf{F_t} = (F_{1t}...F_{rt})$. By substituting (2.2) into (2.1) we have:

$$x_{it} = \lambda_{\mathbf{i}}^{'}\mathbf{F_t} + \xi_{it}. \tag{2.3}$$

Let $\mathbf{x_t} = (x_{1t}...x_{nt})'$, $\chi_{\mathbf{t}} = (\chi_{1t}...\chi_{nt})'$, $\xi_{\mathbf{t}} = (\xi_{1t}..\xi_{nt})'$, and $\mathbf{\Lambda} = (\lambda_{\mathbf{1}}...\lambda_{\mathbf{n}})'$. Equations (2.2) and (2.3) can be written in a compact matrix form as

$$\chi_{\mathbf{t}} = \mathbf{\Lambda}\mathbf{F_t} \tag{2.4}$$

$$\mathbf{x_t} = \chi_{\mathbf{t}} + \xi_{\mathbf{t}} = \mathbf{\Lambda}\mathbf{F_t} + \xi_{\mathbf{t}} \tag{2.5}$$

The number of factors in the study is determined via the Bai and Ng (2002) factor selection criteria which proposed 6 to 8 factors. We set $r = 7$.

The method also accommodates the general case where data contain linear deterministic trends. Hence in a more general representation, we can consider the case where we do not directly observe $\mathbf{x_t}$ but instead, we observe $\mathbf{y_t} = (y_{1t}...y_{nt})'$ where,

$$y_{it} = \alpha_i + \beta_i \cdot t + x_{it} \tag{2.6}$$

Following the procedure of Barigozzi et al. (2021) we estimate the factor loading via principal components analysis on the differenced data $\Delta\mathbf{y_t} = (\Delta y_{1t}...\Delta y_{nt})'$. Let the $n \times n$ matrix $\widehat{\mathbf{\Gamma}}$ be the covariance matrix of $\Delta\mathbf{y_t}$ and the $n \times r$ matrix $\widehat{\mathbf{Q}}$ to contain the right normalized eigenvectors which correspond to the first r eigenvalues of $\widehat{\mathbf{\Gamma}}$. The estimation of the loadings matrix is described as

$$\widehat{\mathbf{\Lambda}} = \sqrt{n}\widehat{\mathbf{Q}}. \tag{2.7}$$

In order to proceed with the factor estimation, we de-trend each element of $\mathbf{y_t}$ by OLS regression on a constant and a linear trend. The estimation of β_i

is given by

$$\widehat{\beta}_i = \frac{\sum_{t=1}^{T}\left(t - \frac{T+1}{2}\right)(y_{it} - \bar{y}_i)}{\sum_{t=1}^{T}\left(t - \frac{T+1}{2}\right)^2}, \tag{2.8}$$

where $\bar{y}_i$ represents the sample mean of y_{it}. Therefore, we define $\widehat{x}_{it} = y_{it} - \widehat{\beta}_i t$ and $\widehat{\mathbf{x}}_\mathbf{t} = (\widehat{x}_{1t}...\widehat{x}_{nt})'$. To estimate the common factors we project $\widehat{\mathbf{x}}_\mathbf{t}$ onto $\widehat{\mathbf{\Lambda}}$ as described below

$$\widehat{\mathbf{F}}_\mathbf{t} = \frac{1}{n}\widehat{\mathbf{\Lambda}}'\widehat{\mathbf{x}}_\mathbf{t} = \frac{1}{n}\sum_{i=1}^{n}\widehat{\lambda}_\mathbf{i}\widehat{\mathbf{x}}_\mathbf{it}. \tag{2.9}$$

Having the factors estimated allows us to model the dynamics via a Factor Augmented VAR (FAVAR). In order to identify monetary policy shocks we introduce in the model the variable z_t, which is a proxy of the structural monetary shock, and we order it first. Then we treat the augmented model as a standard recursive VAR. The choice of this identification strategy is motivated by the fact that z_t is constructed from movements of the 3-month Short-Sterling Future (SS) in a close window of 30 minutes around inflation reports. Hence, z_t carries information about future economic conditions and anticipation for future monetary actions. However, in such case, invertibility fails (Noh, 2017). Plagborg-Møller and Wolf (2021) show that we can obtain unbiased estimates of impulse response functions even in cases of non-invertible shocks. Including the proxy in the vector of endogenous variables controls for information communicated in the past and is relevant with the present or equivalently controls for autocorrelation in z_t. The identification assumptions require z_t to satisfy the relevance and exogeneighty conditions:

$$E\left(z_t, \varepsilon_t^m\right) = \tau, \quad \tau \neq 0 \tag{2.10}$$

and

$$E\left(z_t \varepsilon_t^{-m}\right) = 0. \tag{2.11}$$

Equation (2.10) requires z_t to be correlated with the monetary policy shock ε_t^m and Equation (2.11) demands z_t to be uncorrelated with all the other structural shocks. Note that these conditions are untestable and rely on the proper selection of the proxy. The reduced form representation of the model is described by Equation (2.12)

$$Y_t = X_t B + u_t, \quad u_t \sim \mathcal{N}(0, \Sigma) \tag{2.12}$$

where $Y_t = \begin{pmatrix} z_t & R_t & \widehat{\mathbf{F}}_\mathbf{t} \end{pmatrix}'$ is $1 \times (2 + r = N)$ matrix of endogenous variables, z_t denotes the monetary policy shock series of Gerko and Rey (2017) and R_t is the 5-year zero coupon that captures the stance of monetary policy. $X_t = (Y_{t-1}, ...Y_{t-P}, 1)$ is the $1 \times (NP + 1)$ matrix of regressors in each equation, and B is $(NP + 1) \times N$ coefficient matrix, it is relevant to set the lag length to 4 as we deal with quarterly observations ($P = 4$). u_t is the Gaussian white noise vector of the reduced form residuals which are linked with the mutually uncorrelated structural shocks ε_t via matrix A, such that $\Sigma = AA'$ and $\varepsilon_t = Au_t$. Following Plagborg-Møller and Wolf (2021) we define A as the lower triangular Cholesky decomposition of Σ. We estimate the model parameters of Equation (2.12) via Bayesian techniques. Section 2.3.1 provides details on the estimation procedure.

2.3.1 Model estimation

We set Normal-Inverse Wishart priors to the VAR parameters using artificial data. The priors are normal for the VAR coefficients and Inverse-Wishart for the error covariance matrix

$$B|\Sigma \sim \mathcal{N}(b_0, \Sigma \otimes \Omega)$$

and

$$\Sigma \sim \mathcal{IW}\left(\bar{S}, \alpha\right).$$

To implement the Normal-Inverse Wishart prior, we augment the endogenous variables in the model and their regressors with generated data as in Bańbura et al. (2010), i.e., we augment the matrices Y_t and X_t of Equation (2.12) with Y_D and X_D respectively, where the process of data generation is described from Equation 2.13 below.

$$Y_D = \begin{pmatrix} diag\left(\psi_1\sigma_1, \ldots, \psi_N\Sigma_N\right)/\lambda \\ 0_{N(P-1)\times N} \\ \ldots\ldots\ldots\ldots\ldots \\ diag(\sigma_1, \ldots, \Sigma_N) \\ \ldots\ldots\ldots\ldots\ldots \\ 0_{1\times N} \\ \frac{diag(\psi_1\mu_1,\ldots,\psi_N\mu_N)}{\tau} \end{pmatrix} \qquad X_D = \begin{pmatrix} J_P \otimes diag\left(\sigma_1, \ldots, \Sigma_N\right)/\lambda & 0_{NP\times 1} \\ \ldots\ldots\ldots\ldots\ldots\ldots & \\ 0_{N\times NP} & 0_{N\times 1} \\ \ldots\ldots\ldots\ldots\ldots\ldots & \\ 0_{1\times NP} & c \\ \frac{(1,2,\ldots,P)\otimes diag(\psi_1\mu_1,\ldots,\psi_N\mu_N)}{\tau} & 0_{N\times 1} \end{pmatrix} \tag{2.13}$$

Parameter λ governs the overall tightness of the priors, i.e., for $\lambda = 0$ posterior and prior distributions coincide, and thus there is no influence by the data. For $\lambda = \infty$ the posterior equals the OLS estimates. ψ_i denotes the prior mean for the coefficients on the first lag of the dependent variable. The standard Minnesota prior sets $\psi_i = 1$ for every $i = \{1, 2, \ldots, N\}$, see Litterman (1986). As argued in Bańbura et al. (2010), this prior belief can not be supported for variables with strong mean reversion. We set ψ_i using OLS estimates of the coefficient of an $AR\,(1)$ regression for each dependent variable, the scale parameter σ_i is the standard deviation of the errors of the $AR\,(1)$ regression. μ_i denotes the sample mean of each variable and J_P is a diagonal matrix with the lag order in the main diagonal, such that $J_P = diag\,(1, \ldots, P)$. The last block of Y_D and X_D implements the prior belief that the sum of the coefficients of the lagged dependent variables equals one. The parameter $\tau = 1/\gamma$ controls the tightness of the prior, which increases with γ. We set $\lambda = 0.2$ and $c = 1/10000$. A regression of Y_D on X_D

provides the prior mean for the VAR coefficients and the prior scale for the covariance matrix,

$$b_0 = \left(X_D' X_D\right)^{-1} \left(X_D' Y_D\right), \qquad \bar{S} = \left(Y_D - X_D b_0\right)' \left(Y_D - X_D b_0\right).$$

