ESSAYS ON MONETARY POLICY AND HOUSE PRICES

A Dissertation

by

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ABSTRACT

The first chapter revisits Romer and Romer's (2004) narrative identification approach to monetary policy shocks by allowing a monetary authority to respond systematically to corporate credit spreads and real house price dynamics. The chapter documents the systematic response of interest rates to these variables and shows that accounting for this systematic response solves an observed empirical puzzle in the literature, where unanticipated increases in the interest rate, instead of contracting the economy, acted as expansionary shocks during the Great Moderation period. Specifically, it investigates the Federal Open Market Committee (FOMC) transcripts using natural language processing tools to document the increased importance of house prices in discussions among FOMC members about the implementation of monetary policy.

A measure of high-frequency monetary policy shocks is an important tool for identifying the effects of policy surprises on real house prices. The second chapter documents that high-frequency changes in market rates around FOMC announcements can be explained multi-dimensional way; Surprise changes in the federal funds rate, forward guidance, and large-scale asset purchases. Real house prices respond stronger to the surprises to longer-term future rates as compared to the surprise changes in the federal funds rate. These findings are established using panel data in the United States between 1991 to 2018 across divisions. The responsiveness of house prices to monetary policy shocks depends on the nature of the shock - expansionary versus contractionary. The chapter documents that contractionary monetary policy shocks have a considerably greater and more persistent impact on real house prices.

The last chapter utilizes a multi-level dynamic factor model estimated on quarterly state-level data from 1976 to 2022 using Bayesian methods to estimate the relative importance of the national component in real house price movements compared to local shocks. The chapter provides evidence that regional components account for an average of 48% of the variation in real house price dynamics from 1976 to the late 1990s, indicating a significant role played by regional and state-specific (local) factors during this period. However, in contrast, a national factor contributes

to a substantial portion of real house price fluctuations in recent periods, with an average of 87% for 2007-2011 and 85% for 2020-2022.

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1.1 Introduction and literature review

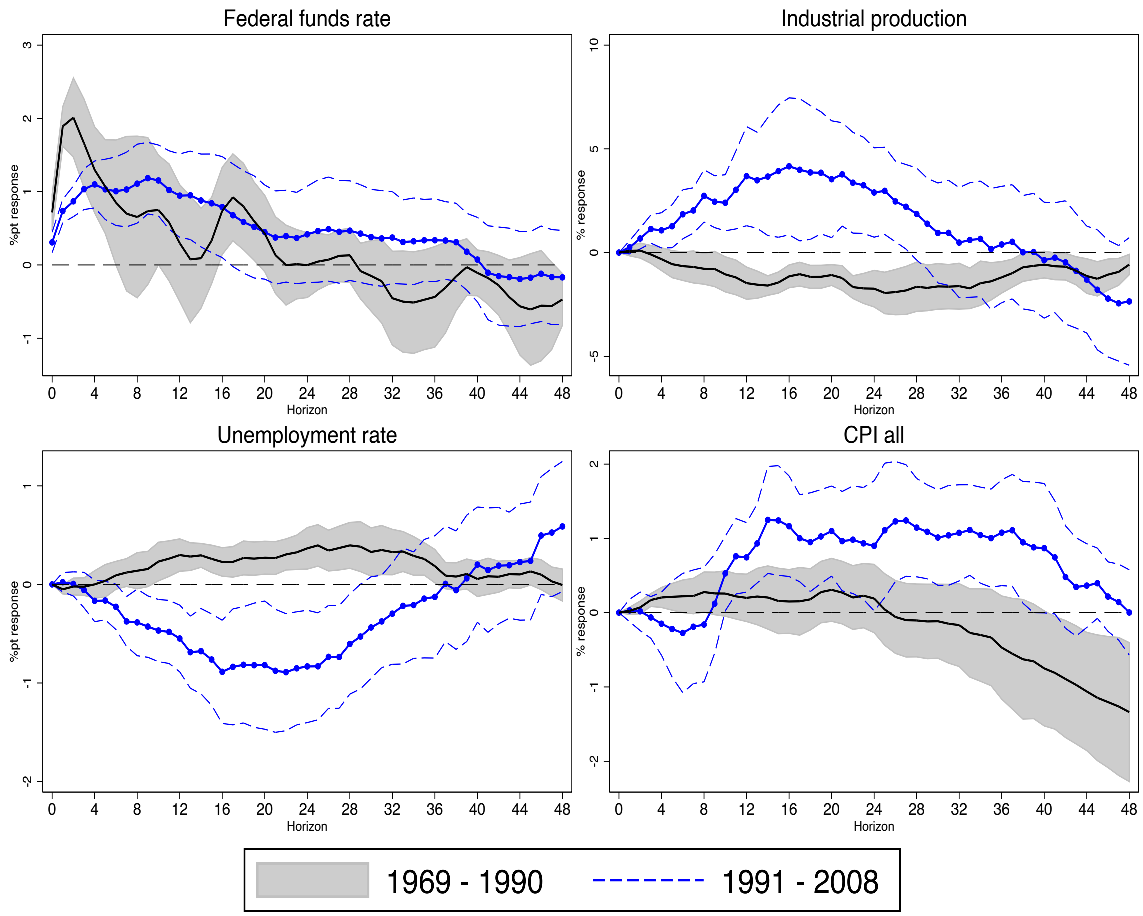
Standard macroeconomic theory suggests that an unexpected increase in interest rates should generate a contraction in real economic activity and reduce inflation, acting as typical demand shocks. This is the basis of the central bank's monetary policy. However, this evidence has been challenged recently (see Ramey, 2016 for a discussion) as in the post-1984 period, known as the Great Moderation, it is difficult to empirically uncover theoretically consistent responses for economic variables to unexpected changes in interest rates.

Figure 1.1 compares the impulse responses of the Federal funds rate, industrial production, the unemployment rate, and the aggregate price level to traditionally used, narratively identified monetary policy shocks, as in Romer and Romer (2004), for two different sample periods: 1969 to 1990 and 1991 to 2008[1]. The responses of the first sample period (in solid black lines and shaded areas) follow the classic effects of monetary policy shocks, which are consistent with conventional macroeconomic theory. A 100 basis point increase in the Federal funds rate results in a recession: industrial production falls, and unemployment increases, but both recover towards their steady-state levels after four years. Prices, as measured by CPI, decline after the initial increase, a phenomenon usually referred to as a price puzzle. The responses for the second subperiod, depicted in blue dotted lines, show instead that increases in the Federal funds rate raise industrial production and lower the unemployment rate. These results echo Barakchian and Crowe (2013) and Ramey (2016), who show that the traditional specifications imply that contractionary monetary policy had surprising expansionary effects in the sample from 1991 through 2008.

Overall, previous research on the transmission of monetary policy during the Great Moderation period has demonstrated that the estimated dynamic responses to policy innovations are sensitive to using different samples, estimation methodologies, and identification strategies. This chapter

[1] The sample stops in 2008 to exclude the effectively zero low-bound period in the US.

Figure 1.1: Jordà local projection with R&R monetary policy shock



Note: The solid black line in each panel depicts the impulse response function of the specified variable (Federal funds rate, real industrial production, the unemployment rate, and headline CPI) to a 100 basis point deviation of the Romer and Romer (2004) monetary policy shock for 1969-1990, based on Jordà's local projection method (Jordà, 2005). The blue dotted line in each panel shows the response function of the specified variable to a 100 basis point deviation from the Romer and Romer (2004) monetary policy shock for 1991-2008. Shaded bands and blue dashed lines denote the associated 90% confidence intervals.

contributes to the literature on the narrative identification of monetary policy by improving how we account for the systematic response of monetary policy and shows that controlling for real house prices, in addition to credit spreads, recovers the responses of macroeconomic variables in ways that are consistent with the theory.

This chapter contributes to two strands of the literature. First is the literature on the identification of monetary policy shocks.[2] My work is more closely related to Gertler and Karadi (2015) and Caldara and Herbst (2019), which both pay close attention to the shocks' financial conditions, particularly credit cost, as a critical component in the monetary authority's information set when setting the interest rate. There is also relatively new and fairly scant literature that discusses the relevance of housing prices for monetary policy. Finocchiaro and von Heideken (2013) estimate the house price coefficient in a monetary policy feedback rule and find evidence of a positive and significant response of interest rates to house prices in the US, specifically in the context of a DSGE model. A similar result emerges in Aastveit et al. (2017), who show that the Federal Reserve had responded systematically to house prices, but this response changed over time, using a VAR model with time-varying parameters and stochastic volatility. This chapter instead evaluates the role of house prices for the identification of monetary policy shocks by revisiting Romer and Romer's (2004) narrative identification strategy.

My first contribution to this literature is providing evidence of the relevance of house prices for monetary policy decisions by applying standard natural language processing (NLP) analysis. To show that house prices are on the radar of policymakers is a necessary, though not sufficient, condition for arguing for the relevance of house prices in decision-making. I use a direct measure of mentions of housing-related words that appear in Federal Open Market Committee (FOMC) discussions from 1991 M2 to 2008 M12. In this step, I define five groups of terms related to major macroeconomic variables that are relevant for monetary policy: "Inflation," "Output," "Labor," "Housing," and "Credit." I then derive the frequency of words expressed in each group compared to all five groups. This setup allows me to track the systematic reactions of monetary policy to the five components in each FOMC meeting over my sample period.

I find that housing- and credit-related terms account for 11.23 percent and 15.62 percent, respectively, of the total words identified to be important for monetary policy over the whole sample period. Interestingly, a word search suggests that terms associated with the housing market ap-

[2]See Bernanke and Blinder (1992); Christiano, Eichenbaum, and Evans (1996); Leeper, Sims, and Zha (1996); Leeper and Zha (2003); Romer and Romer (2004); and, more recently, Coibion (2012); Finocchiaro and von Heideken (2013); Arias, Caldara, and Ramirez (2015); Gertler and Karadi (2015); Ramey (2016); Aastveit et al. (2017); and Caldara and Herbst (2019).

peared frequently after 2000. Before 2000, the average frequency of words related to housing was only 8.85 percent, but it increased by five percentage points after 2000. By contrast, the frequency of labor-related terms decreased after 2000. Though this finding does not necessarily identify why house prices are important for the policymakers, i.e., it might be because they have been moving a lot or because the policymakers prefer to stabilize them, it still provides suggestive evidence for the importance of house prices in FOMC discussions, above and beyond the regular variables traditionally considered to be important for monetary policy.

Does accounting for house price movements improve the identification of monetary policy shocks? To characterize this question, I revisit the narrative approach to monetary policy shocks discussed in Romer and Romer (2004) by re-constructing their monetary policy shocks (the baseline specification throughout this chapter) with two changes to their identification framework. I expand the earlier model by adding indicators of both real house prices and credit spreads into their identification regression equation. The estimated residuals in the expanded model constitute the newly proposed narrative measures of the policy innovations matching the FOMC (regular) meeting frequency. These newly orthogonalized monetary policy shocks resolve various puzzle-type effects in output, inflation, and other variables previously discussed in local projections or structural VAR frameworks, at last reconciling the effects of the monetary policy with traditional macroeconomic theory.

Notably, the estimated results show that the central bank reacts to changes in the Baa spread beyond the information contained in the Greenbook forecasts. Consistent with the evidence from Caldara and Herbst (2019), FOMC meetings occurring in periods with elevated levels of corporate credit spreads are associated with cuts in the intended Federal funds rate. While the results on the responses to credit spreads are in line with the previous literature, one new finding is that the response to real house price growth is also important. The empirical evidence, though in a different empirical context, shows that the central bank systematically and positively responded to real house price growth for the 1991-2008 period, consistent with Aastveit et al. (2017).

More importantly, accounting for the systematic reactions of policy to house prices has a significant role in understanding the transmission of monetary policy shocks in terms of standard macroeconomic theory, i.e., interest rate surprises generate recessions, which are accompanied by declines in prices. I further show that the results are robust to various estimation strategies by considering both local projections as well as hybrid VAR-based responses. For all the different estimation methods, the empirical findings support the importance of incorporating house prices to understand the transmission of monetary policy shocks to the macroeconomy during the Great Moderation period.

The rest of the first chapter is structured as follows. Section 1.2 describes the NLP procedure utilized in the chapter and the results on the frequency of topics mentioned in FOMC transcripts. Section 1.3 revisits the narrative identification of monetary policy shocks proposed by Romer and Romer (2004) and derives a new measure of the policy shocks by adding two important systematic components into their estimation framework. Sections 1.4 and 1.5 examine narrative-based identification of the effects of monetary policy on macroeconomic variables in local projections and structural VAR frameworks. Section 1.6 discusses the implications of my results for monetary policy and lays out some ideas that hold promise for future research.

1.2 Discussion of FOMC transcripts

Have house prices been important for discussions about establishing monetary policy? To engage this question, this section proposes a measure of the central bank's preferences associated with identifying exogenous policy shocks and with determining whether or how policymakers consider those shocks. I accomplish this by examining the FOMC's preferences directly by evaluating participants in the FOMC monetary policy meetings. In particular, I measure the presence of the Fed's systematic responses to house prices by applying standard natural language processing (or textual analysis) to publicly available FOMC meeting transcripts. That is, rather than basing the measure on specific events or numerical data and having to investigate whether the FOMC is sufficiently concerned about them, I use a direct measure of mentions that actually appear in FOMC discussions.

Since these word counts are taken directly from FOMC meeting transcripts, they are particularly well suited for explaining the behavior of the FOMC. In general, examining such an indicator should highlight the degree of importance the FOMC accords to maximum employment, prices, and financial stability, and hence their importance to the implementation of monetary policy. For instance, if FOMC members never discuss housing markets at these meetings, it would be difficult to argue that the stance of monetary policy has been affected by concerns about housing market performance. If the committee does discuss financial instability concerns, then it either cares about financial instability separately or believes that the forecast has not incorporated these concerns fully or accurately enough. My key finding from the textual analysis is that the FOMC significantly considered housing (and credit) markets, in addition to the real macroeconomic variables which were typically expressed, such as real GDP, inflation, and the unemployment rate (and those forecasts), when the central bank established its monetary policy, especially during the Great Moderation period.

My main textual data source is the public archive of FOMC transcripts, which are the most detailed records of FOMC meeting proceedings and can be obtained directly from the Federal Reserve Board of Governors website with a five-year lag. Specifically, the FOMC Secretariat produced the transcripts shortly after each meeting from an audio recording of the proceedings, lightly editing the speakers'original words to facilitate readers'understanding. Meeting participants are given an opportunity in the subsequent several weeks to review the transcript for accuracy[3]. These transcripts cover all regular FOMC meetings from 1976 to 2015, though I only make use of February 1991-December 2008 transcripts in this chapter given other data constraints. To this end, my baseline sample is scheduled for FOMC meeting days from February 1991 to December 2008, when the Federal funds rate hit the zero lower bound.

I do not use days with unscheduled FOMC meetings. The main reason for this is pragmatic:

[3]For the meetings before 1994, the transcripts were produced from the original, raw transcripts in the FOMC Secretariat's files. Though these records have also been lightly edited by the Secretariat, some errors undoubtedly remain since the raw transcripts were not fully edited for accuracy at the time they were prepared. At that time, they were intended only as an aid to the Secretariat in preparing meeting minutes. While some have questioned whether it is appropriate to use the transcripts before 1994, to my knowledge, this is the best data available to the public and is sufficient to capture the FOMC's preferences.

the test in the following section for the presence of a systematic response of monetary policy to financial conditions and house prices uses the projections from the Greenbooks for the Federal Reserve Board of Governors. Greenbooks are produced only before each scheduled FOMC meeting, so they are not available for unscheduled meetings.[4]. Since the FOMC had eight scheduled meetings per year, my samples include a total of 144 transcripts.