Hence, the priors take the form:

$$B|\Sigma \sim \mathcal{N}\left(vec\left(b_0\right), \Sigma \otimes \left(X_D' X_D\right)^{-1}\right) \tag{2.14}$$

and

$$\Sigma \sim \mathcal{IW}\left(S, T_D - (NP+1)\right), \tag{2.15}$$

where T_D denotes the length of the dummies. By augmenting the data with dummies as described above, the reduced form VAR of Equation (2.12) takes the form:

$$\tilde{Y}_t = \tilde{X}_t B + \tilde{u}_t \tag{2.16}$$

where $t = (1, \ldots, (T + T_D))$, $\tilde{Y} = (Y', y_d')'$ and $\tilde{X} = (X', x_D')'$. The conditional posterior for the VAR coefficients and Σ take the form:

$$vec\left(B\right)|\Sigma, Y \sim \mathcal{N}\left(vec\left(\tilde{B}\right), \Sigma \otimes \left(\tilde{X}'\tilde{X}\right)^{-1}\right) \tag{2.17}$$

and

$$\Sigma|Y \sim \mathcal{IW}\left(\tilde{\Sigma}, T_D + 2 + T - (NP+1)\right) \tag{2.18}$$

where $\tilde{B} = \left(\tilde{X}'\tilde{X}\right)^{-1} \tilde{X}'\tilde{Y}$ and $\tilde{\Sigma} = \left(\tilde{Y} - \tilde{X}\tilde{B}\right)' \left(\tilde{Y} - \tilde{X}\tilde{B}\right)$. To approximate the marginal posteriors of the VAR parameters we employ the Gibbs sampling algorithm. The algorithm draws samples according to Equations (2.17) and (2.18). We set the number of iterations to 40,000 and the burn-in to 20,000[6].

[6]We repeated the procedure with 100,000 iterations and a burn-in of 50,000 and the results were identical to 3 decimals. Therefore, 40,000 is an adequate number of iterations for the convergence of the algorithm.

2.4 Empirical results and analysis

This section provides the empirical results of the study and discusses the drivers of the heterogeneous effects of monetary policy shocks on regional house prices. Figure 2.1 illustrates the impulse responses of 5 main macroeconomic variables to an expansionary monetary policy shock which decreases the 5-year zero coupon by 1 percentage point. The solid red line illustrates the median response, and the shaded areas denote the 68% credible density interval. The empirical results are in line with the predictions of standard theoretical macro models since the real GDP, the retail price index (RPIX), industrial production and the house price index increase, and the unemployment rate declines after a monetary expansion. Thus, these results provide support to the validity of the identification approach.

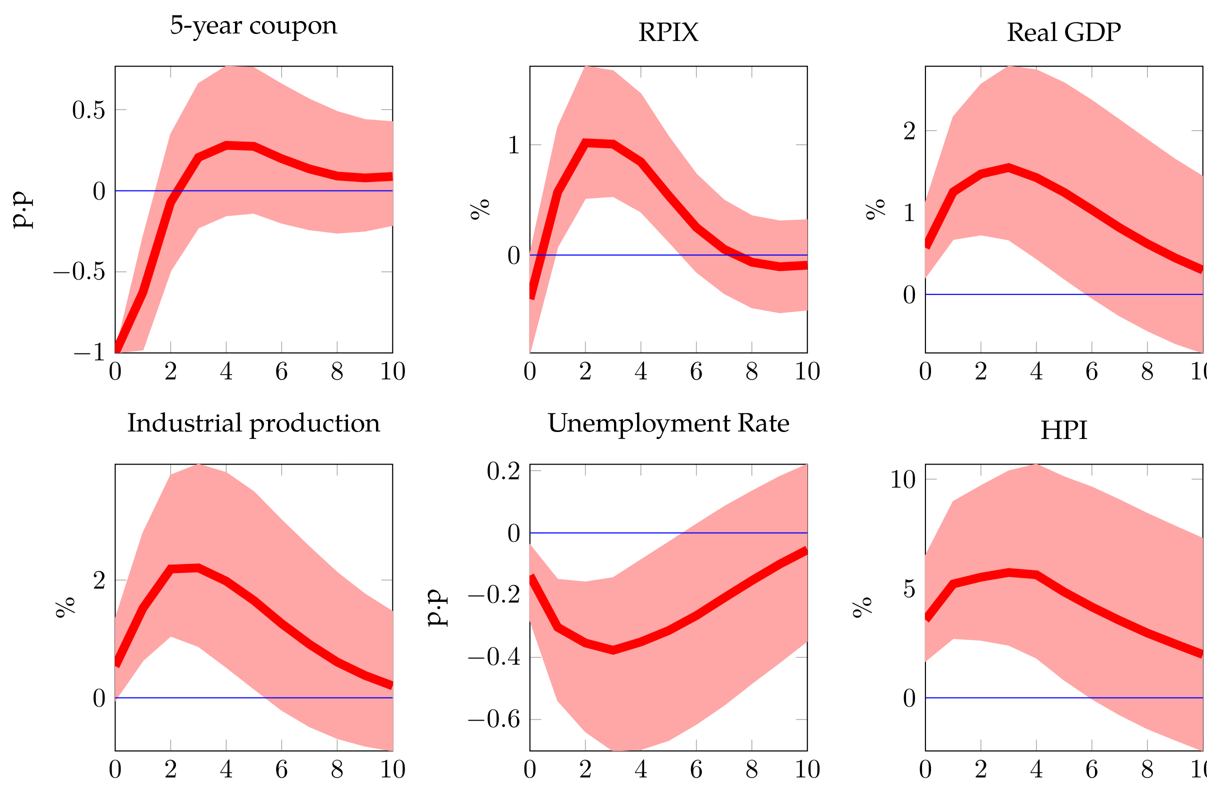

Figure 2.1: Impulse response functions of 5 main macroeconomic variables. p.p denotes percentage points.

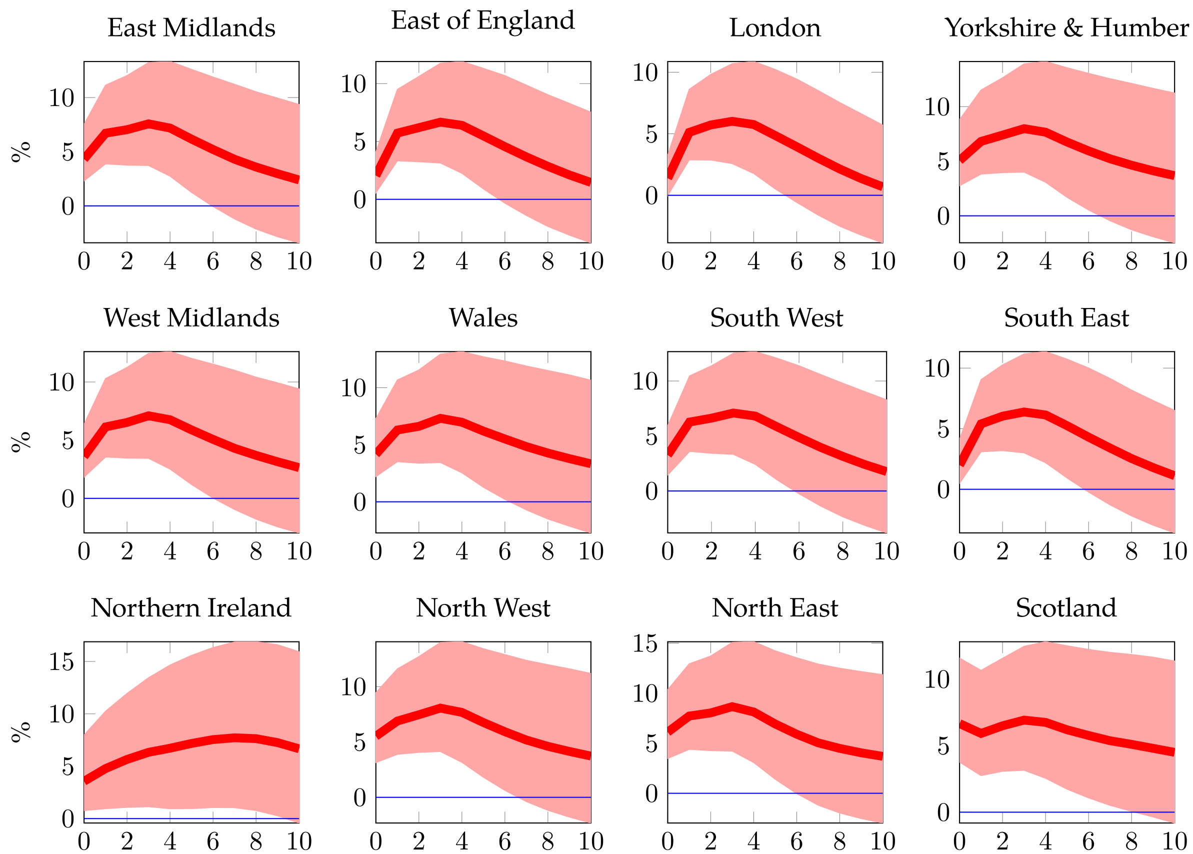

Figure 2.2: Impulse response functions of regional house prices.