The textual analysis provides narrative evidence for estimating the Fed's preferences, relying on the assumption that the central bank's concerns are embedded in the words spoken by the policymakers at internal meetings. Accordingly, I count the frequency of terms expressed by FOMC members, which can be related to the systematic components of monetary policy, including implicit inflation targets, economic growth, and financial and housing market performance. The advantage of this approach is that it could be used internally and externally to study the preferences of any central bank with transcripts, statements, or detailed summaries of their policy-making deliberations.

Initially, I convert all the transcripts from the PDF format to text files, then apply several filters to remove words likely to be especially noisy. I proceed in three steps. Once a corpus, a collection of text documents, is created, I modify the documents to aid later analysis. First, I drop punctuation, except for inter-word dashes. Second, I remove extra white space and "stop-words", defined as common words that usually have no analytic meaning in English. Third, I reduce word forms to stems, which makes any form of a term primitive. In some cases, I wish to preserve a concept that is only apparent as a collection of two or more words, such as economic growth, inflation expectation, and house prices; hence I combine them (or reduce them) to a meaningful acronym.

I begin my analysis by defining five different groups in a list of terms related to a specific economic variable. Table 1.1 provides a list of the words I select for each group. The group "Inflation" is composed of terms that might be related to price stability, such as inflation expectation,

[4]A potentially important concern relates to the role of unscheduled meetings, where the FOMC takes urgent decisions in moments of particular economic distress. These unexpected meetings may, in fact, be the ones responsible for the information channel, as discussed in Miranda-Agrippino and Ricco (2021). They addressed this concern by repeating the estimation using market surprises registered around scheduled FOMC meetings only and found that the results were robust. My sample has 52 unscheduled meetings out of 196 total events from February 1991 to December 2008.

Table 1.1: List of Economic Terms in Each Group

Inflation	**Output**	**Labor**	**Housing**	**Credit**
			house	
inflation	output		home	
inflation expectation	output gap		house price	
inflationary	potential output	unemploy	home price	credit
inflationary expectation	gdp	unemployment	housing price	credit spreads
deflation	industrial production	nonemploy	housing related	treasuries
deflationary	slack	employ	housing sector	bond
disinflation	utilization	employment	homeownership	corporate bond
disinflationary	recession	natural rate	residential	yield curves
consumer prices	expansion	labor	mortgage	securities
producer prices	economic activity	hire	fannie mae	forward rate
cpi	economic growth	jobless	freddie mac	
pce	economic development		ofheo	
price stability	economic performance		foreclosure	
			collateral	
13	13	9	15	8

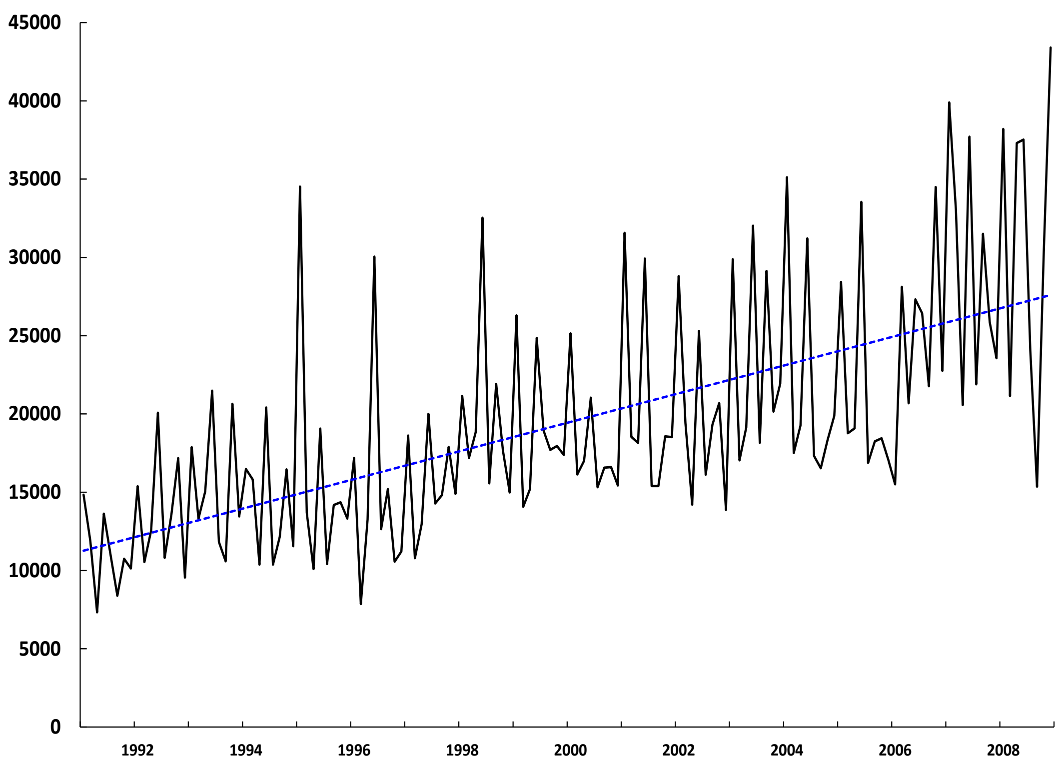
* For inflation, output, and labor, see Peek et al. (2016) and Shapiro and Wilson (2021). Otherwise, my own specification.

deflation, and several price indexes. The terms for the group "Output" are related to economic growth, such as output gap, potential output, GDP, industrial production, slack, utilization, recession, and economic activity. The list of words in the group "Labor" are unemployment, labor, hire, jobless, and natural rate, all of which are associated with unemployment rates. In the group "Housing", I choose several terms that might be highly related to housing markets, such as housing sector, house (home, housing) price, home-ownership, residential, mortgage, Fannie Mae, Freddie Mac, OFHEO (Office of Federal Housing Enterprise Oversight), foreclosure, and collateral. Lastly, the group "Credit" is composed of words that could be highly associated with credit market performances, e.g., credit spreads, treasuries, corporate bonds, yield curve, and forward rate. To classify the key economic terms, I follow Peek et al. (2016) and Shapiro and Wilson (2019, 2021), specifically using their filtered subsets of transcript text for "Inflation," "Output," and "Labor." For the lists of transcript text for housing and credit, I use my own specification[5] after selecting and

[5]The main point is to understand how the FOMC members described which topic and who described them at each meeting. Based on this, word classification was carried out for the last two groups. In that sense, subjectivity inevitably

investigating several representative meeting transcripts.

Figure 1.2: Total word count stated by the FOMC members at each meeting



Note: The solid black line shows the frequency of words expressed in transcripts from FOMC meetings over the sample period of 1991 through 2008. The dotted blue line represents the fitted line of the linear estimation given the sample.

Given a collection of text documents and categorization, I calculate the total number of words stated for each group of transcript text. An important issue is that, as seen in Figure 1.2, the total word count for transcripts in each FOMC meeting increased over the sample period, from

played a role in the selection of which words to examine. The purpose of the selection, however, is to identify terms that are likely to be used to address concerns about the housing and credit markets.

under 11,000 words in 1991 to about 31,000 words in 2008. Accounting for that, I compute the frequency of words expressed in each group vs. in all five groups[6] I defined. The associated results are shown in Table 1.2, which provides the average frequency of terms expressed for each group and the total number of times these words are mentioned in the FOMC meeting transcripts across the three different sample periods. During the full sample period from 1991 to 2008, the average total number of words mentioned in each FOMC meeting was 19,431; on the other hand, the frequency of terms selected in all five groups accounts for 2.63% on average of the total number of words expressed. Within the five groups, in particular, the terms related to Output, Labor, Inflation, Housing, and Credits account for 20.18%, 19.45%, 33.52%, 11.23%, and 15.62% on average, respectively.

Table 1.2: Frequency of terms expressed by the group across the sample

Group (%)	Full sample: 91-08	Pre-period: 91-99	Post-period: 00-08
Output	20.18 [5.226]	20.51 [4.397]	19.85 [5.954]
Labor	19.45 [6.612]	21.48 [5.711]	17.43 [6.866]
Inflation	33.52 [10.036]	33.09 [8.054]	33.95 [11.73]
Housing	11.23 [7.001]	8.85 [4.676]	13.61 [8.083]
Credits	15.62 [8.329]	16.08 [8.53]	15.16 [8.158]
All groups (#)	521	373	670
Total (#)	19431	15549	23314

The results of this word search imply three key elements of FOMC preferences. First, the results indicate that the frequency of terms associated with the groups "Inflation" and "Output" have on averaged about 33% and 20%, respectively, over the entire sample period. There is no no-

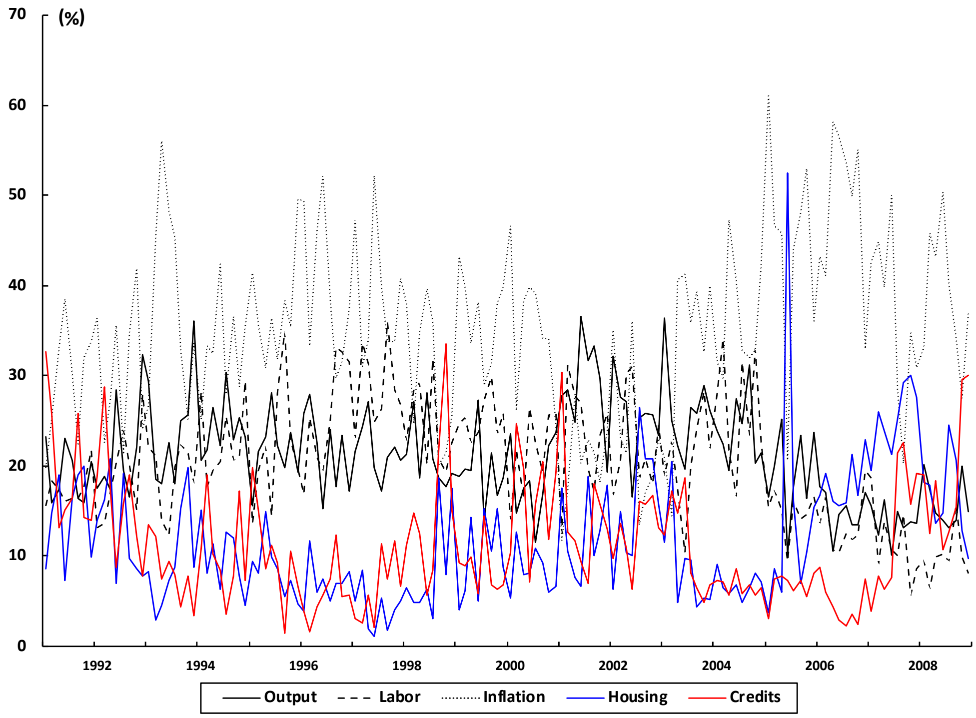
[6]For instance, the frequency of terms associated with the group "Inflation" in a given FOMC meeting can be computed as $\frac{\textit{\# of words expressed in the group Inflation}}{\textit{\# of words expressed in all five groups}} \times 100$

ticeable change in those frequencies across the Pre- and Post-period. These findings are consistent with the fact that the Fed conducts monetary policy to promote stable growth in economic activities and prices (see Walsh, 2017), which is commonly known as the dual mandate. Second, the results show that the frequency of terms related to “Credits” averages 15.5% over the full sample period, which can imply that the Fed was steadily concerned with credit market performances during the Great Moderation period, which is compatible with findings by Caldara and Herbst (2019). Finally, the results support the fact that the Fed considered the housing market when they discussed the monetary policy and whether its extent had changed. For the Pre-period from 1991 to 1999, the average frequency of terms related to the group “Housing” was 9%, which is about half the frequency of those from the “Output” or “Labor” groups. However, the average "Housing" frequency increased to 14% during the Post-period, a comparatively large proportion compared to the other groups. Overall, a preliminary reading of the transcripts[7] clearly indicates that housing market concerns were discussed by FOMC members, with the key terms appearing more frequently during the Post-period.

Figure 1.3 provides a graphical description of how the frequency of the words in each group at each FOMC meeting moves for the period 1991 to 2008. The solid black line in Figure 1.3 represents the group “Output.” The black dashed line indicates the group “Labor.” The black dotted line shows the group “Inflation.” The blue and red solid lines describe the frequency of terms related to housing and credit, respectively. The results from Table 1.2 and Figure 1.3 indicate two points. First, inflation-related words were consistently mentioned at each meeting, at an average rate of 33% over the entire sample period. On the other hand, terms related to output, labor, housing, and credit showed different frequencies and varied across the sample period. Specifically, the frequency of words related to output and labor maintained an average of about 20% until the early 2000s. Then the number sharply decreased, showing a frequency of about 10% in 2008.

[7] For comparison purposes, I compare the frequency of terms for each group I defined to the total number of words expressed at each FOMC meeting in my sample period. In this case, from 1991 to 2008, the overall average frequency was 0.5% for output and labor, 1% for inflation, and 0.3% for housing and credits. The frequency levels using the total number of words in each FOMC meeting are much less than those using the number of words in all five groups, but the trends across periods are similar. The associated results are described in Table A.1 and Figure A.3 in the Appendix.

Figure 1.3: Frequency of word count for each group, FOMC transcripts, 1991 - 2008



Note: Each line represents the frequency (%) for the five groups of words mentioned in the transcripts of each FOMC meeting from February 1991 to December 2008.

In contrast, the frequency of words related to housing and credit changed significantly in the late 1990s. Before 1998, the frequency of words related to housing and credit reached around 10% on average, which is less than half of the frequency of other groups during the same period. However, from 1999 the frequency of words related to housing and credit gradually increased, reaching about 15% on average until the early 2000s, which is consistent with the findings from Peek et al. (2015), Walsh (2017), and Shapiro and Wilson (2019), who argue that the FOMC systematically responded to financial variables in this period. Further, the frequencies of both groups rose sharply from 2005 onward. Housing-related frequency exceeded an average of 20%, while credit-related frequency accounted for about 18% on average. Those frequencies were relatively high, considering that the frequencies of terms related to output and labor were both less than 15% in this period. Overall, the housing sector and credit market performances were steadily and non-negligibly discussed by the FOMC members, along with concerns about full employment and price stabilization, which implies that those are the systematic components in the central bank's information set. This result suggests that a simple dual-mandate-style reaction function, which does not consider concerns about the financial market, may not capture the actual behavior of monetary policymakers. In this sense, these findings are consistent with those obtained earlier by Aastveit et al. (2017) and Caldara and Herbst (2019).

There is, in fact, considerable external support for these results. Thornton (2011) documents that from 1991 until 2009, the FOMC's policy directive, announced to the public after each FOMC meeting, stated, "*The Federal Open Market Committee seeks monetary and financial conditions that will foster price stability and promote sustainable growth in output*." In both periods, indeed, the volatility of the financial market changed significantly[8]. The late 1990s was a period when the stability of the US financial market deteriorated significantly due to the rise and burst of the IT bubble and the financial turmoil around the globe. On the other hand, in 2007, excessive risk-taking by banks, combined with the bursting of the U.S. housing bubble, caused the values of securities tied to U.S. real estate to plummet and damaged financial institutions. In both cases, FOMC participants recognized the serious volatility of financial markets at their meetings during these two periods and discussed potential ways to stabilize them. Below is an excerpt from the transcript of the November 17, 1998, FOMC meeting, where FOMC participants explicitly expressed their concerns for stability in financial markets.

> **Excerpt from a transcript of the November 17, 1998, FOMC meeting:**
>
> Because of the recent financial market volatility, we made a special effort to contact some market participants at the Chicago futures and options exchanges. Although our contacts believe they have successfully weathered the extraordinary volatility of late summer and early fall, many were apprehensive about the market's ability to withstand future shocks.

[8]The Cboe Volatility Index (VIX), which is commonly known to measure the risk of financial markets, exceeded 20 in the late 1990s and after 2007.

> One concern is that market depth may suffer in the months ahead. ... Banks face pressure to get exposure off their books, and consequently, they have canceled lines of credit to some clearing members. ... Financial markets have improved from their earlier unstable condition, but they are not yet back to normal. We need to continue to facilitate a return to normalcy. Financial markets currently are like a sick person who feels better after taking antibiotics for a few days but still needs to stay on medication to avoid a relapse and to aid a return to good health. ... Although conditions in financial markets have settled down materially since mid-October, unusual strains remain. With the 75 basis point decline in the federal funds rate since September, financial conditions can reasonably be expected to be consistent with fostering sustained economic expansion while keeping inflationary pressures subdued.

As can be seen in Table 1.2 and Figure 1.3, the proportion of housing-related words has increased rapidly since 2005. Starting with the FOMC meeting in June 2005, the frequency of these terms, accounting for more than 50%, has increased significantly. The FOMC participants at the June 2005 meeting used terms related to housing at an unprecedentedly high level, considering that the share of words related to inflation was 61% at the February 2005 meeting, the highest during the entire sample period. From then on, housing-related words were expressed frequently, with an average 20% share from 2005 to 2008. These results imply that the central bank had a considerable concern for the housing markets when developing its rules for establishing monetary policy. Interestingly, the changes in frequency for the housing group were highly related to aggregate house prices. Indeed, by 2005 the growth rate in real house prices had been increasing significantly since the early 2000s, and it peaked in November 2005. Notably, participants in the FOMC meeting in June 2005 discussed this issue from various perspectives. Particularly, they tried to find out which models could best capture the macroeconomic implications of changes in house prices. The following is an excerpt from the transcript for June 30, 2005, in which some FOMC participants explicitly stated performance goals for the housing market.

> **The Transcript of June 30, 2005, FOMC Meeting:**
>
> *MR.GALLIN.* House prices, adjusted for general inaction, have risen at a rapid pace in

> recent years and did not even pause during the last recession. Indeed, the real rate of appreciation has increased, and the most recent readings have been at annual rates greater than 7 percent. By comparison, the average annual increase in real house prices during the past 30 years is only about 1.75 percent. ...
>
> *MR. LEHNERT.* The popular consensus appears to be that homebuyers, especially in hot housing markets, now make token down payments and can just scrape into their homes by resorting to interest-only mortgages; in this view, borrowers and lenders alike are vulnerable to any fall in house prices. In my prepared remarks, I will address each of these issues.
>
> *MR. WILLIAMS.* I'll lay out a few scenarios that illustrate the potential macroeconomic fallout resulting from a significant decline in house prices, and I will examine policy responses that minimize it. ...
>
> *MS. YELLEN.* A second comment I wanted to make concerns the relationship of creative finance to the housing market. One view that I think is very prevalent is that the use of credit in the form of piggyback loans, interest-only mortgages, option ARMs [adjustable-rate mortgages], and so forth involves financial innovations that are feeding a kind of unsustainable bubble. But an alternative perspective on that is that high house prices, in fact, are curtailing effective demand for housing at this point and that house appreciation probably is poised to slow. So the increasing use of creative financing could be a sign of the final gasps of house-price appreciation at the pace we've seen and an indication that a slowing is at hand.

Overall, the results in Section 1.2 indicate two insights. First, by directly measuring the central bank's preferences in the FOMC meeting transcripts (1991-2008) using textual analysis, I can suggest that the Fed explicitly considered the housing market conditions during their decision-making, which can imply the presence of a crucial interdependence between monetary policy and house prices during the Great Moderation period from 1991 to 2008. Second, in contrast with conventional wisdom, identifying the monetary policy shocks without accounting for the endogenous reactions induced by the housing market performances would exhibit the confounding effects of monetary policy on the real economy, especially during the Great Moderation period. Apparently, this narrative exercise is more obvious when compared to numerical evidence. In the next section, to see whether monetary policy systematically responds to house prices (and credit spreads), I rebuild a new measure of exogenous monetary policy shocks by making two changes to Romer and Romer's (1989, 2004) estimation framework.

1.3 Policy surprises

The previous section provides a narrative result using textual analysis to establish the presence of interdependencies between monetary policy and changes in economic conditions, especially housing and credit market performances. In this section, I build on that result to re-examine the narrative identification of monetary policy shocks by Romer and Romer (2004). I first describe their identification strategy, then propose a new measure of monetary policy shocks by adding two components to their traditional framework. Specifically, I add a measure of the average Baa corporate credit spreads and the 3-month moving average of monthly growth in the real house price index. According to the stylized facts I discussed in Section 1.2, both factors are systematically important and can endogenously affect monetary policy shocks, especially during the Great Moderation period. Ultimately, I develop monetary policy shocks as shifts to the policy rate that is exogenous to changes in economic conditions (and their revisions), house prices, and corporate credit spreads. Hence, by building on Romer and Romer's identification, I propose a new measure of monetary policy shocks that take into account the systematic components, as well as house prices and credit spreads, in the function of the central bank's policymaking. At the end of this section, I provide several implications of these findings by comparing them to the narrative evidence generated using textual analysis, which I discussed in the previous section.

In general, narrative approaches involve constructing a series of historical documents to identify the reason and/or the quantities associated with a particular change in a variable. Romer and Romer (2004) proposed identifying monetary policy shocks by using the real-time “Tealbook (formerly Greenbook)” forecasts prepared by the Federal Reserve's economic staff in advance of each FOMC meeting. Greenbook forecasts have the appeal of being the actual figures and numbers discussed by the FOMC members at the meeting. Importantly, because the Greenbook forecasts are prepared before the FOMC meets (usually 5 to 10 days prior), they can be considered exogenous with respect to the committee's dialogue.

Following Romer and Romer (2004), Coibion and Gorodnichenko (2011), and others, my baseline specification is constructed by regressing the intended Federal funds rate change, Δff_m, decided at the FOMC meeting date (m), on Greenbook forecasts to control for current economic conditions and the future economic outlook, especially on the level of and the revisions to the Federal Reserve's forecasts of real GDP growth, the unemployment gap, and inflation. These forecasts are typically published a week prior to each scheduled FOMC meeting and can be thought of as a proxy for the information set of the FOMC at the time of making a policy decision. For Δff_m, I update the series of intended Federal funds changes to the end of 2008[9]. The following regression is the original form of the equation introduced by Romer and Romer (2004);

$$\Delta ff_m = \alpha + \beta ffb_m + \sum_{i=-1}^{2}\Big[\gamma_i \Delta\tilde{y}_{m,i}\Big] + \sum_{i=-1}^{2}\Big[\phi_i \tilde{\pi}_{m,i}\Big] + \sum_{i=-1}^{2}\Big[\lambda_i(\Delta\tilde{y}_{m,i} - \Delta\tilde{y}_{m-1,i})\Big] + \sum_{i=-1}^{2}\Big[\theta_i(\tilde{\pi}_{m,i} - \tilde{\pi}_{m-1,i})\Big] + \rho\tilde{u}_{m,0} + u_m, \quad (1.1)$$

where m is the monthly date of the scheduled FOMC meeting, Δff_m is the change in target rate around FOMC meeting m, ffb_m is the level of the intended Federal funds rate before any policy decisions associated with meeting m; $\tilde{u}$, $\tilde{y}$, and $\tilde{\pi}$ refer to the Greenbook forecasts of the unemployment rate, the real output growth, and inflation, respectively (prior to the choice of the interest rate); and i is the index in the summations that refers to the horizon of the forecasts. The equation 1.1 includes both the forecasts for the contemporaneous meeting and the revision in the forecast from the previous meeting because it is plausible that both the levels and the changes in the forecasts are important factors in Federal Reserve behavior. The estimated residuals $\hat{u}_m$ are interpreted as policy innovations at FOMC meeting frequency.

The second key contribution of this chapter is providing a new measure of monetary policy

[9] While Greenbook forecasts are available until the end of 2016 (as of the time of this writing), the interest rates approached the zero lower bound from 2009 onward, so a regression including the sample period after 2009 might not appropriately capture the Federal Reserve's intended rates for policy targets.

shocks based on the narrative approach by reconstructing the conventional Romer and Romer monetary policy shocks with two changes to their estimation framework. Thus, I next include in the regression an indicator of house prices and credit spreads. I then estimate the following equation at FOMC meeting frequency over my sample period from 1991 to 2008:

$$\begin{aligned}\Delta ff_m = \alpha + \beta ffb_m + \delta cs_m^{5D} + \psi \Delta h_m^{2M} + \sum_{i=-1}^{2} \Big[\gamma_i \Delta \tilde{y}_{m,i}\Big] \\ + \sum_{i=-1}^{2} \Big[\lambda_i (\Delta \tilde{y}_{m,i} - \Delta \tilde{y}_{m-1,i})\Big] + \sum_{i=-1}^{2} \Big[\phi_i \tilde{\pi}_{m,i}\Big] \\ + \sum_{i=-1}^{2} \Big[\theta_i (\tilde{\pi}_{m,i} - \tilde{\pi}_{m-1,i})\Big] + \rho \tilde{u}_{m,0} + \varepsilon_m. \end{aligned} \tag{1.2}$$

Because Greenbook forecasts for credit spreads are only available starting in 1998, my instrument in the equation 1.2 is instead cs_m^{5D}, the average Baa spread for the five days prior to the FOMC meeting[10]. I denote the associated regression coefficient by δ. Since forecasts for house prices are not provided in the Greenbook[11], my instrument is instead Δh_m^{2M}, the 3-month moving average of monthly growth in the real house price index, for the two months prior to the FOMC meeting m. ψ is the regression coefficient associated with house prices.

The house price index (HPI)[12] is published by the FHFA (Federal Housing Finance Agency). The HPI is a weighted repeat sales index, which measures average price changes in repeat sales for the value of single-family homes or refinancing of the same properties and weights them. The data is nominal, so I deflate the index using headline CPI inflation at meeting m. It should be noted that house price data are generally released with a lag of 2-3 months. For example, the FHFA published the November 2020 HPI report on January 26, 2021, and the January 2021 data on March 30, 2021. Therefore, the monetary authorities have to make predictions based on information about house

[10] Results are robust to using the average Baa spread calculated from the first day of the month when the FOMC meeting takes place to the day prior to the meeting.

[11] While Greenbook forecasts for house prices had been used in several meetings, (e.g., the Greenbook forecast for house prices was shown graphically based on the staff projection in the FOMC meeting on March 2006. See Figure A.4 in Appendix), the numerical data are not yet available to the public.

[12] This price information is obtained from repeat mortgage transactions since January 1975 on single-family properties whose mortgages have been purchased or securitized by Fannie Mae or Freddie Mac.

Table 1.3: Determinants of the Change in the Intended Federal Funds Rate

	[1]	[2]	[3]	[4]
Old Target	-0.0732***	-0.109***	-0.0917***	-0.116***
	[0.0213]	[0.0220]	[0.0226]	[0.0231]
Credit Spreads		-0.162***		-0.132***
		[0.0394]		[0.0368]
House Prices			0.250**	0.198*
			[0.111]	[0.110]
Forecasts				
Unemployment				
h = 0	-0.0760**	-0.101***	-0.0965***	-0.111***
	[0.0319]	[0.0294]	[0.0322]	[0.0305]
Output				
h = -1	0.0366**	0.0221	0.0411**	0.0285*
	[0.0156]	[0.0139]	[0.0161]	[0.0153]
h = 0	0.0735***	0.0603***	0.0685***	0.0604**
	[0.0219]	[0.0222]	[0.0240]	[0.0237]
h = 1	0.0216	0.00487	0.00927	-0.00302
	[0.0243]	[0.0250]	[0.0241]	[0.0250]
h = 2	0.0172	0.0146	0.00127	0.00132
	[0.0269]	[0.0265]	[0.0245]	[0.0246]
Inflation				
h = -1	0.0257	0.0194	0.0345	0.0286
	[0.0209]	[0.0204]	[0.0213]	[0.0209]
h = 0	0.0359	0.0427*	0.0539*	0.0539*
	[0.0273]	[0.0254]	[0.0284]	[0.0275]
h = 1	0.0688	0.0632	0.0870	0.0785
	[0.0693]	[0.0651]	[0.0684]	[0.0666]
h = 2	0.167**	0.126*	0.214***	0.168**
	[0.0738]	[0.0725]	[0.0809]	[0.0808]
Forecasts Revisions				
Output				
h = -1	-0.0256	-0.0141	-0.0220	-0.0133
	[0.0271]	[0.0250]	[0.0259]	[0.0249]
h = 0	0.0145	-0.00414	0.0184	0.00139
	[0.0321]	[0.0298]	[0.0329]	[0.0316]
h = 1	0.0563	0.0510	0.0688*	0.0640*
	[0.0366]	[0.0338]	[0.0367]	[0.0355]
h = 2	0.0411	0.0110	0.0312	0.00665
	[0.0610]	[0.0567]	[0.0556]	[0.0529]
Inflation				
h = -1	0.000661	0.00501	0.00636	0.0105
	[0.0944]	[0.0880]	[0.0953]	[0.0926]
h = 0	-0.0623	-0.0515	-0.0681	-0.0561
	[0.115]	[0.107]	[0.115]	[0.111]
h = 1	-0.0310	-0.0361	-0.0322	-0.0362
	[0.0545]	[0.0495]	[0.0440]	[0.0423]
h = 2	-0.0466	-0.0622*	-0.0619**	-0.0703**
	[0.0288]	[0.0315]	[0.0269]	[0.0274]
Observations	144	144	142	142
Adj. R-squared	0.515	0.566	0.561	0.593

Note: Projection of Δff_m, the series of changes in the intended Federal funds rate around FOMC meetings, are constructed using the methodology in Romer and Romer (2004), based on Greenbook Forecasts (revisions), corporate credit spreads, and house prices in the sample 1991-2008. Robust standard errors are in brackets. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$. Details on the specifications are reported in the text.

prices two to three months ago, no matter how early. This can be seen in more detail by looking at the transcript of each FOMC meeting and the transcript forecast (as shown in Figure A.4 in the Appendix). To reflect this, the 3-month moving average of house price growth[13] for the two months prior to the meeting are included. According to equation 1.2, I build four different types of monthly[14] monetary policy shocks: (I) for the conventional specification by Romer and Romer (2004), (II) for shifts to the policy rate that additionally control for the central bank's concern regarding credit costs, (III) for shifts to the policy rate that control for the house prices, and (IV) for shifts to the policy rate that control for both credit spreads and the house prices at the time of the FOMC meeting. The results from these four different versions of regression 1.2 are reported in Table 1.3.

The first column [1] of Table 1.3 tabulates the estimated coefficients and relative significance level of the projection of the changes in the intended Federal funds rate over Greenbook forecasts and revisions to forecasts for output, in terms of inflation and unemployment. The regression is run at a monthly frequency on all surprises registered between 1991 and 2008. I do not include the zero-lower bound (ZLB) period because there is no time variation in the Federal funds rate. This result suggests that output and inflation forecasts have significant and positive coefficients. Moreover, unemployment forecasts have a negative coefficient with a small standard error. In line with the results reported by Romer and Romer (2004), Coibion and Gorodnichenko (2011), and Cloyne and Hürtgen (2016), the estimation result implies that monetary policy tends to behave counter-cyclically and stabilizes movements in output and inflation. The R^2 of the regression is 0.51, suggesting that although most of the changes in US monetary policy were taken in response to the evolution of forecasted output, unemployment, and inflation, there is no guarantee that the unexplained variation is exogenous to the state of the economy.