Figure 2.2 provides the impulse response functions of the regional house prices. We observe that all IRFs exhibit a similar pattern, with house prices appreciating in all regions and nationally. However, Figure 2.3 provides us with evidence that the magnitude of the house price appreciation varies between regions. On impact, the response of Scotland (SC) and North East (NE) is nearly four times larger than the response of London (Lon), East of England (EE) and South East (SE). The majority of regional house prices peak at a horizon of 3 quarters after the shock, where the most responsive regions exhibit an increase of 8 to 9 percent and the less responsive regions face a house price increase of 5.5 to 6.5 percent. To obtain a broader view of how regional house prices respond to monetary policy shocks, we calculate

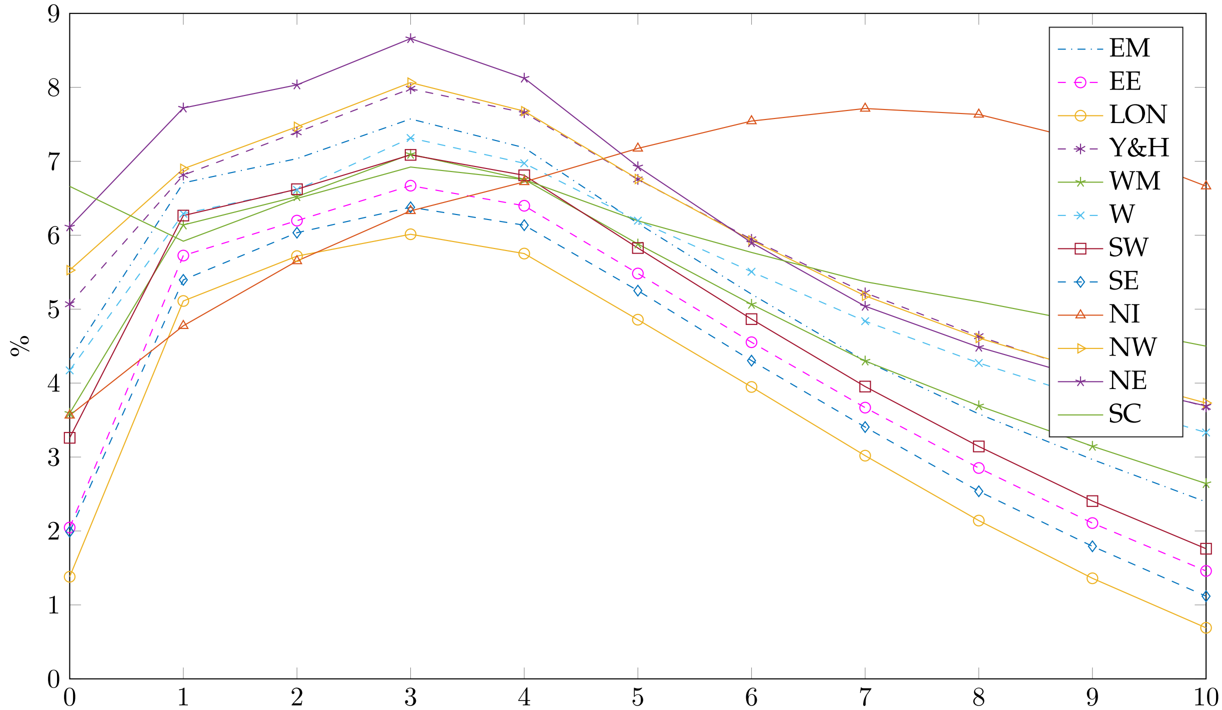

Figure 2.3: Impulse responses (median) of regional house prices.

their average response in a horizon of 6 quarters after the shock. Figure 2.4 shows that, on average, house prices increase by 6.5% to 7.5% in the most responsive regions and 4.5% to 5.5% in the less responsive regions[7]. In Section 2.4.3, we provide a probability approach to test the stability of the heterogeneous response across regions.

One of the aims of this study is to provide a regional-level analysis of the housing market and shed light on the driving forces of the heterogeneous effects of monetary policy on regional house prices. We consider house prices to be determined by the interaction of housing demand with housing supply. To this extend, fluctuations in house prices can be explained by disturbances in any of the two curves. Monetary policy surprises are responsible for shifts in housing demand, thus the heterogeneous response of regional house prices could occur due to a non-homogeneous influence

[7]The last column of Table 2.4 provides an analytical ranking, from most responsive to less responsive region.

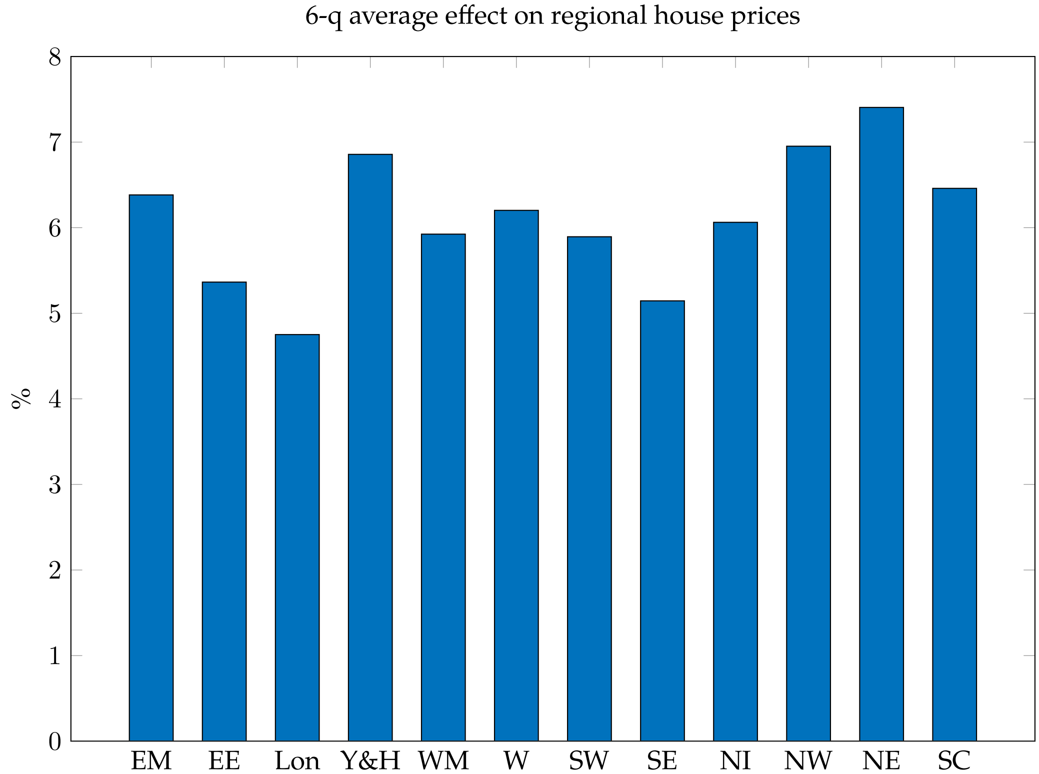

Figure 2.4: 6 quarter average response of regional house prices.

of monetary policy on housing demand across regions. Furthermore, the level of house price appreciation after an increase in housing demand depends on local housing supply elasticity. Even in the case where monetary policy influences housing demand homogeneously, house prices respond heterogeneously due to different regional housing supply elasticities. In the rest of the analysis, we disentangle local characteristics of the housing market which determine the local housing supply elasticity, and we reveal regional idiosyncrasies responsible for the heterogeneous impact of monetary policy on regional housing demand.