The second column [2] of Table 1.3 tabulates the estimated coefficients for the version of regression 1.2 that includes the average Baa spread for the five days prior[15] to the FOMC meeting

[13] Results are robust to using the real house price changes for the two months, three months, and four months prior to the meeting.

[14] Months without FOMC meetings are assigned a zero.

[15] The associated results are robust to using the average Baa spread calculated from the ten days prior to the meeting.

over the same sample period. The estimated coefficients of the changes in the intended Federal funds rate over Greenbook forecasts and revisions are similar to those in column [1]. Notably, I find that the central bank reacts to changes in the Baa corporate credit spreads beyond the information contained in the Greenbook forecasts of output, unemployment, and inflation. δ has a point estimate of -0.16 with a small standard error; all else being equal, FOMC meetings occurring in periods with elevated levels of corporate credit spreads are associated with cuts in the intended Federal funds rate. This evidence shows that, for the 1991–2008 period, the standard estimates of the Romer and Romer shocks are affected by the endogenous response of monetary policy to changes in credit spreads.

The third column [3] of Table 1.3 reports the estimated coefficients for the version of regression 1.2 that includes the 3-month moving average of monthly growth in the real house price index for the two months prior to the meeting. The estimated coefficients of the changes in the intended Federal funds rate over Greenbook forecasts and revisions are similar to the results shown in columns [1] and [2]. Further, the results show clear evidence that the U.S. monetary authority systematically responded to changes in real house prices by weighting them with positive values for the Great Moderation period. This is in line with the findings by Aastveit et al. (2017), who show that the Fed has, on average, responded to fluctuations in house prices and that this response has, on average, been quantitatively important. The coefficient ψ has a point estimate of 0.25 with a small standard error; all else being equal, FOMC meetings occurring in the period with elevated levels of house price growth are associated with a rise in the intended Federal funds rate.

Lastly, column [4] in Table 1.3 reports the estimation result for the version of regression 1.2 that contains both credit spreads and house prices. In line with the previous results reported in columns [1] to [3], the estimated coefficients provide evidence that the monetary authority tends to endogenously respond to the current economic conditions and its outlooks (output, unemployment, and inflation forecasts, and those revisions). The estimated coefficient δ, which is associated with credit spreads, has a point estimate of -0.12, and the estimated coefficient ψ, which is associated with house prices, has an estimate of 0.2 with small standard errors[16], with an R^2 that is a bit higher. Overall, the results in Table 1.3 confirm that the conventional estimates of the Romer and Romer shocks are affected by the endogenous response of monetary policy to changes in credit spreads and house prices, simultaneously[17].

Further, the estimated residuals of the four specifications in regression 1.2 shown in Table 1.3 constitute four different versions of narrative-based measures for monetary policy shocks. Here, I denote those as follows: (I) "RR," the conventional Romer and Romer (2004) monetary policy shocks; (II) "RR+CS," adjusted monetary policy shocks which are constructed by controlling for the Baa corporate credit spreads in the regression; (III) "RR+HP," adjusted monetary policy shocks which are constructed by controlling for the 3-month moving average of real house price growth in the regression; and (IV) "RR+CS+HP," fully-adjusted monetary policy shocks which are constructed by controlling for both credit spreads and house prices in the regression. Though the shocks are highly correlated (0.91 on average) with each other, they lead to dramatically different implications for monetary policy, as I show in the next section.

Taking stock of this numerical evidence, I empirically document two testable implications for the results of the textual analysis of the FOMC transcripts discussed in Section 1.2. In particular, I proceed in two steps. First, I construct a measure of distance to show the numerical differences caused by credit spreads from the residuals of the regression shown in Table 1.3, by applying a simple Euclidean distance formula. I use the following specification:

$$D\textit{[RR, RR+CS]} = \sqrt{(\textit{[RR]} - \textit{[RR+CS]})^2} * 100,$$

$$D\textit{[RR+HP, RR+CS+HP]} = \sqrt{(\textit{[RR+HP]} - \textit{[RR+CS+HP]})^2} * 100.$$

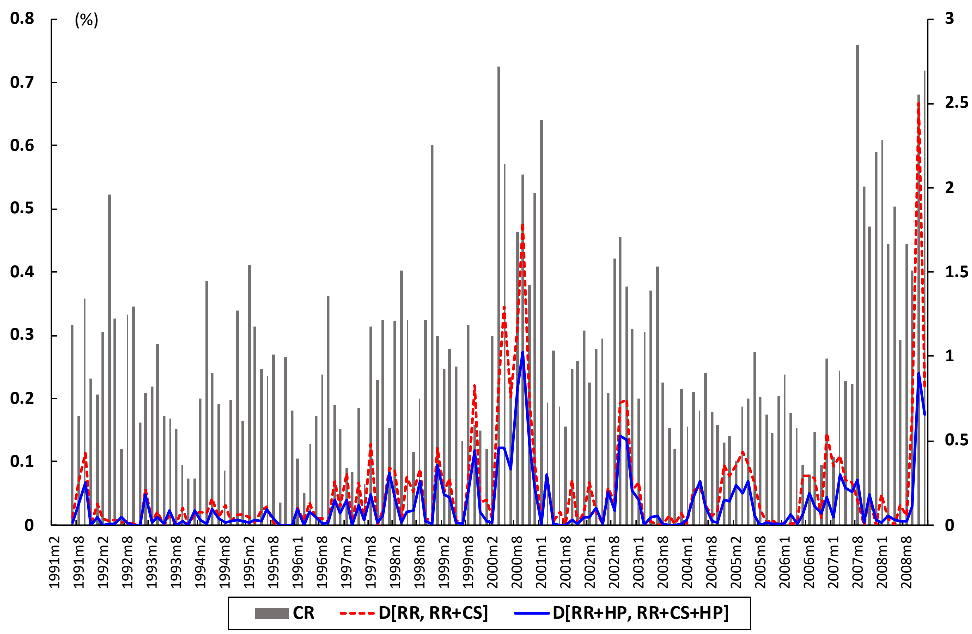
Both indicators, *D[RR, RR+CS]* and *D[RR+HP, RR+CS+HP]*, imply that those values are posi-

[16] Aastveit et al. (2017) find that the estimated coefficient associated with real house price growth is significant and roughly equal to 0.1, using a structural VAR model with a time-varying parameters model. They describe how such a response to house prices is estimated over most of their sample, 1975 Q2 to 2008 Q4, on a quarterly basis, with the important exception of the second part of the 1990s.

[17] See the Appendix B, which provides related evidence on the exogeneity of house prices using High-Frequency instrument for monetary policy surprises.

tive if one should not consider credit spreads to identify the monetary policy shocks in terms of the narrative approach. Further, both indicators are compatible with the results of the textual analysis, which reflects the frequency of terms that are associated with the credit market, as discussed in Section 1.2. To make the comparison easier, the size of distances is rescaled by multiplying them by 100.

Figure 1.4: Implications for credit spreads: word search and distances



Note: Shaded bars (CR) denote the share (%) of word counts related to credit market performances over the total terms expressed in the transcripts for each FOMC meeting from July 1991 to December 2008. The share rates are plotted on the left axis. The re-scaled Euclidean distances in residuals are plotted on the right axis; Red-Dashed lines for “RR" and “RR+CS" and Blue-Solid lines for “RR+HP" and “RR+CS+HP."

Figure 1.4 reports the test for correlation with the frequency of word counts in the credit group (a list that contains terms related to credit market performances) and the numerical distance that can occur if changes in corporate spreads are not taken into account when estimating the narrative-based monetary policy shocks. The shaded bars in Figure 4 depict the frequency (%) of word counts related to credit market performances over the total terms expressed in transcripts for each FOMC meeting over the sample period from July 1991 to December 2008. The black dashed line, *D[RR, RR+CS]*, refers to rescaled Euclidean distances between “RR" and “RR+CS," and the blue solid line, *D[RR+HP, RR+CS+HP]*, shows the rescaled distances between “RR+HP" and “RR+CS+HP". Notably, I document that the values of both distance indicators are caused when one does not control for the systematic responses of monetary policy shocks to changes in corporate spreads. Two remarkable results can be found in Figure 1.4. First, the movements in each distance line are very similar to each other over the sample period, which implies that the differences can be due to credit spreads. Second, the two distance indicators and the word search results of textual analysis for the credit group in Section 1.2 have a higher relationship. Indeed, the correlation between CR and those distances depicted in Figure 1.4 is around 0.4 to 0.45. This can imply that the narrative evidence, based on textual analysis using FOMC transcripts, is consistent with the numerical results estimated through the reconstructed Romer and Romer (2004) estimation. Thus, both approaches provide empirical evidence that, for the Great Moderation period, the effects of monetary policy shocks depends on the presence of a systematic response of monetary policy to financial performance[18].

In the same manner, I build another measure of distance to assess further the numerical differences caused by house prices from the estimated residuals of the regression shown in Table 1.3. Specifically:

$$D\textit{[RR, RR+HP]} = \sqrt{(\textit{[RR]} - \textit{[RR+HP]})^2} * 100, \tag{1.3}$$

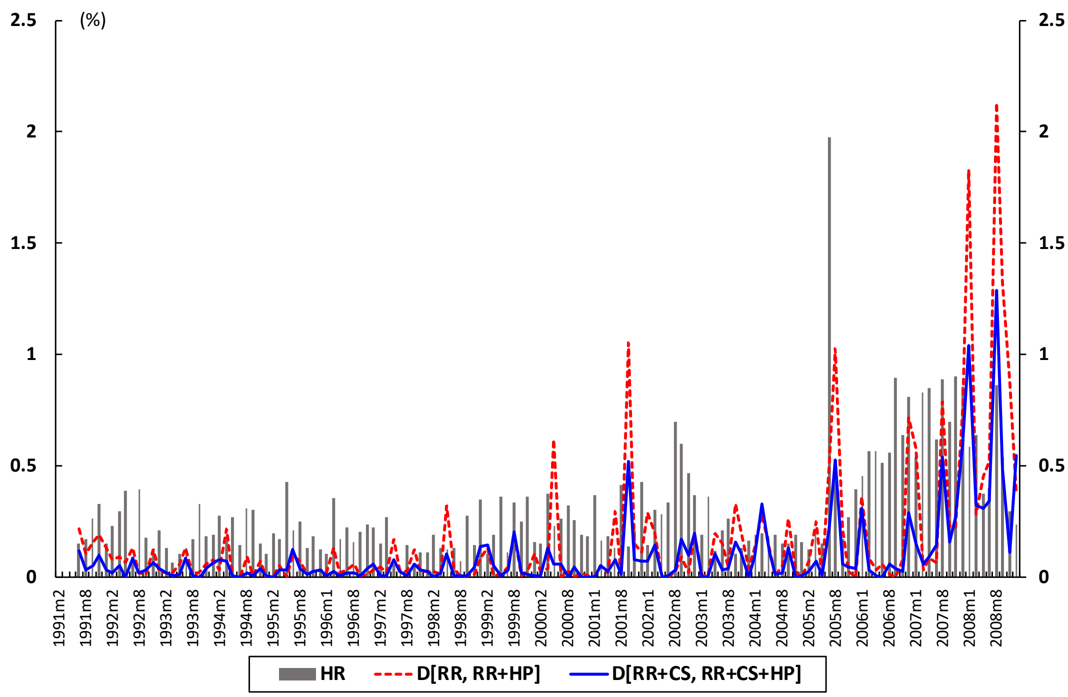
$$D\textit{[RR+CS, RR+CS+HP]} = \sqrt{(\textit{[RR+CS]} - \textit{[RR+CS+HP]})^2} * 100. \tag{1.4}$$

Equations 1.3 and 1.4 illustrate the distances of the Romer and Romer shocks, which originate from house prices for their shock construction. Similarly, both indicators are compatible with the results of textual analysis, which reflect the frequency of terms associated with the housing market,

[18]There are several ways to measure distance indicators, such as using a square function or an absolute function of the difference between two distinct points. Nevertheless, the correlations are robust to using these other methods.

as discussed in Section 1.2.

Figure 1.5: Implication for house prices: word search and distances



Note: Shaded bars (CR+HR) denote the share (%) of word counts related to housing and financial markets over the total terms expressed in the transcripts for each FOMC meeting from July 1991 to December 2008. The share rates are plotted on the left axis. The re-scaled Euclidean distances in residuals are plotted on the right axis; the Blue-Solid line is for “RR" and “RR+CS+HP."

Figure 1.5 reports the test for correlation with the frequency of word counts in the housing group (a list that contains terms related to the housing market) and the numerical distance that can be created if changes in house prices are not taken into account when estimating the narrative-based monetary policy shocks. The shaded bars in Figure 1.5 depict the frequency (%) of word counts related to the housing market over the total terms expressed in transcripts for each FOMC meeting over the same sample period. The black dashed line, *D[RR, RR+HP]*, refers to rescaled Euclidean distances between “RR" and “RR+HP," and the blue solid line, *D[RR+CS, RR+CS+HP]*, shows the rescaled distances between “RR+CS" and “RR+CS+HP". Both distance indicators are positive values when one does not control for the endogenous reactions of monetary policy shocks to changes in house prices. In Figure 1.5, similarly, the trends in each distance line are comparable, implying that the disparities can be due to house prices. Moreover, the two distance indicators and the word search results of textual analysis for the housing group in Section 1.2 have a close relationship. Indeed, the correlation between HR and those distances, as illustrated in Figure 1.4, is around 0.42. Thus, the narrative evidence based on textual analysis and the subsequent numerical results provides clear evidence that the effects of monetary policy shocks depend on the presence of a systematic response of monetary policy to the housing market.

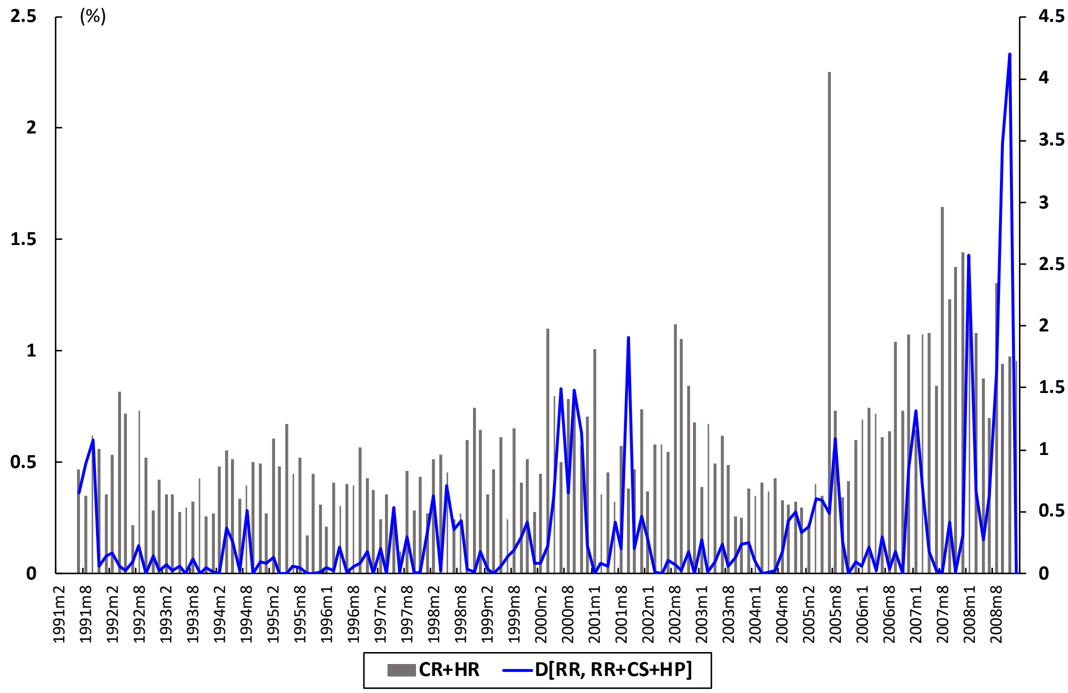
Lastly, I define a measure of distance to show the numerical differences caused by both house prices and credit spreads from the estimated residuals of the regression shown in Table 1.3, specifically the distance between the first and last columns, applying the same formula. I use the following specification:

$$D[RR,\ RR{+}CS{+}HP] = \sqrt{([RR] - [RR{+}CS{+}HP])^2} * 100. \tag{1.5}$$

The equation 1.5 indicates the distances of the Romer and Romer shocks, which are caused by both house prices and credit spreads for their shock identification. Again, the indicator is compatible with the word search, which reflects the frequency of terms that are associated with housing and credit markets, as discussed in Section 1.2.

In Figure 1.6, I repeat the test for correlation with the frequency of word counts in both groups (housing + credit), a set of lists that contain all terms related to housing and credit markets, and the distance that can occur if changes in house prices and corporate spreads are not taken into account. The shaded bars in Figure 1.6 depict the frequency (%) of word counts over the sample period from July 1991 to December 2008. The blue solid line, *D[RR, RR+CS+HP]*, shows the rescaled distances between “RR" and “RR+CS+HP." The associated results are almost identical to those described in Figure 1.4 and Figure 1.5. Particularly, *D[RR, RR+CS+HP]* and the word search results for “CR+HR” have a higher relationship, and both follow a similar pattern. The correlation

Figure 1.6: Implications for house prices and credit spreads: word search and distances



Note: Shaded bars (CR+HR) denote the frequency (%) of word counts related to both housing and credit markets over the total terms expressed in the transcripts for each FOMC meeting from July 1991 to December 2008. The rates of frequency are plotted on the left axis. The re-scaled Euclidean distances in residuals are plotted on the right axis; the Blue-Solid line is for “RR" and “RR+CS+HP."

between these two indexes is around 0.39, which implies that the narrative evidence based on textual analysis is consistent with the numerical result estimated. Consequently, both approaches provide empirical evidence that the effects of monetary policy shocks rely on the presence of a systematic response of monetary policy to not only credit spreads but also house prices.

From a technical point of view, if one doesn’t control for elements that can systematically affect monetary policy shocks, this identification strategy will create an endogenous component to the monetary policy shocks. In turn, the failure to account for these systematic reactions induces an attenuation in the response of all real variables to monetary policy shocks. In that sense, my view is that the evidence in Section 1.3 most strongly supports the fact that house prices and corporate credit spreads are critical components in the monetary authority's information set. What matters is that the conventional narrative-based monetary policy shocks are correlated with house prices and credit spreads, which has important implications for estimating monetary policy transmission to the real macroeconomic variables using these shocks. This is what I turn to next.

1.4 Econometric methodology

In conventional wisdom, the study of dynamic causal inference of monetary policy can be divided into two steps. The first would be identifying exogenous (and unexpected) variations in monetary policy, which I discussed in detail in Section 1.3. My results there imply that traditional narrative-based monetary policy shocks are correlated with house prices and credit spreads. From this point of view, I propose a novel measure of monetary policy shocks that control for house prices and corporate credit spreads by re-building the original Romer and Romer (2004) estimation framework, then compare the estimates to those obtained for conventional measures of monetary policy shocks.

The second step delivers the impulse response functions estimated for the policy shocks given by the first step. Hence, I now investigate to what extent the narrative identification of the effects of monetary policy shocks in structural VARs (SVARs) and local projections is affected by these correlations, along with my proposed correction. I begin, in Section 1.4.1, by laying out the basic local projections similar to those in Ramey (2016). In Section 1.4.2, I first document standard SVARs and consider the alternative estimation method of Plagborg-Møller and Wolf (2021), which uses a recursive SVAR with the monetary policy shock ordered first; the model typically used to track the effects of policy shocks using external instruments.

1.4.1 Local projections

Jordà (2005)'s local projection is an approach to estimate the dynamic effects of a monetary policy shock. The idea is to directly regress future values of macroeconomic variables on the identified monetary policy shock, with controls for lags and other relevant macroeconomic variables.

When the monetary policy shock is observed, I can perform the local projections regressions. Based on the four series of residuals from the regressions shown in Table 3, I estimate the specified macroeconomic variables directly at horizon $t + h$ on the shock in period t to construct impulse responses. The advantage of this method is that impulse responses are not functions of the structural parameters of the standard Vector Autoregressive (VAR) model and hence are less sensitive to model misspecification. Moreover, Ramey (2016) shows that the use of local projections, as opposed to VAR models, can have a major impact on the sign and size of impulse responses to a monetary policy shock. To investigate the results of this less restrictive specification, I estimate the following series of regressions: For each $h = 0, 1, ..., H$,

$$y_{j,t+h} = \alpha_h + \beta_{j,h} e_{i,t} + \psi_{j,h}(L) z_t + \varepsilon_{j,t+h}, \tag{1.6}$$

where y_j is the variable of interest, z is a vector of (pre-treatment) control variables, $\psi_{j,h}(L)$ is a polynomial in the lag operator, and $e_{i,t}$ is one of the identified monetary shocks which I discussed in the previous section: “RR," “RR+CS," “RR+HP," and “RR+CS+HP." The coefficient $\beta_{j,h}$ gives the response of y_j at time $t + h$ to the shocks at time t. Thus, one constructs the impulse responses as a sequence of the $\beta_{j,h}$s estimated in a series of single regressions for each horizon.

In this exercise, the vector of endogenous variables, y, consists of real industrial production (IP), the unemployment rate, the consumer price index (CPI), real durable/non-durable consumption indexes, the real house price index[19], the average 10-Year Baa corporate credit spread, and the Federal funds rate[20]. Variables enter the specification in log levels, with the exception of interest rates and credit spreads. By keeping the composition of the variables of interest fixed across the four specifications, I can assess the differences in the impulse response functions as an indication of the shocks constructed under different identification strategies. The estimation is run on a monthly basis for the sample period January 1991 through December 2008. The term $\psi(L)$ is

[19] I deflate the price information using the consumer price index for all items in a U.S. city average since the index is measured on a nominal basis.

[20] My sample period does not include the zero lower bound.

a polynomial of order 6[21]. The vector of (pre-treatment) control variables, z, contains six lags of interest rates, the log of industrial productions, the unemployment rates, the log of prices, the log of durable and non-durable consumptions, the log of commodity prices, and 1-year treasury constant maturity rates. Most of the relevant data can be obtained from the Federal Reserve Bank of St Louis database (FRED) and the Federal Housing Finance Agency (FHFA). As described in Silvia and Giovanni (2019), ε_{t+h} will be serially correlated, so the standard errors must incorporate a correction, such as Newey-West.

1.4.2 Standard SVARs

Consider the following VAR, written in the structural form:

$$A_0 y_t = \sum_{\ell=1}^{p} A_\ell y_{t-\ell} + c + e_t = A_+ x_t + e_t, \quad \textit{for} \quad 1 \leq t \leq T, \tag{1.7}$$

where y_t is a $n \times 1$ vector of endogenous variables, e_t is $n \times 1$ vector of structural shocks, A_ℓ is an $n \times n$ matrix of structural parameters for $0 \leq \ell \leq p$, c is a $n \times 1$ vector of intercepts, p is the lag length, T is the sample size, $x_t = [y_{t-1}' \cdots y_{t-p}' \ 1]'$, and $A_+ = [A_1 \cdots A_p \ c]$. The reduced-form representation of this model is given by

$$y_t = \Phi x_t + u_t, \quad u_t \ \sim N(0, \Sigma), \tag{1.8}$$

where the reduced-form parameters and the structural parameters are related through

$$\Sigma = (A_0' A_0)^{-1}, \quad \textit{and} \quad \Phi = A_0^{-1} A_+. \tag{1.9}$$

As discussed in Leeper, Sims, and Zha (1996), specifying the monetary policy shock, denoted $e_{mp,t}$, is equivalent to specifying an equation that characterizes monetary policy behavior. In what follows, I assume, without loss of generality, that $e_{mp,t}$ is the first shock in e_t. Consequently, the

[21]The estimation results are robust to include the contemporaneous value of the control variables to preserve the recursiveness assumption.

first equation of the SVAR is the monetary policy rule, for $1 \leq t \leq T$,

$$A_{0,1} y_t = A_{+,1} x_t + e_{mp,t}, \tag{1.10}$$

where $A_{0,1}$ and $A_{+,1}$ denote the first rows of A_0 and A_+, respectively. If we assume that the policy rate r_t is also ordered first in y_t, I can rewrite equation (12) as follows: For $1 \leq t \leq T$

$$r_t = \sum_{j=2}^{n} y_{j,t}^{'} \ \psi_{0,j} + \sum_{\ell}^{p} y_{t-\ell}^{'} \ \psi_\ell + \ \sigma_{mp} e_{mp,t}, \tag{1.11}$$

where $\psi_{0,j} = -a_{0,1j}/a_{0,11}$, $\psi_\ell = a_{\ell,1\cdot}/a_{0,11}$, and $\sigma_{MP} = 1/a_{0,11}$ with $a_{\ell,ij}$ denoting the ijth element of A_ℓ. The first two terms on the right-hand side of equation 1.11 describe the systematic component of monetary policy (in the central bank's information set), characterizing how the policy rate at time t responds to contemporaneous and lagged movements in the variables included in the model.

It is clear from equations 1.10 and 1.11 that the identification of the monetary policy shock $e_{mp,t}$ is equivalent to the identification of a systematic component of monetary policy. In turn, to characterize that shock, we require knowledge of a subset of the structural parameters, $A_{0,1}$ and $A_{+,1}$. As is well known, without additional restrictions, it is not possible to discriminate between the many possible combinations of structural parameters ($A_{0,1}$, $A_{+,1}$) that yield the same reduced-form parameters (Σ, Φ), that is, the likelihood of the SVAR model exists with respect to these combinations. If the VAR adequately captures the components in the information set of the monetary authority, this method is optimal at all horizons. The majority of the literature, beginning with Sims (1980) and also discussed in CEE (1999) and Stock and Watson (2001), has used theoretical restrictions to achieve identification, that is, to inform the choice of ($A_{0,1}$, $A_{+,1}$), and most debates in the SVAR literature are about the "correct" choice of restrictions for any given application. In turn, if the VAR is misspecified, then the specification errors will be compounded at each horizon.

Plagborg-Møller and Wolf (2021) (henceforth, PMW) recommend a procedure for estimating impulse response functions using an external instrument, which they call the "internal instrument" approach. They suggest including the instrument in the VAR, ordering it first, and using recursive (Cholesky) ordering to estimate its effects. Intuitively, this allows the other variables in the VAR to respond to the instrument on impact while the dynamics are asymptotically the same (in population and for infinite lag length) as a conventional VAR or LP-IV estimation. As discussed in Section 1.3, the residuals of the four regressions shown in Table 1.3 constitute narrative-based measures of monetary policy shocks. Here I rebuild the estimates of PMW, which I will call hybrid SVARs, using my new series of shocks based on the narrative identification I discussed.

Typically, the hybrid SVARs specification substitutes the narrative (and cumulative) shocks for the Federal funds rate (ordered last) in a standard VARs model, as shown in Coibion (2012), Barakchian and Crowe (2013), and Ramey (2016). In my explorations, instead of substituting the narrative shocks for the Federal funds rate, I use the PMW version, a monthly VAR with a fixed composition of variables, to trace the effects of each identified monetary policy shock in the estimation system. This specification uses the recursive assumption, placing the narrative policy shock first, followed by the Federal funds rate, the log of real industrial production, the unemployment rate, the log of prices, and the log of commodity prices, thus assuming that the monetary shock can have an impact on the macroeconomic variables within a month but not vice versa.

1.5 The dynamic causal inference of monetary policy

Section 1.5 applies the new measure to reassess previous empirical estimates of the effects of monetary policy on macroeconomics. I begin my empirical reassessment of the transmission of monetary policy with the shocks that control for the endogenous reactions of monetary innovations to house prices and credit costs. In Section 1.5.1, I estimate the local projections, and in Section 1.5.2, I revisit Hybrid SVARs to estimate the impulse response functions of real economic variables equipped with the new measures of exogenous variation in the monetary policy shocks. In each section, the estimation is run on a monthly basis for the sample period January 1991 through

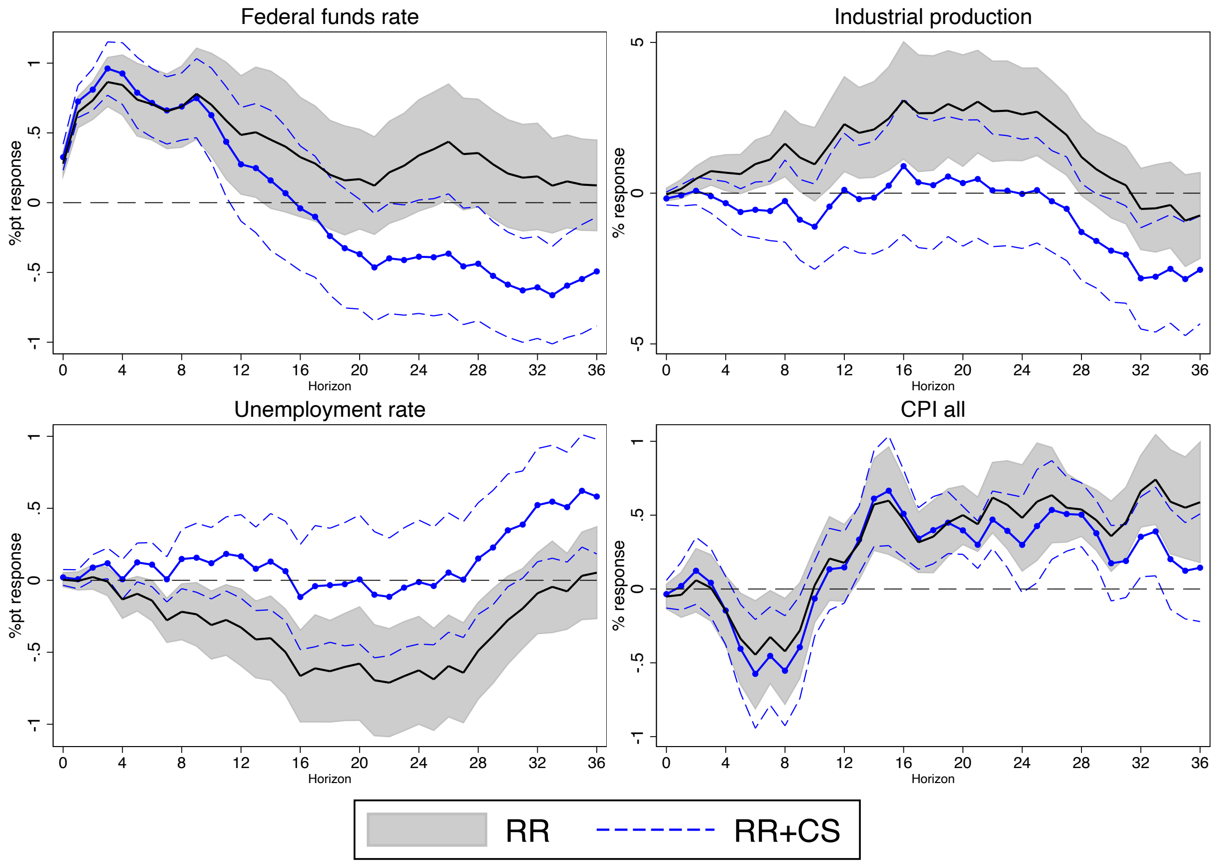
December 2008, with three variants of the specification: the first excludes both credit spreads and house prices from the standard Romer and Romer (2004) equation, in the second variant monetary shocks are estimated by imposing that the target rates endogenously react to changes in credit spreads, and the last variant includes both credit spreads and house prices in the identification of monetary policy shocks.