2.4.1 Housing supply

Our reasoning starts from the preposition of Hilber and Vermeulen (2016). The authors suggest that the response of local house prices to housing demand shifts depends on local supply constraints, where local supply constraints determine the regional supply elasticity of housing. In our empirical exercise, monetary policy serves the role of the housing demand shifter. The magnitude of price variation due to surprises in monetary policy depends on the elasticity of housing supply in each region. As more inelastic the supply of houses, the higher the expected house price variation after an outward shift in housing demand. More intuition on the problem is provided by Figure 2.5 which describes two housing markets before and after an increase in housing demand. Assume a generic region 1 with relatively high supply constraints and a generic region 2 to be less supply-constrained, their supply curves for housing are given by S_1 and S_2 respectively. Point A represents the equilibrium before the shock hits the economy and D is the initial demand curve. After an expansionary monetary policy shock the demand curve shifts to D' and house prices increase. The inelastic region reaches equilibrium at point C where $P = P_2^*$, the more elastic at point B where $P = P_1^*$ and $P_1* < P_2^*$. In supply-inelastic regions, an increase in housing demand leads to strong price growth and relatively less housing construction. In regions with loose housing supply elasticity, an increase in housing demand translates into a larger increase in quantity and a lesser increase in prices.

Local housing supply constraints can be decomposed into physical and regulatory. By physical supply constraints, we describe any predetermined geographic features such as lack of developable land, steep terrain, lakes and oceans, which cause limitations in housing development and rigidity in housing supply (Saiz, 2010; Paciorek, 2013; Gyourko et al., 2013). To discuss the presence of physical constraints and their role in the house price response to monetary policy shocks, we exploit information on terrain elevation and share of developable land developed provided by Hilber and

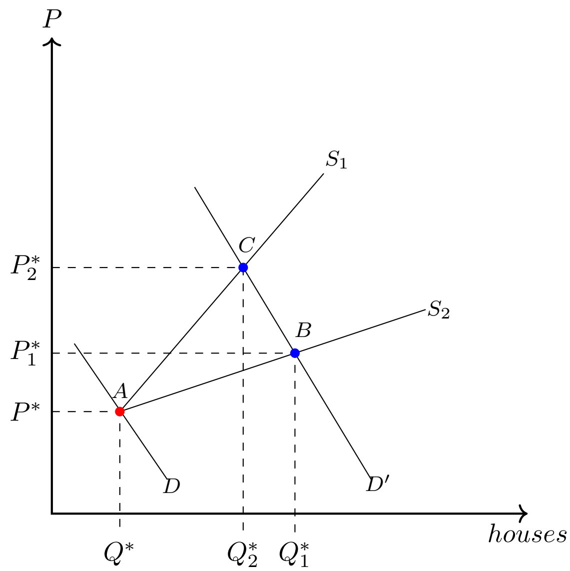

Figure 2.5: Representation of two supply-different regional housing markets after a demand shock.

Vermeulen (2016) and illustrated in Figure B.1.1 and Figure B.1.2 respectively. Terrain elevation is positively correlated with housing supply rigidities. In the U.K., terrain elevation is fairly small, but there is some variation with some areas in the North West and North East having relatively higher elevation than the rest of England. The relatively larger terrain elevation in these regions would be a plausible explanation of our observed pattern but it is not the only existing constraint. The data on the share of available developable land suggest that London and South East display low levels of available land, which restricts housing construction and creates supply rigidities. London's house prices exhibit the smallest increase among all regions due to expansionary monetary policy shocks. In contrast, in North East and North West, where the land availability is higher than in London and South East, house prices increase stronger. Therefore, we cannot conclude that the pattern in our empirical results occurs due to physical constraints per se.

Apart from physical constraints, regional housing supply elasticity is also linked with regulations in housing construction (regulatory constraints). Regulatory constraints affect housing supply by affecting the cost of building and the time needed to build (Hilber and Vermeulen, 2016; Paciorek, 2013; Cheshire and Sheppard, 2005). Regions with high regulation face a lower elasticity of supply, thus we would expect the less regulated regions to have minor house price variations due to demand shifts. In the case of the U.K., regulations on regional housing development imposed by the local planning authorities which are part of the British planning system. Local planning authorities regulate the development of land and buildings aiming long sustainability and prosperity in each region.

However, various studies argue that regulations caused by the local planning authorities are responsible for regional house price variations (Evans and Hartwich, 2005; Barker, 2004). Hilber and Vermeulen (2016) quantify the proportion of regulation due to the planning system in each region using the refusal rate of major residential projects, see Figure B.1.3. According to the authors, South East is the most regulated region in the U.K. and North East the less. Therefore, the two regions should exhibit significant differences in housing supply elasticity. Particularly, we expect South East to be supply-inelastic, and thus, we expect the house price variations due to shifts in housing demand to be higher than in the less regulated North East. Our empirical results do not support this hypothesis as the 6-quarters average effect of monetary policy on house prices in the North East is higher than in the South East. Thus, the heterogeneities in the impact of monetary policy on regional house prices do not appear to occur due to region-specific supply restrictions.

2.4.2 Housing demand

The analysis in the above subsection is based on the assumption that monetary policy shocks shift housing demand homogeneously across regions and thus house price developments depend solely on housing supply elasticities. However, shifts in housing demand might not be common across regions and that provides a plausible interpretation of our empirical results. In the rest of this section, we provide some evidence for the heterogeneous impact of monetary policy on regional housing demand and link the heterogeneity with the level of regional housing affordability. We approximate housing affordability by exploiting regional-level data on gross residence-based earnings, income requirements to issue a mortgage, loan-to-value ratios and housing upfront costs.

As mentioned in previous sections of this chapter, the main link between monetary policy and house prices is the mortgage rate. Monetary expansions reduce the mortgage rate across regions. Although, in our view, this does not directly translates to a homogeneous increase in housing demand, equivalently, a mortgage rate depreciation affects regional housing demands heterogeneously. The linkage of mortgage rate with regional housing demand is conditional on the capability of households to utilize a reduction in the former, i.e., the borrowing capacity of households. That allows us to narrow the investigation to a comparison of the borrowing capability of households between regions. The ability of households to borrow and purchase a house depends on the level of income relative to the level of house prices, that is, housing affordability. In regions where housing is relatively affordable, households can exploit a reduced mortgage rate and increase their demand for housing. In contrast, in regions where the household income is considerably lower than the house prices and housing is rela-

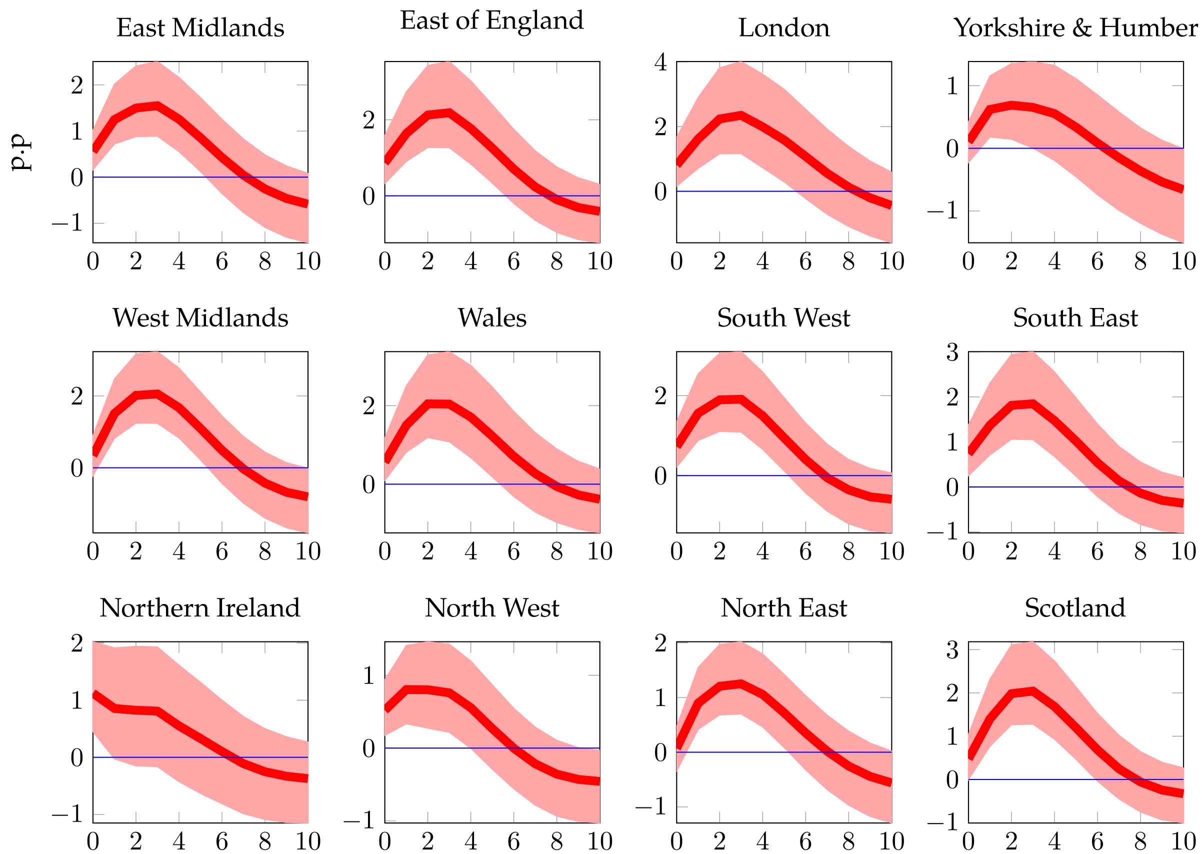

Figure 2.6: Impulse response functions of regional gross value added (GVA).

tively unaffordable, households face significant constraints to borrowing and purchasing houses. As a consequence, a reduced mortgage rate after a monetary policy expansion has negligible effects on regional housing demand. Utilizing relevant regional data allows us to approximate housing affordability and draw some conclusions about the significance of mortgage depreciation for housing demand.

In London, the median gross annual residence-based income is £30,007, and the income requirements to issue a mortgage for a median house with the 10% of the property's value paid upfront is £46,920. Similarly, in South East, South West and East of England, the income to mortgage requirement ratio is £27,140 to £39,511, £23,211 to £32,650 and £25,905 to £31,060 respec-

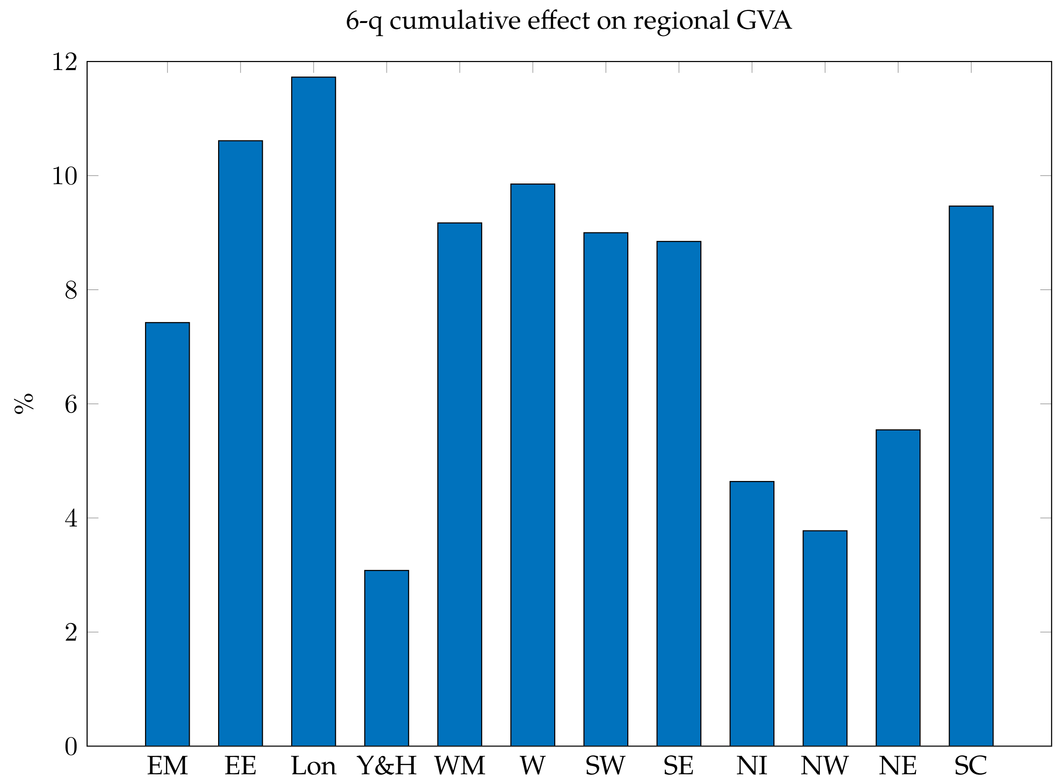

Figure 2.7: 6-quarters cumulative impulse responses of regional GVA.

tively. Hence, in those regions, median-income households do not meet the requirements to purchase a median-value house. On the contrary, in the North East the median income is £21,634 and the required income to issue a mortgage is £18,060. In the North West are £22,971 and £20,347 respectively. Column four in Table 2.3 provides the difference between the median income and the income requirements to issue a mortgage for a median-value house. We observe that monetary policy is more effective in regions where the median income exceeds the median value house mortgage requirements.

Apart from income requirements, another measure that reveals constraints in housing markets for some regions is the loan-to-income (LTI) ratio. As in the case of income requirements, the regions of the British South have a considerably higher loan-to-income ratio than the rest of the U.K. In London, South East, East of England and South West, the LTI ratio varies from 6.55 to 5.88, such high values of LTI ratios are sometimes restricted by regulations, but even in the absence of regulations in the mortgage market, the outstanding amount of debt a median income household has to issue to purchase a house is not in favour of significant increases in housing demand after a reduction in mortgage rate. The last measurement we utilize to approach housing affordability is the upfront cost. Diversity across regions in the upfront expenses is as apparent as in the previous measurements. In London, the upfront expenses for a median house reach 0.92 of the median annual income. In South East the ratio is 0.69, and in South West 0.64. In regions where house prices appear to be more sensitive to monetary shocks, the upfront cost of a property drops to 0.41 of the annual income in North East, 0.45 in North West and 0.46 in Yorkshire & the Humber. Table 2.3 provides the data and the measurements we use for the analysis of all available regions. In Table 2.4, we present a ranking of regions with respect to the characteristics we described above and the 6-quarters average impulse responses of regional house prices. The pattern observed in this table is that regions with higher housing affordability relative to others exhibit higher sensitivity of house prices to monetary policy shocks.

The results relate to a strand of literature which examines the transmission of monetary policy considering heterogeneous households (McKay et al., 2016; Kaplan et al., 2018; Bilbiie, 2008, 2020). This literature departs from the standard representative agent model by introducing heterogeneity in households' balance sheets. Generally, the literature characterises households with low levels of liquid and illiquid assets as "hand-to-mouth" agents. Households with large amounts of liquid and illiquid assets can be considered as the standard household in a representative agent context.

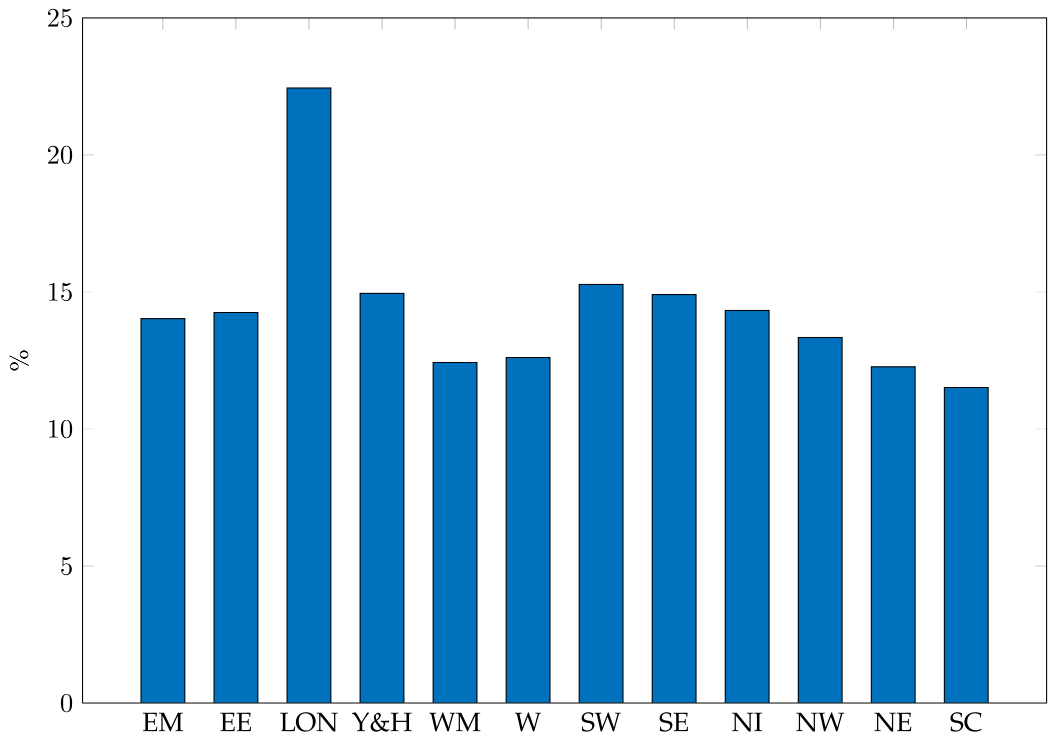

Figure 2.8: Renters as share of total households.

Kaplan et al. (2018) shows that monetary policy has powerful effects on households with a large amount of liquid and illiquid assets via intertemporal substitution; these results are consistent with the standard representative agent model. In the case of hand-to-mouth households, substitution effects are negligible, and the monetary policy transmits through general equilibrium (employment-income effects). Yet, monetary policy is particularly effective on hand-to-mouth agents' consumption, as they exhibit a higher marginal propensity to consume than the standard household. This behaviour can be explained by the fact that they do not accumulate assets, and in every time period, they consume their disposable income.