1.5.1 Results from local projections

The estimation results are presented in Figures 1.7 through 1.9. Figure 1.7 reports impulse response functions to a monetary policy shock estimated using local projections that encompass two different identifications, “RR" and “RR+CS," over the sample from Jan. 1991 through Dec. 2008. The solid black line in each panel depicts the impulse response function of the specified variable (Federal funds rate, real industrial production, the unemployment rate, and headline CPI) to one percentage point change in monetary policy shock identified in the original R&R (2004) equation. The blue dotted line in each panel depicts the impulse response of the specified variable to one percentage point change in monetary policy shock identified in the R&R (2004) equation with Baa corporate credit spreads, using the “RR+CS" shocks as the policy variable. Shaded bands and blue dashed lines report the associated 68% confidence intervals around those point estimates. For the baseline specification (solid black line), the near-term effect of the contractionary monetary policy shock causes the Federal funds rate to increase by about 0.25 percent. Then the rate slowly falls, returning to zero after approximately three years. The shock elicits expansionary effects on real industrial production, consumption, and unemployment, hence delivering real activity puzzles that are not in line with the standard theory of monetary policy[22]. Industrial production begins to rise in the next period and peaks 16 months later. The unemployment rate falls and reaches the bottom around 24 months later. Both industrial production and the unemployment rate gradually head back toward a steady state after 32 months. The response of house prices and credit spreads are likewise not consistent with the standard monetary theory. The CPI is affected over the first

[22]These results echo those of Barakchian and Crowe (2013) and Ramey (2016), who show that the leading specifications imply expansionary effects in the sample from 1988 through 2007; contractionary monetary policy shocks appear to be expansionary.

Figure 1.7: IRFs to monetary policy shocks: “RR" and “RR+CS"



Note: The solid black line in each panel depicts the impulse response of the specified variable (Federal funds rate, real industrial production, the unemployment rate, and headline CPI) to 1 percentage point changes in monetary policy shock identified in the R&R (2004) equation. The blue dotted line in each panel depicts the impulse response of the specified variable to 1 percentage point changes in monetary policy shock identified in the R&R (2004) equation with Baa corporate credit spreads, using the “RR+CS" shocks as the policy variable. Shaded bands and blue dashed lines denote the associated 68% confidence intervals. Sample: 1991:1 - 2008:12.

year in a contractionary way, although it rises over a longer horizon onward. Overall, the results from using baseline R&R shock as an instrument for monetary policy in Figure 1.7 echo Ramey (2016), who finds no evidence of the contractionary effects of monetary policy during the Great Moderation. Hence, the use of the conventional R&R instrument triggers real activity puzzles and price puzzles over a longer horizon, implying that conventional estimates of the effects of monetary policy on the macroeconomy, using narrative identification, are substantially biased due to the endogeneity of the monetary policy shocks.

One possible explanation for the odd features of the impulse responses shown in Figure 1.7 is that misidentification of the policy shock is distorting the estimated impulse responses. Caldara and Herbst (2019) argue that a systematic component of monetary policy is crucially characterized by a direct reaction to changes in corporate credit spreads. They show that monetary policy shocks, identified using Bayesian proxy SVARs, that include corporate spreads have large economic effects compared to shocks identified using conventional SVAR identification schemes. The second regression model employs corporate credit spreads in the estimation framework to assess their findings. Indeed, the results imply that the propagation of monetary policy shocks to real economic variables depends on the presence of a systematic response of monetary policy to credit spreads. In the case of an RR+CS shock (blue dotted line), the impact (near-term) responses of the Federal funds rate, industrial production, the unemployment rate, consumption, and prices are nearly identical to those in the case of baseline specification. In contrast, the two identifications display different dynamics. The Federal funds rate rises quickly after the shock and turns negative after about one and a half years, which implies that monetary policy becomes more accommodative relative to its initial level. This is intuitive if we think of economic data as being persistent so that the Fed's response to that data leads to an upwardly biased estimate of interest rate persistence. This change in monetary policy stance also can be explained by inspecting the real and financial consequences of the shock.

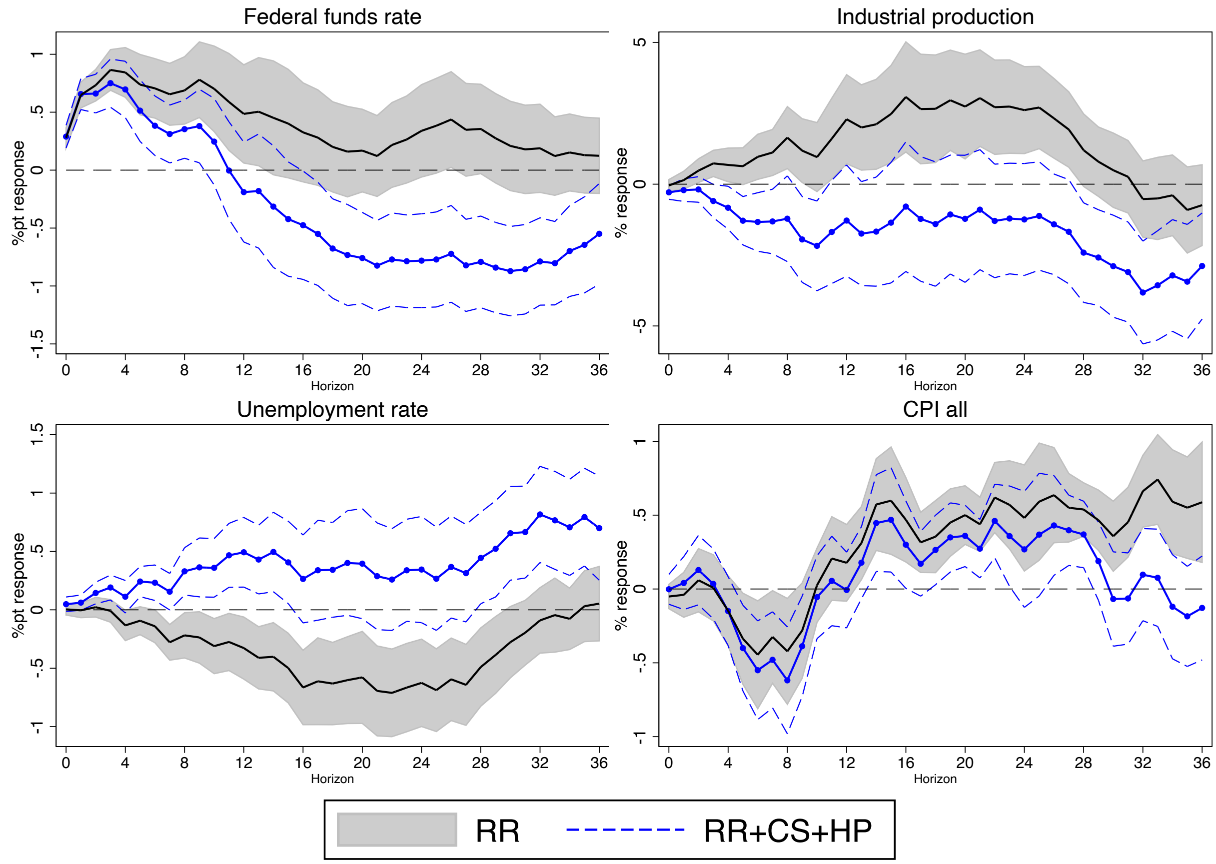
Overall, the second model shows that the shocks constructed after controlling for corporate credit spreads do not give rise to puzzles on real activity but induce no statistically significant changes in real economic variables under the 68% confidence interval. This can imply that a systematic component other than corporate credit spreads can explain the endogenous response of monetary policy rules. However, the key point to take away from Figure 1.7 is that using narrative policy shocks identified with credit spreads is crucial for understanding the direction of propagation of policy innovations during the Great-Moderation period.

I now turn to the main research questions of this chapter: How much difference does control for the endogenous response of monetary policy shocks to house prices make for estimating the effects of monetary policy on the economy? Figure 1.8 provides an answer to this question. In particular, the associated results imply that the direction and size effects of monetary policy shocks on the real economy depend on the presence of a strong systematic response of monetary policy to real house prices and credit costs. Figure 1.8 reports impulse response functions to monetary policy shocks by estimating local projections that encompass the two identification strategies, “RR" and “RR+CS+HP," over the sample from Jan. 1991 through Dec. 2008. The solid black lines report the baseline results, which are identical response functions of each variable I discussed in Figure 1.7. The blue dotted line in each panel in Figure 1.8 depicts the impulse response functions of the Federal funds rate, real industrial production, the unemployment rate, and the aggregate price index to the identified monetary shocks with house prices and credit spreads, using the “RR+CS+HP" shocks as the policy variable.

The first key point to note in Figure 1.8 is that, in contrast with the results in Figure 1.7, the real activity puzzles become less pronounced, with statistically significant estimates and long-lasting responses, when using my improved measure of monetary policy shocks constructed by controlling for both house prices and credit spreads. Industrial production and consumption fall on impact, and they are significantly persistent over the sample period. The unemployment rate rises on impact, with theoretically consistent results. Two years after the shock, output has fallen by about one percentage point, and the unemployment rate has increased by about 0.5 percentage points. Interestingly, real house prices drop significantly on impact and contract persistently. These results align with those that Iacoviello (2005) and Del Negro and Otrok (2008) obtained earlier. In addition, the exercise supports the empirical finding that a contractionary monetary policy shock causes a sudden tightening in financial conditions, with corporate Baa credit spreads significantly increasing on impact, as discussed in Gertler and Karadi (2015), Peek, Rosengren, and Tootell (2016), and Caldara and Herbst (2019).

The second key point to take away from Figure 1.8 is that the differences in the blue dotted lines

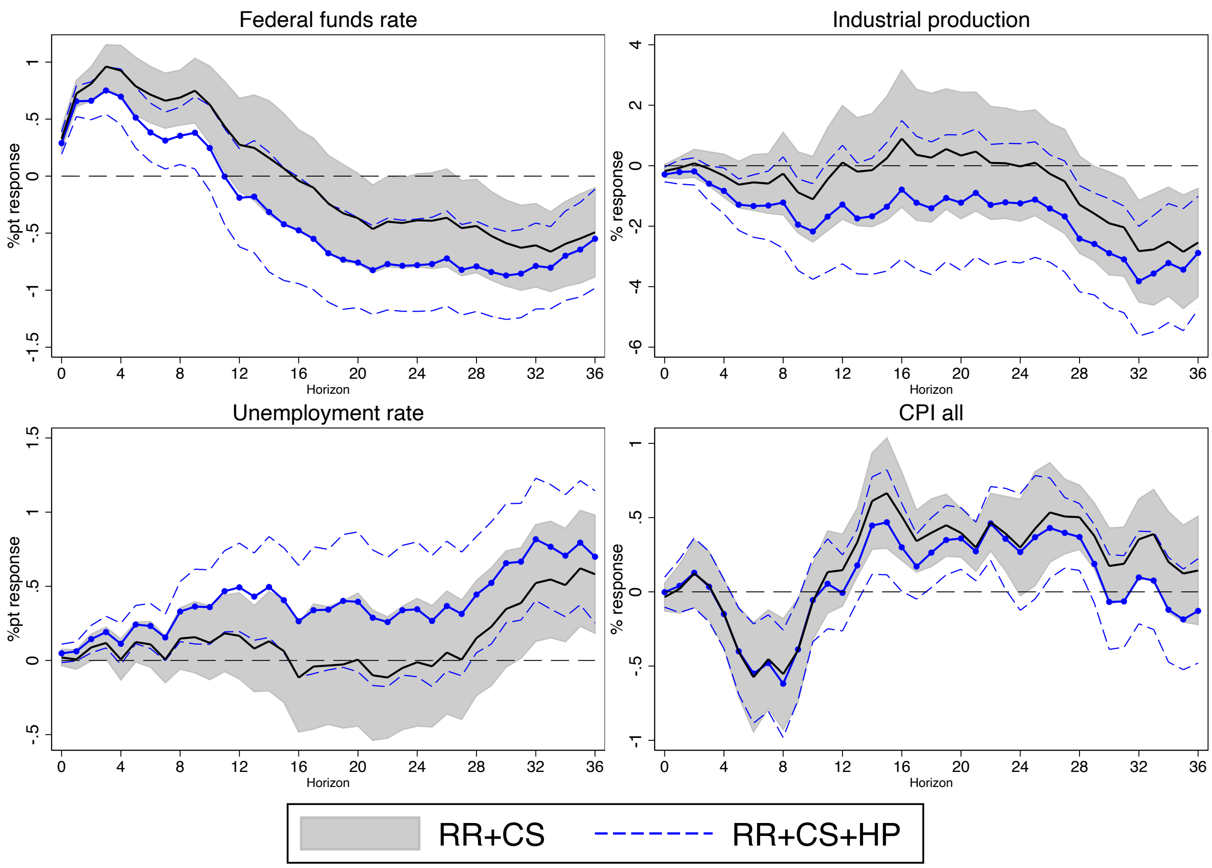
Figure 1.8: IRFs to monetary policy shocks: “RR" and “RR+CS+HP"



Note: The solid black line in each panel depicts the impulse response of the specified variable (Federal funds rate, real industrial production, the unemployment rate, and headline CPI) to 1 percentage point changes in monetary policy shocks identified in the R&R (2004) equation. The blue dotted line in each panel depicts the impulse response of the specified variable to 1 percentage point changes in monetary policy shocks identified in the R&R (2004) equation with both Baa corporate spreads and real house prices, using the “RR+CS+HP" shocks as the policy variable. Shaded bands and red dashed lines denote the associated 68% confidence intervals. Sample 1991:1 - 2008:12.

in both Figure 1.7 and 1.8 provide important implications on how the attenuation occurs in the magnitude of monetary policy shocks to economic fluctuations when the shocks are not identified with real house prices. By embracing all the implications of the empirical results in Figure 1.7 and 1.8, and to find out the potential role of house prices in the identification strategy of monetary policy shocks, I finally investigate impulse response functions to monetary policy shocks by estimating local projections that encompass the two identification strategies, “RR+CS" and “RR+CS+HP," over the same sample period. The solid black line in each panel in Figure 1.9 illustrates the re-

Figure 1.9: IRFs to monetary policy shocks: “RR+CS" and “RR+CS+HP"



The solid black line in each panel depicts the impulse response of the specified variable (Federal funds rate, real industrial production, the unemployment rate, and headline CPI) to 1 percentage point changes in the monetary policy shocks identified in the R&R (2004) equation with Baa corporate spreads. The red dotted line in each panel depicts the impulse response of the specified variable to 1 percentage point changes in the monetary policy shocks identified in the R&R (2004) equation with both Baa corporate spreads and real house prices, using the “RR+CS+HP" shocks as the policy variable. Shaded bands and red dashed lines denote the associated 68% confidence intervals. Sample: 1991:1 - 2008:12.

sponse functions of the Federal funds rate, real industrial production, the unemployment rate, and headline CPI to one percentage point change in the monetary policy shock identified in the R&R

(2004) equation by controlling only Baa corporate spreads. On the other hand, the blue dotted line in each panel shows the response function of the variables to one percentage point change in the monetary policy shock identified in the R&R (2004) equation with both Baa corporate spreads and real house prices, using the “RR+CS+HP" shocks as the policy variable. The results in Figure 1.9 provide supporting evidence that controlling for endogenous reactions of monetary policy to changes in house prices has a significant role in understanding the transmission of policy innovations to the macroeconomy. In Figure 1.9, the fully-adjusted monetary policy innovation shows a fall in output and a rise in unemployment rates significantly within two months, effects which are 30 percentage points larger than those in the second model.