The heterogeneous agents framework provides an intuitive mechanism to explain the heterogeneous effects of monetary policy on regional house prices. To move from the household level to the regional level, we use the dominant type of household in each region to characterise it as hand-to-mouth or non-hand-to-mouth. This extrapolation requires the knowledge of household balance sheets in each region. To overcome this difficulty, we follow Cloyne et al. (2020) and proxy household types using the housing occupancy status. As described by Cloyne et al. (2020), renters satisfy the profile of hand-to-mouth agents as they are low in liquid and illiquid assets. Figure 2.8 illustrates the percentage of regional households registered as renters. Using this, we are allowed to characterize London as a hand-to-mouth region and South East as a non-hand-to-mouth. A monetary tightening is expected to have sizable general equilibrium effects in London, and monetary policy is expected to be particularly effective in stimulating the economy. This rationale is corroborated by Hedlund et al. (2017), where monetary policy is particularly effective in the presence of high Loan-to-Value households. The impulse responses of regional GVA are in line with this view as London, the region with the higher Loan-to-Value ratio and the higher proportion of renters exhibits the highest increase.

Regarding house prices, in regions where intertemporal substitution is important, households exploit the reduction in the cost of borrowing and increase the demand for housing. In contrast, in financially depressed regions, monetary expansions have negligible effects on housing demand. This is because the majority of households have limited access to external financing; thus, substitution is not taking place. As a result, the bulk of extra income gained after a monetary expansion flows to consumption, and the change in housing demand is relatively low.

2.4.3 Testing for spatial heterogeneity

The arguments made in section 2.4 rely heavily on the strength of the empirical results and particularly on the significance of the difference between regional house price impulse responses. To ensure that the spatial heterogeneity we presented is stable, we perform a statistical exercise using the generated impulse distributions for every forecast horizon. We start by defining London as the reference region because this region's house prices are the least responsive to monetary shocks among all regions. The next step is to obtain the distribution of the difference between the impulse responses of London and the rest of the regions at every forecast horizon. To achieve that, we draw from the conditional posterior, we calculate the impulse response of house price for the given draw at each region and then subtract London from the rest. Repeating this procedure as many times as the Gibbs algorithm iterates and after excluding the relevant burn-in sample, we obtain distributions for the difference between London's impulse responses and the rest of the regions. To draw inference, we utilize the cumulative density functions (CDF) of the aforementioned distributions on every forecast horizon, and we calculate the probability of drawing a value smaller or equal to zero[8]. Let Z describe the difference between IRFs of London and any other region. F_Z is the CDF of Z evaluated at $\varrho = 0$,

$$F_Z(\varrho) = P(Z \leq \varrho). \tag{2.19}$$

If Equation 2.19 provides high probabilities, the pattern of regional heterogeneity suggested by the empirical results is stable. Table 2.1 illustrates the probability of the difference between impulse responses of London and the remaining regions to be negative across the forecast horizon. The results of the statistical exercise suggest that the pattern of heterogeneity in regional house price responses to monetary policy shocks is stable for the majority of the forecast horizons with probabilities to occur in an interval of 0.7 to

[8]Since London is the less responsive region, the subtraction of the IRFs of the latter with any other region should provide a negative number, otherwise the IRFs overlap with some probability.

H	EM	EE	Y&H	WM	W	SW	SE	NI	NW	NE	SC
0	0.9949	0.9202	0.9943	0.9862	0.9873	0.9915	0.9652	0.8303	0.9951	0.9955	0.9934
1	0.8769	0.8111	0.8354	0.7828	0.7646	0.8817	0.7476	0.4530	0.8252	0.8882	0.6310
2	0.8102	0.7292	0.8075	0.7040	0.6881	0.7951	0.7723	0.4951	0.8042	0.8377	0.6257
3	0.8191	0.7759	0.8191	0.7303	0.7223	0.8145	0.8062	0.5377	0.8125	0.8357	0.6300
4	0.7721	0.7355	0.7832	0.6940	0.6922	0.7767	0.8018	0.6108	0.7732	0.7827	0.6314
5	0.7358	0.7177	0.7689	0.6858	0.7006	0.7445	0.7951	0.7278	0.7579	0.7370	0.6706
6	0.7254	0.7179	0.7794	0.7036	0.7315	0.7319	0.7920	0.8202	0.7681	0.7228	0.7258
7	0.7257	0.7202	0.7974	0.7314	0.7625	0.7258	0.7898	0.8799	0.7851	0.7283	0.7870
8	0.7454	0.7305	0.8206	0.7664	0.7957	0.7335	0.7954	0.9093	0.8130	0.7551	0.8462
9	0.7634	0.7409	0.8407	0.7948	0.8210	0.7411	0.7946	0.9193	0.8369	0.7840	0.8819
10	0.7783	0.7480	0.8485	0.8139	0.8331	0.7465	0.7944	0.9163	0.8491	0.8037	0.9014

Table 2.1: Probability table

0.99 except for Northern Ireland and Scotland. In the case of Northern Ireland, we observe particularly low probabilities, however, this is due to wide posterior coverage. The time series for Northern Ireland exhibit a structural break and high volatility. The linear econometric framework of our study struggles to fit the feature of the series and produces large intervals which lead to low probabilities in our test.

2.5 Conclusion

This chapter examines the effects of monetary policy shocks on regional house prices in the U.K. The results reveal spatial heterogeneity of monetary policy on house prices. The spatial pattern of heterogeneity differs from the traditional view, which supports that differences in regional housing supply are the main source of heterogeneity in house price developments. Particularly, regions with inelastic housing markets face relatively small house price appreciations after monetary expansions. At the same time, we observe a relation between the efficacy of monetary policy on house prices, the level of housing affordability and the balance sheet position of households. Hence, we add to the literature by providing empirical evidence that monetary shocks influence regional housing demand heterogeneously. We argue that in regions with low housing affordability, households are indifferent to the level of interest and mortgage rate. In such regions, a large fraction of households are hand-to-mouth and intertemporal substitution is limited. Hence, our findings provide evidence in favour of the view that monetary policy is effective on house prices mainly via its partial equilibrium effects. In the absence of smoothing due to financially depressed households, monetary policy operates via general equilibrium (income) effects. In this case, monetary policy is found to be relatively weak in influencing house prices.

Table 2.2: Acronyms of the regions.

Regions	Code names
London	LON
North East	NE
Scotland	SC
Yorkshire & the Humber	Y&H
East Midlands	EM
North West	NW
East of England	EE
South East	SE
West Midlands	WM
Northern Ireland	NI
South West	SW
Wales	W

Table 2.3: Regional housing cost related data.

Regions	Median earnings	Income req.	Mortgage	Entry	LTI	Upfront/Inc
NE	21,634	18,060	81,268	3,574	3.75	0.41
NW	22,971	20,347	91,560	2,624	3.98	0.44
Y&H	22,648	20,196	90,880	2,453	4.01	0.44
EM	23,094	22,205	99,922	889	4.32	0.48
WM	22,848	22,759	102,414	90	4.48	0.51
EE	25,905	31,059	139,767	-5,154	6.00	0.63
LON	30,007	46,920	196,604	-13,683	6.55	0.92
SE	27,139	39,512	165,971	-9,743	6.11	0.69
SW	23,211	32,650	136,590	-7,142	5.88	0.64
W	22,096					
SC						
NI						

Notes: This table provides data on median residence-based earning, income requirement to issue a mortgage when 10% is paid upfront and total mortgage amount to purchase a median value house. The column "Entry" provides a measure of whether a median-income household fulfils the income requirements for a mortgage. The LTI column shows the mortgage to income ratio.

Ranking	Upfront cost/Inc	Income req.	LTI	6-q IRFs
1	NE	NE	NE	NE
2	NW	NW	NW	NW
3	Y&H	Y&H	Y&H	Y&H
4	EM	EM	W	EM
5	WM	WM	EM	SC
6	EE	EE	WM	NI
7	SW	SW	EE	W
8	SE	SE	SE	SW
9	LON	LON	SW	WM
10			LON	EE
11				SE
12				LON

Table 2.4: Regional ranking of housing characteristics and the 6-quarter average response of regional house prices. Blank cell are due to lack of data.

Concluding Remarks

The conclusions of the first chapter contribute to the existing literature by measuring the effects of monetary policy on GSEs' market activity and by shedding light on the role of GSEs in the transmission of monetary policy shocks. The Chapter presents an unexplored aspect of the transmission mechanism of monetary policy and provides new information for the bank-lending channel. In a nutshell, government-sponsored securitization partly disrupts the amplification mechanism of monetary policy through financial intermediaries. The empirical evidence presented in the chapter is a prominent example that the financial system evolved rapidly in the last 30 years, and the dynamics of the financial markets on the economy become relevant with the passing of time. In the aftermath of the global financial crisis leading economists started developing economic models with integrated financial markets to study monetary policy and the business cycle. The results presented in chapter one motivate further research in this field considering also GSEs and securitisation as an important element in the transmission of monetary policy.

The conclusions of the second chapter of this thesis add to the macro literature regarding the regional effects of monetary policy on regional housing markets and point out that heterogeneity can be attributed to demand-side regional differences, an explanation that had remained relatively unexplored by the relevant literature prior to this thesis. For future research, we suggest the development of a DGSE model with at least two types of agents, one standard representative agent and a second constrained-to-borrowing agent, goods and a housing sector and a monetary authority. Simulating the results of monetary policy shocks in such economies with different shares of household composition would (at least qualitatively) deliver results similar to the empirical results of the second chapter. Our approach would be validated if, in an economy with a high share of constrained agents, monetary policy has milder effects on house prices against an economy with a high share of standard representative agents. Apart from validating the empirical results of the second chapter, this model could be used to reveal the transmission of monetary policy on house prices in detail.

Appendix A

Appendix Chapter 1

A.1 Model estimation

We adopt a Bayesian approach to estimate the model in Equation (1.6). We impose the standard Normal-Inverse Wishart prior for the model parameters as advocated by (Kadiyala and Karlsson, 1997). The priors take the form:

$$\Sigma \sim \mathcal{IW}\left(s, v\right)$$

and

$$B|\Sigma \sim \mathcal{N}\left(b_0, \Sigma \otimes H\right)$$

v, the degrees of freedom of the Inverse-Wishart, is defined as $v = n+2$. The scale matrix, s, is a $(n+1) \times (n+1)$ diagonal matrix with diagonal entries to be functions of the residual variance resulting from a regression of each endogenous variable on its own p lags. The parameters of the priors for the VAR coefficients are chosen to match the moments of Minnesota priors.

$$\mathbb{E}\left[(B_k)_{ij}\right] = \begin{cases} \delta_i, & j = i, k = 1 \\ 0, & \text{otherwise} \end{cases}, \quad \mathbb{V}\left[(B_k)_{ij}\right] = \begin{cases} \frac{\lambda^2}{k^2}, & j = i \\ \frac{\lambda^2}{k^2}\frac{\sigma_i^2}{\sigma_j^2}, & \text{otherwise} \end{cases}, \tag{A.1.1}$$

where $(B_k)_{ij}$ denotes the coefficient of regressor j at equation i at lag k. The prior mean implies the coefficient of the first lag $(k = 1)$ of the endogenous variable in each equation $(j = i)$ is δ_i, and the coefficients of lags of the rest of the variables or higher order lagged values of the endogenous variable move towards zero. Originally Litterman (1986) sets $\delta_i = 1$, i.e., the prior strictly imposes that the data generating process follows a random walk. Bańbura et al. (2010) advocates that we can relax this for variables which exhibit considerable mean reversion. They propose that a prior towards white noise would be more appropriate. Thus, for variables with low persistency, we set $\delta_i = 0$. The VAR coefficients' prior variance decays with the lag length at a rate of $1/k^2$. Scaling by the ratio σ_i^2/σ_j^2 accommodates differences in scale and variability of the data. The hyperparameter λ governs the tightness of the prior, i.e., how strong the prior's influence would be on the posterior. Following Giannone et al. (2015), we treat λ as a random variable and estimate its value.

A.2 Data description

This section describes the data used in the study. Table A.2.1 summarizes data transformations and sources. The macro aggregates and the cost of credit indicators are standard, and we do not wish to go through an exhausting description. Our main data source for the macro variables is the publicly available dataset used in Miranda-Agrippino and Ricco (2021). Details on the data can be found in their online appendix. The GSE-related data are taken from Fieldhouse et al. (2018). The authors provide a thorough description of the data in the online appendix of the paper, although we desire to briefly describe some indicators that are not broadly known in the macro literature. First, GSE mortgage holdings denote the total value of mortgage portfolios of Freddie and Fannie in whole loans and mortgage pools for Mortgage Backed Security issuance. Private mortgage holdings are defined as total mortgage debt minus GSE mortgage holdings (including Ginnie Mae and the Fed). Net commitments are monthly commitments made by GSE to buy mortgages minus monthly commitments to sell. The GSE-issued MBS yield is the lowest possible yield (yield-to-worst) on GSEs MBS, thus is serving as a lower bound of the GSEs cost of finacing via mortgage-backed securities.

Name	Filter	Source
1-Y Treasury Rate	None	Miranda-Agrippino and Ricco (2021)
Industrial Production	Natural log	Miranda-Agrippino and Ricco (2021)
Unemployment Rate	None	Miranda-Agrippino and Ricco (2021)
Consumer Prices (CPI)	Natural log	Miranda-Agrippino and Ricco (2021)
Commodity prices (CRBPI)	Natural log	Miranda-Agrippino and Ricco (2021)
Excess Bond Premium	None	Miranda-Agrippino and Ricco (2021)
2-Y Treasury Rate	None	Miranda-Agrippino and Ricco (2021)
5-Y Treasury Rate	None	Miranda-Agrippino and Ricco (2021)
10-Y Treasury Rate	None	Miranda-Agrippino and Ricco (2021)
20-Y Treasury Rate	None	Miranda-Agrippino and Ricco (2021)
AAA Corporate Bond	None	Miranda-Agrippino and Ricco (2021)
BAA Corporate Bond	None	Miranda-Agrippino and Ricco (2021)
Mortgage Spread	None	Fieldhouse et al. (2018)
GSE expected market share	None	Fieldhouse et al. (2018)
GSE Mortage Holdings	Natural log	Fieldhouse et al. (2018)
GSE-issued MBS Yields	None	Bloomberg Terminal
Private Mortgage Holdings	Natural log	Fieldhouse et al. (2018)
Mortgage Originations	Natural log	Fieldhouse et al. (2018)
Housing Starts	Natural log	Miranda-Agrippino and Ricco (2021)
House Price Index	Natural log	Freddie Mac HPI
House Price Index (Shiller)	Natural log	Shiller (2015)
Housing Sales	Natural log	FRED-St. Louis

Table A.2.1: Data sources and transformations.

Appendix B

Appendix Chapter 2

B.1 Housing supply elasticity

Hilber and Vermeulen (2016) provide maps with physical and regulatory determinants of housing supply elasticity in England. The provided data are limited to English counties and regions and do not convey information for Wales, Northern Ireland and Scotland. We acknowledge this as a limitation to our analysis of housing supply which is conducted focusing on regions of England instead of all the regions in the U.K. Figure B.1.1 illustrates terrain elevation to be prevalent mainly in the North East and North West of England, although Hilber and Vermeulen (2016) advocate that terrain elevation has no significant effects on housing supply elasticity and plays no role in land availability, see Figure B.1.2 where land availability for housing development in those two regions is among the highest in England. Moreover, in Figure B.1.2, we see that the share of developable land developed is particularly high in the London and South East area and around the large cities in West Midlands, implying a smaller housing supply elasticity for those areas. Last, Figure B.1.3 indicate the refusal rates of new housing projects in each area of England. Regulations are particularly tighter in South East and London than in West Midlands, North East and

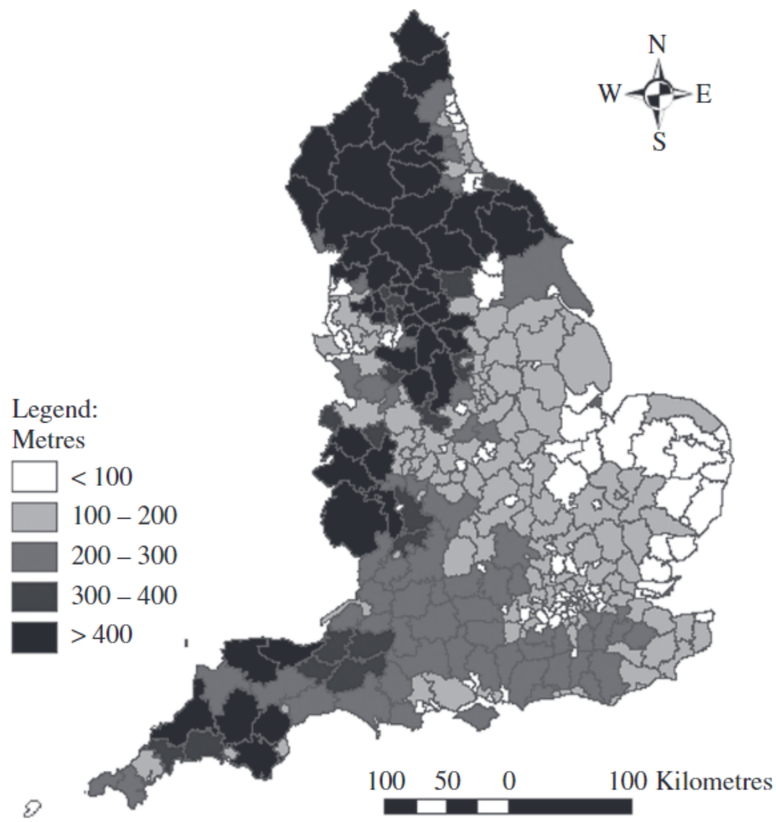

Figure B.1.1: Terrain elevation in meters from Hilber and Vermeulen (2016)

North West. This leads to the conclusion that the overall housing supply elasticity must be lower in regions such as London and the South East than in regions such as the North East and North West.