Overall, the empirical results presented in Section 5.1 can be stylized in two aspects. The key implication of the analysis presented in this section is that models that do not embed the systematic response of monetary policy to corporate credit spreads or house prices identify a monetary policy shock that is contaminated by the endogenous response of monetary policy to the spreads and prices. As shown in Figures 1.7 through 1.9, this section provides the quantitative evidence that shocks constructed without controlling for the systematic response of monetary policy to credit spreads and house prices have no discernible effect on real activity for the Great Moderation period by estimating local projections given external instruments. In addition, not only does the use of the identified instrument accounting for the credit spreads or house prices provide strong evidence, but the shocks identified by controlling for both credit spreads and house prices simultaneously show response functions more consistent with standard macroeconomic theory. Further, these findings offer strong evidence that a contractionary monetary policy shock induces a contraction in output/consumption, a rise in unemployment/credit spreads, and a reduction in (house) prices. The most reasonable explanation for these findings is that both credit spreads and house prices are either conduits of changes in monetary policy to the real economy or important to quantifying the systematic response of monetary policy to economic conditions in both the financial and housing market, which are highly correlated to each other. Consequently, any model missing these interactions is likely to underestimate the effect of policy on business cycle analysis.

1.5.2 Results from hybrid VARs

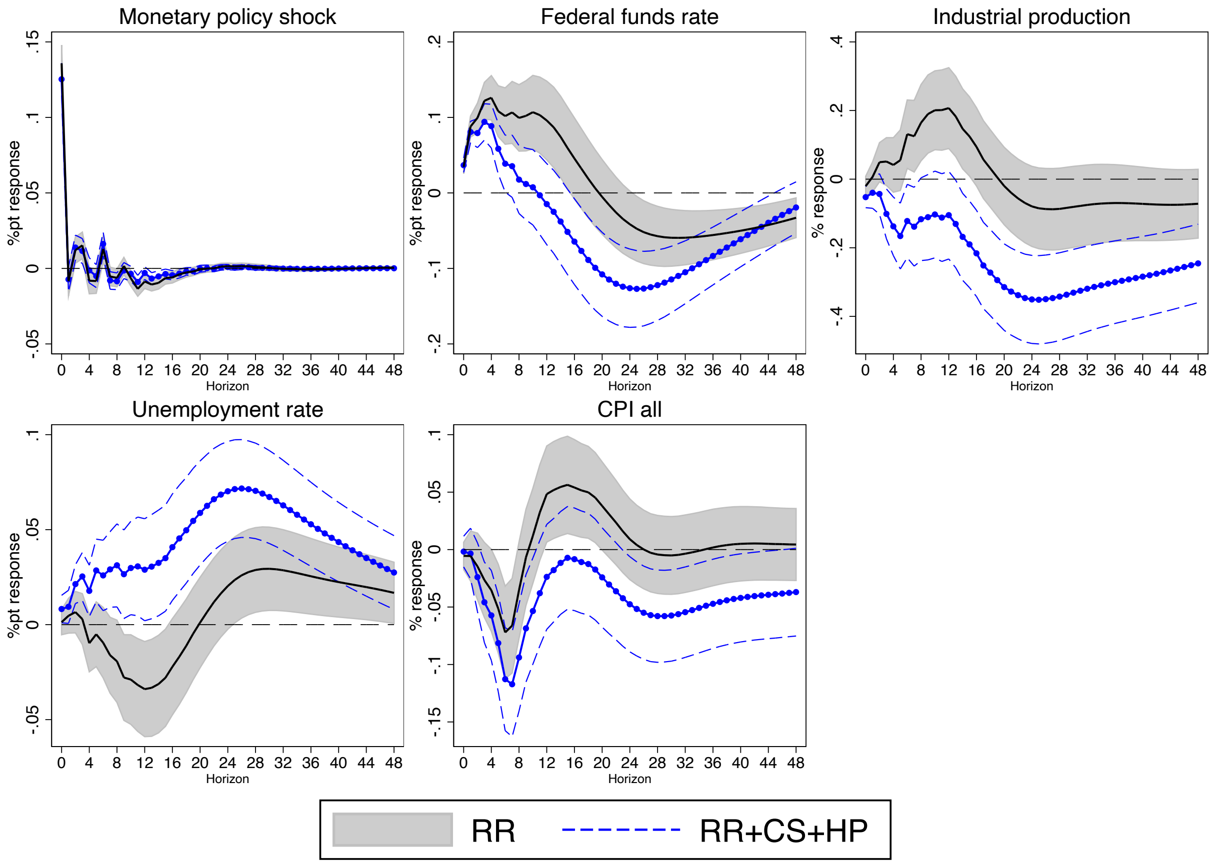
The empirical results from estimating local projections provide strong evidence of interdependence between monetary policy and two systematic components; credit spreads and house prices. In particular, the findings discussed in Section 1.5.1 are primarily based on the heterogeneous responses of the real macroeconomic variables to changes in narrative monetary policy shocks across different identification strategies using the local projection method. To ensure that the empirical results are not dependent on changes in estimation methodologies, Section 1.5.2 examines estimated responses with a hybrid approach by integrating the newly measured monetary policy shocks into standard VARs with the same composition of variables of interest. As discussed in Section 1.4.2, the specification uses the recursive assumption, placing the narrative shocks first in the ordering, followed by the Federal funds rate, output, unemployment, and the price index.

To show how monetary policy and real activity interact in hybrid VARs, I present empirical results from two models. I first estimate a five-equation Hybrid VAR model that consists of the policy shock projected from the baseline specification; the Federal funds rate; the log of manufacturing industrial production; the unemployment rate; and a measure of prices, the log of the consumer price index [23]. The second model is also a five-equation Hybrid VAR model that consists of the same specifications as the first model, except for the policy innovation, here the R&R narrative monetary policy shocks that control for the systematic responses of monetary policy to both credit spreads and house prices. The regressions, which include a constant, are estimated on data from 1991 to 2008 using six lags.

The estimated results with Hybrid VARs align with those in local projections. Figure 1.10 shows the dynamic impulse responses to monetary policy shocks using the Hybrid VARs under the alternative identification strategies, “RR” and “RR+CS+HP.’. In each panel, the solid black line represents the impulse response of the variables of interest (policy shock, Federal funds rate, real industrial production, unemployment rate, and the headline consumer price index) to a 100

[23] Coibion (2012) substitutes the cumulative sum of monetary policy shocks in place of the Federal funds rate, but the selection of endogenous variables is similar to Coibion (2012) and Ramey (2016).

Figure 1.10: Hybrid VARs, IRFs to monetary policy shocks: “RR" and “RR+CS+HP"



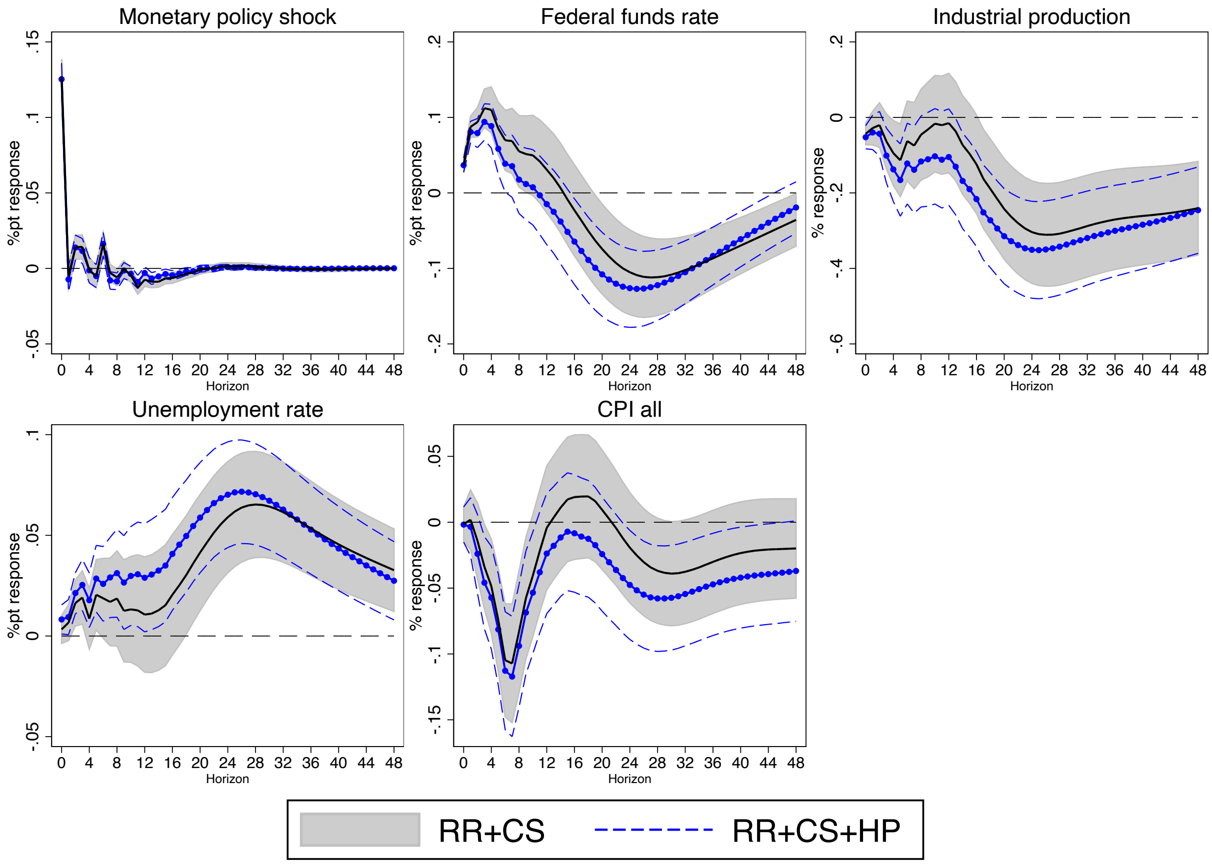
Note: The solid black line in each panel depicts the impulse response of the specified variable (policy shock, Federal funds rate, real industrial production, the unemployment rate, and headline CPI) to a 100 basis point deviation in the monetary policy shocks identified in the R&R (2004) equation. The blue dotted line in each panel depicts the impulse response of the specified variable to a 100 basis point deviation of the monetary policy shocks identified in the R&R (2004) equation with both Baa corporate spreads and real house prices, using the “RR+CS+HP" shocks as the policy variable. Shaded bands and red dashed lines denote the associated 68% bootstrap confidence intervals for the system estimated over the sample period, 1991:1 - 2008:12.

basis point deviation of the monetary policy shocks identified by applying the standard R&R equation. The blue dotted line in each panel depicts the impulse response of the specified variable to a 100 basis point deviation of the monetary policy shocks identified from the R&R equation with the components of Baa corporate spreads and real house prices. The shaded areas and red dashed bands denote the associated 68% confidence intervals, estimated over the sample period from 1991 to 2008. The baseline identification shows that a contractionary monetary policy shock induces a similar puzzle on real variables, in which industrial production rises and unemployment falls instantly. On the other hand, the new measure of policy shocks can account for many of the historical fluctuations at business cycle frequencies in production, employment, and inflation. The response of the real activities does not exhibit pronounced puzzles, which is theoretically consistent. Consequently, regardless of using different estimation methods, the empirical findings support the importance of incorporating house prices to understand the transmission of monetary policy shocks to the macroeconomy during the Great Moderation period.

I then show the further implications of this finding by estimating a five-equation Hybrid VAR model that consists of the same specifications as the first model except for the policy instruments, with the RR shocks containing the systematic response of monetary policy to corporate credit spreads only. Figure 1.11 shows the impulse response functions of the variables of interest to monetary policy shocks using the Hybrid VARs under the alternative identification strategies, "RR+CS" and "RR+CS+HP." In each panel, the solid black line represents the impulse response to a 100 basis point deviation of the monetary policy shocks identified by incorporating credit spreads into the R&R (2004) equation. The blue dotted line in each panel depicts the impulse response of the specified variable to a 100 basis point deviation of the monetary policy shocks identified from the R&R equation with the components of Baa corporate spreads and real house prices. The shaded areas and blue dashed bands denote the associated 90% bootstrap confidence intervals for the system, estimated over the sample period of 1991 to 2008.

Overall, the estimated real effects of monetary policy shocks using Hybrid VARs align with the local projection results. The baseline identification shows that a contractionary monetary policy shock induces a similar puzzle on real variables, in which industrial production rises and unemployment falls instantly. The response of the price level to the policy innovation is not significantly different from zero. On the other hand, the new measure of policy shocks can account for many of the historical fluctuations at business cycle frequencies in production, employment, and inflation. The response of the real activities does not exhibit pronounced puzzles, which is theoretically

Figure 1.11: Hybrid VARs, IRFs to monetary policy shocks: “RR+CS" and “RR+CS+HP"



Note: The solid black line in each panel depicts the impulse response of the specified variable (policy shock, Federal funds rate, real industrial production, the unemployment rate, and headline CPI) to a 100 basis point deviation of the monetary policy shocks identified using corporate spreads in the R&R (2004) equation. The blue dotted line in each panel depicts the impulse response of the specified variable to a 100 basis point deviation of the monetary policy shocks identified in the R&R (2004) equation with both Baa corporate spreads and real house prices, using the “RR+CS+HP" shocks as the policy variable. Shaded bands and blue dashed lines denote the associated 68% bootstrap confidence intervals for the system estimated over the sample period, 1991:1 - 2008:12.

consistent. Consequently, regardless of using different estimation methods, the empirical findings support the importance of incorporating house prices to understand the transmission of monetary policy shocks to the macroeconomy during the Great Moderation period.

1.6 Conclusion

The first chapter revisits one of the fundamental questions of macroeconomics: Does monetary policy matter? It is a question that lies at the center of any model of short-run macroeconomic fluctuations. The discussion on the effects of monetary policy appears to be still controversial with a substantial degree of uncertainty, despite the numerous theoretical and methodological advances. Like so many empirical questions in economics, omitted variable bias is a central issue. If monetary policy matters, then it is vital to include a channel through which changes in aggregate demand have real effects. Both monetary policy actions and real economic activity are likely to be influenced by other variables. Anything that affects output expectations, fiscal policy, and financial stress - is also likely to drive decisions by the Fed.

Accordingly, a simple regression of output on an indicator of monetary policy would naively and incorrectly conclude that monetary policy would not have a significant effect on the real economy. That is, if countercyclical monetary policy actions are common, the estimated impact of monetary policy will be biased toward zero. Specifically, not only the magnitude and significance but also the sign of the responses of economic variables such as output and prices rely on the given identification strategy, the details of the model specification, and the sample period. This chapter helps rationalize these puzzling and inconsistent results by introducing house prices and credit spreads into the identification strategy in terms of the narrative approach.