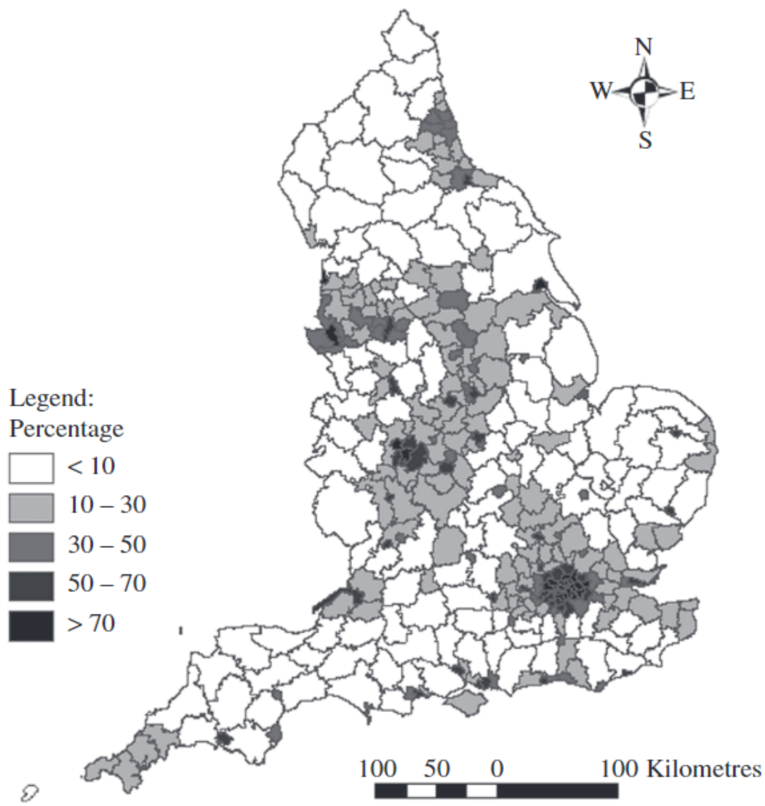

Figure B.1.2: Developable land developed from Hilber and Vermeulen (2016)

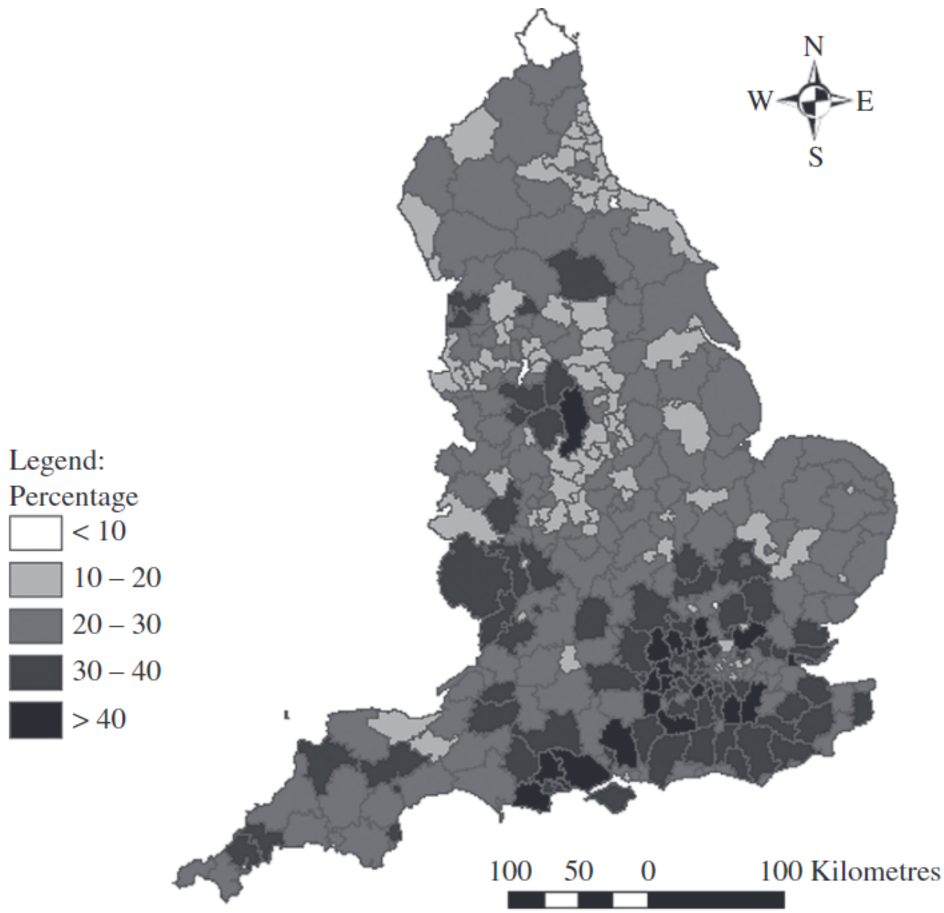

Figure B.1.3: Refusal rates on new housing projects from Hilber and Vermeulen (2016)

B.2 Macro Irfs

Figure B.2.1 provides the impulse response functions of the rest of the aggregate level variables included in the FAVAR. A description of the variables is provided by Table B.3.1

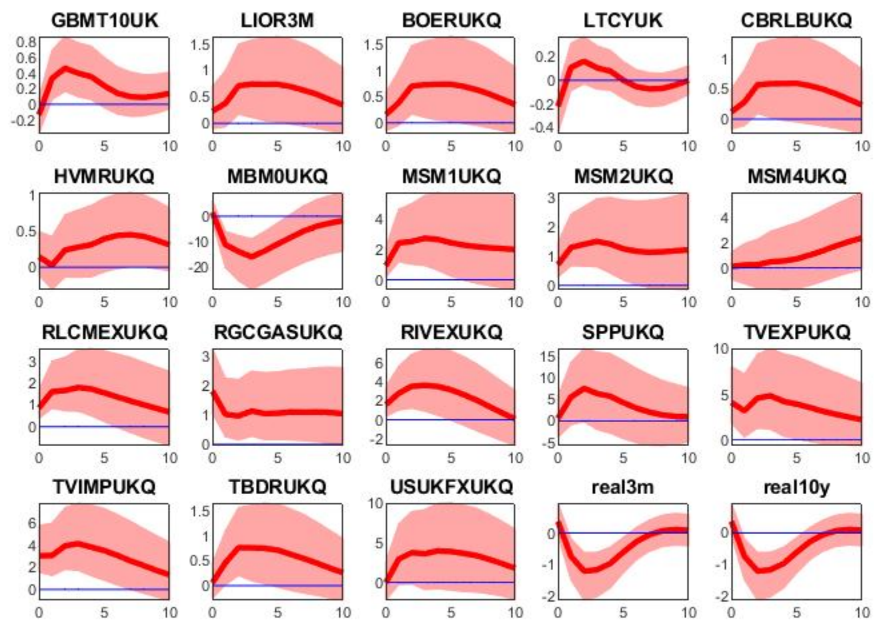

Figure B.2.1: Impulse responses of macro variables included in the model.

B.3 Data description

Code	Description	Transf.
Regional HPI	House prince index of each region	Nat. log
Regional GVA	Gross Value Added of each region	None
GBMT10UK	10-Year (Medium-Term) Government Bond Yields	None
LIOR3M	3-month London Interbank Offered Rate (LIBOR)	None
BOERUKQ	Bank of England Policy Rate	None
LTCYUK	Consol (Long-term bond) yields	None
CBRLBUKQ	Corporate Borrowing Rate on Loans from Banks	None
HVMRUKQ	Household Variable Mortgage Rate	None
MBM0UKQ	M0 Money Stock	Nat. log
MSM1UKQ	M1 Money Stock	Nat. log
MSM2UKQ	M2 Money Stock	Nat. log
MSM4UKQ	M4 Money Stock (Break Adjusted)	Nat. log
RLCMEXUK	Real Consumption Expenditures	Nat. log
RGCGASUKQ	Real Government Consumption of Goods and Services	Nat. log
RIVEXUKQ	Real Investment Expenditures	Nat. log
SPPUKQ	Share Prices (Weighted by Market Capitalisation)	Nat. log
TVEXPUKQ	Trade Volumes: Export Volumes	Nat. log
TVIMPUKQ	Trade Volumes: Import Volumes	Nat. log
TBDRUKQ	3-month Treasury Bill Discount Rate	None
USUKFXUKQ	U.S. / U.K. Foreign Exchange Rate	None
real3m	3-month real interest rate	None
real10y	10-year real government bond yield	None

Table B.3.1: Description of variables used in the model and their transformations.

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