This chapter provides strong evidence that conventional estimates of the effects of monetary policy on the macroeconomy using narrative identification are substantially biased due to the endogeneity of the monetary policy shocks. In particular, the direction and size effects of monetary policy shocks on the real economy depend on the presence of a strong systematic response of monetary policy to real house prices and credit costs. I find that monetary policy affects and endogenously reacts to house prices, at least for the Great Moderation period. Compared with conventional estimates, which often ignore the endogenous response of monetary policy to house prices, monetary policy shocks have a more prominent role in business cycle fluctuations. The empirical evidence shows that following a monetary tightening, production, unemployment, and prices contract, while lending and house prices cool down, which is in line with the standard theory of monetary policy. The effects are both sizable and persistent, suggesting that monetary policy is meaningful for both economic stabilization and financial stability. These findings are robust to a number of severe tests. It is important to stress that the dynamic responses of the real activities follow the standard theory of monetary policy, provided one includes house prices as well as credit spreads in the estimation system. These results imply that both are crucial conduits of changes in monetary policy to the real economy, as well as factors in quantifying the systematic response of monetary policy.

2. THE EFFECTS OF UNANTICIPATED MONETARY POLICY ON REAL HOUSE PRICES

2.1 Introduction

Since the great financial crisis and in the wake of the short but steep COVID-19 recession, the housing sector has gained much attention in the macroeconomic literature, as house prices have risen at record levels, hitting the peak increase of 19.3 percent in April 2022. A departure from the global financial crisis in 2008, there has been a lot of debate about the relationship between monetary policy and the housing market. Lately, it is well-established studies show that the housing sector plays an important role in the transmission mechanism of monetary policy; Iacoviello (2005), Del Negro and Otrok (2007), Calza, Monacelli, and Stracca (2013), Luciani (2015), and Dias and Duarte (2019) are examples of studies showing the effects of monetary policy on housing.

Why focus on house prices? There are several reasons that house price is an essential variable of macroeconomics, although the effect of monetary policy on house prices generally exhibits one channel by which it affects financial stability. First, the global financial crisis shows the severe and devastating effects of a debt-fuelled housing bubble and crash, and real estate finance has grown enormously in recent years. Therefore it is conceivable to remain a critical source of risk to financial stability. Second, the standard macroeconomics theory suggests that monetary policy should generally affect house prices and housing credit. How do house prices respond to changes in the central bank's monetary policy? One of the transmission channels for policy actions by the Federal Reserve is to stimulate house prices by lowering the cost of consumer credit. It does so primarily by controlling its target interest rate (the federal funds rate) or the future interest rate path, which influences short-term and long-term market rates that can be converted into borrowing rates. Although monetary policy accommodation affects all household borrowing rates, from credit cards to auto loans, its potential is arguably most significant in mortgage markets[1]. All else equal, lower

[1]There is clear evidence for this: Housing constitutes the largest and most widely held asset of U.S. households, with 78 million homeowners owning roughly $30 trillion of real estate. This real asset serves as collateral for mortgage loans, making mortgages the most prominent consumer credit market, with an aggregate value of approximately $11 trillion.

interest rates reduce the cost of borrowing (or owning) a house, which implies a higher demand in the housing market. Consequently, a rise in demand leads to a higher asset value and stimulates house prices.

There is a growing literature looking at the nexus between monetary policy and house prices (see, e.g., Del Negro and Otrok (2007), Iacoviello (2005), Jordà et al. (2015), and Williams (2016)). These papers are, however, confined to studying aggregate effects on house prices. Another branch of the literature has attributed an asymmetric impact of expansionary versus contractionary monetary policy shocks on the real economy. Tenreyro and Thwaites (2016), Barnichon and Matthes (2017), and Angrist et al. (2018) are the studies showing that tight policy may have a more substantial effect on output (or yield curve) than loose policy. Interestingly, most of the literature on housing and monetary policy has primarily focused on its aggregate impact on house prices, and there are a few studies on the non-linear effect of monetary policy on house prices. In this chapter, I aim to fill this gap.

The recent empirical literature on monetary policy has relied on incorporating external high-frequency instruments[2], which are likely to provide direct measures of structural policy disturbances. The use of monetary policy surprises is particularly appealing in these applications because they focus on market interest rate changes within a narrow window of time around FOMC announcements. In this sense, first, this chapter analyzes the measure of high-frequency monetary policy shocks by extending the data[3] of Gürkaynak et al. (2005a). According to the rank test suggested by Cragg and Donald (1997), monetary policy has at least three dimensions in terms of its effects on financial markets. As noted by Gürkaynak et al. (2007a) and Swanson (2021), FOMC announcements are potentially high-dimensional objects which contain information about the future paths of interest rates, asset purchases, and the economy. In this regard, despite the potential

[2]This approach plausibly rules out reverse causality and other endogeneity problems. For instance, FOMC decisions are made an hour or two before the announcement, indicating that the FOMC could not have been reacting to changes in financial markets in a sufficiently narrow window of time around the announcement. Therefore, the asset price changes are clearly caused by the FOMC announcements themselves rather than vice versa.

[3]The data includes the date of every FOMC announcement from 1991 to 2018, together with the change in the number of market interest rates such as federal funds futures (the current-month and three-month-ahead contracts), Eurodollar futures (the current-quarter contract rate, and the contract rates for each of the next three quarters), and the Treasury bond yields (2-, 5-, 10-, and 30-year maturities) in a 30-minute window bracketing each announcement.

complexity, the maximum number of factors in the analysis is assumed to be three.

The analysis broadens the set of measures of monetary policy shock by revisiting the series from Bauer and Swanson (2022), Gürkaynak et al. (2005a), and Swanson (2021) to separately identify the federal funds rate, forward guidance, and large-scale asset purchase (LSAP) component of all FOMC announcement from 1991 to 2018, including the forward guidance and LSAP components of FOMC announcements during the U.S. zero lower bound period from 2009 to 2015. I estimate the effects of changes in the federal funds rate, forward guidance, and LSAPs on a variety of assets and demonstrate that the federal funds rate and forward guidance factor are more effective than LSAPs at moving current level and shorter-term market rates, while LSAPs were more effective than forward guidance and the federal funds rate at moving longer-term Treasury yields. The results are consistent with the findings in Swanson (2021), which suggests that LSAPs had substantial and highly statistically significant effects on asset prices and were effective at moving longer-term corporate bond yields. To the extent that monetary policy affects the real economy through changes in private-sector interest rates like corporate bond yields, this suggests that LSAPs are more effective than the federal funds rate or forward guidance factor at stimulating real house prices.

Second, this chapter investigates the use of orthogonal high-frequency monetary policy surprises to estimate the effects of monetary policy on real house prices. This investigation is necessitated by the emerging consensus in the literature that high-frequency monetary policy surprises are correlated with macroeconomic and financial data that predate monetary policy announcements. The observation follows from regressions comparing the effects of unadjusted high-frequency monetary policy surprises and monetary policy surprises that have been orthogonalized with respect to major macroeconomic and financial news that predates the monetary policy announcement. With three types of identified high-frequency monetary policy surprises for unadjusted and orthogonal measures, this chapter studies impulse responses for real house prices to monetary policy shocks using panel data and the local projection method of Jordà (2005). The real house price data comes from the Federal Housing Finance Agency and covers the period from 1991 to 2018 at a monthly frequency across the nine census divisions in the U.S.

The empirical study finds that unadjusted monetary policy surprises lead to more persistent responses to real house prices. The biased estimates arise because the macroeconomic data are correlated with the monetary policy surprise, e.g., a monetary policy tightening is correlated with positive innovations to output and inflation, which attenuates or even reverses the estimated effects of the tightening. In this case, using orthogonalized high-frequency monetary policy surprises provides an exogenous monetary policy instrument with respect to the other variables and produces impulse response functions that are less persistent. Another point to note in the study is that real house price responses associated with surprises in long-term future interest rates, captured by the LSAP factor, exhibit a negative, long-lasting, and most significant impact compared to the responses to the Federal funds rate and forward guidance factors. The average size of the effect on real house prices resulting from both the Federal funds rate factor and forward guidance factor is around -0.2 percentage points within four years, considerably smaller than the impact of approximately -0.7 percentage points within four years caused by the LSAP factor. Thus, the empirical finding implies that the unconventional monetary policy associated with large-scale asset purchases (or quantitative easing) is about as effective as conventional monetary policy.

To obtain evidence of a mechanism behind the house price responses, the study conducts two additional exercises. In the first exercise, I estimate the impulse responses of the market yield on treasury securities with a constant maturity of 2 years to a surprise increase in interest rates captured by each factor. The associated results present that in response to a surprise about shorter-term and longer-term future interest rates, captured by the forward guidance and large-scale asset purchases factor, 2-Year Treasury yields increase by around 0.08 and 0.2 percentage points, respectively, within one year. By contrast, the response of 2-Year Treasury yields to the level surprise is close to zero. In the second exercise, I estimate the impulse responses of the 30-year fixed-rate mortgage rates to a surprise increase in interest rates with three factors as instruments. In response to a surprise about future interest rates, the 30-year fixed-rate mortgage rates increase by around 0.1 percentage points within 30 months after the shock. In contrast, the response to the monetary surprise associated with the current level of interest rates is not significantly different from zero. Rising mortgage rates make house financing more expensive by tightening debt-to-income or loan-to-value constraints and lead to lower demand for housing (Anenberg and Kung, 2017; Favilukis et al., 2017; Greenwald, 2018; Garriga et al., 2017; Bhutta and Ringo, 2021). In anticipation of the fall in demand, home sellers lower their prices, indicating that activities related to credit channels play a role in house market adjustment to policy announcements.

The main contribution of the second chapter is to study the extent of asymmetry in the response of real house prices to expansionary and contractionary monetary policy shocks. From the view of a standard supply-demand framework with durable housing, as discussed in Glaeser and Gyourko (2005), housing supply is rigid downwards, implying that an interest rate increase should have a larger impact on house prices than a corresponding reduction in the interest rate. To investigate the empirical relevance of these conjectures, finally, this chapter estimates impulse responses to real house prices depending on two types of monetary policy surprise, Expansionary v.s. Contractionary monetary policy. Consistent with the theory, I find that contractionary shocks have a substantially greater and long-lasting impact on real house prices than expansionary shocks, implying that raising interest rates amplifies the volatility of house prices. At the same time, an interest rate reduction does not significantly affect house prices to the same extent as a contractionary monetary policy shock.

The rest of the chapter is structured as follows. Section 2.2 describes the standard methodology for the framework of high-frequency measures of monetary policy surprises. Section 2.3 provides a theoretical primer on the symmetric and asymmetric impact of monetary policy shocks on real house prices and describes the estimation method. Section 2.4 presents the baseline results and provides evidence for the mechanisms underlying the results. Section 2.5 outlines the specification for the non-linear effects of monetary policy shocks and discusses the empirical results. Section 2.6 concludes and lays out avenues for future research.

2.2 Measures of High-Frequency monetary policy surprises

In this section, I first describe the standard methodology for the framework of high-frequency measures of monetary policy surprises that have been used in the existing literature and then review the following three measures of monetary policy surprises, the approach suggested by Bauer and Swanson (2022), Gürkaynak et al. (2005a), and Swanson (2021).

2.2.1 Methodology

To identify the high-frequency component of each FOMC announcement, I extend the dataset of Gürkaynak et al. (2005a) through 2018. The extended data includes the date of every FOMC announcement through 2018, together with the change in the number of asset prices (market interest rates) in a 30-minute window bracketing each announcement.[4] The asset prices include federal funds futures (the current-month and three-month-ahead contracts), Eurodollar futures (the current-quarter contract rate and the contract rates for each of the next three quarters), and the Treasury bond yields (2-, 5-, 10-, and 30-year maturities).

I combine these interest rates responses into a $T \times n$ matrix X, with rows corresponding to FOMC announcements and columns to different assets; each element $x_{i,j}$ of X then reports the 30-minute response of the jth asset to the ith FOMC announcement. The estimation relies on the following regression, as known as a standard factor model, which has been frequently estimated in the literature,

$$X = Z\Lambda + \varepsilon, \tag{2.1}$$

where Z is a $T \times k$ matrix containing $k \leq n$ unobserved factors, Λ is a $k \times n$ matrix of loadings of asset price responses on the k factors, and ε is a $T \times n$ matrix of white noise residuals that are uncorrelated over time and across assets. If k = 0, the data X would be well described by n

[4]The window begins 10 minutes before the FOMC announcement and ends 20 minutes after. The dataset also includes some intraday asset price responses to FOMC announcements going back to January 1990, but the data for house prices and the Treasury yield responses begin in January 1991. To this end, the sample begins from 1991 through 2018 since those are an important part of my analysis. Also, as standard in the literature, I exclude the FOMC announcement on September 17, 2001, which took place before markets opened but after financial markets had been closed for several days following the 9/11 terrorist attacks.

uncorrelated white noise processes; if $k = 1$, X would be well described as responding linearly to a single factor (such as the change in the federal funds rate) plus uncorrelated white noise; if $k = 2$, X would be responding to two underlying dimensions of FOMC announcements plus uncorrelated white noise; and so on.

The restriction on the structure of the data X can be tested using the matrix rank test of Cragg and Donald (1997). Briefly, given a null hypothesis of rank k_0 and an alternative $k > k_0$, the Cragg-Donald test looks for overall possible factor models with k_0 factors to find the one that brings the residuals ε as close to uncorrelated white noise as possible. The test then measures the minimum distance between the residuals and white noise using a Wald statistic. This distance, after a suitable normalization, has a limiting χ^2 distribution with $[(n - k_0)(n - k_0 + 1)/2] - n$ degrees of freedom.

Table 2.1: Tests for the number of factors

H_0: Number of factors equals	Wald Statistic	Degrees of freedom	p-value
0	118.75	45	0.0000
1	80.22	34	0.0000
2	47.73	26	0.0058
3	23.88	18	0.1591
4	11.77	11	0.3815

Results from the Cragg and Donald (1997) test for the number of factors k underlying the 240 × 10 matrix X of 30-minute asset price responses to FOMC announcements from January 1991 to June 2018. The test is for $H_0 : k = k_0$ vs. $H_1 : k > k_0$.

There are 240 FOMC announcements from January 1991 to June 2018 and ten different assets in X. Table 2.1 reports the results of this test. The data significantly reject the hypothesis of rank zero (uncorrelated white noise), so clearly, the yield curve responds systematically to FOMC announcements. Similarly, the hypothesis of rank one and rank two are also rejected strongly, which implies that interest rates respond to FOMC announcements in a multi-dimensional. However, the test fails to reject the null hypothesis of rank three at even the 10% significance level, suggesting the market interest rates are well explained by a factor model with three factors. An important finding is that even the surprise change in the single or two dimensions of monetary policy is insufficient to explain the response of the yield curve to FOMC announcements, in contrast to one of the standard assumptions in the literature[5]. As can be seen in Table 2.1, monetary policy seems to have at least three dimensions in terms of its effects on financial markets. As noted by Gürkaynak et al. (2007a), FOMC announcements are potentially high-dimensional objects which contain information about the future paths of interest rates, asset purchases, and the economy. In this regard, despite the potential complexity, the maximum number of factors in the analysis is assumed to be three as the baseline specification.

2.2.2 Factor estimation

This chapter broadens the set of measures of monetary policy shock by revisiting the series from Bauer and Swanson (2022), Swanson (2021), and Gürkaynak et al. (2005a). Bauer and Swanson (2022) estimate high-frequency measures of monetary policy shock by using a range of Eurodollar futures contracts, ED1–ED4[6], and taking the first principal component of the unanticipated changes in four short-term interest rates within a narrow 30-minute window around scheduled FOMC announcements from 1988 to 2019. The literature shows the principal component captures the combined effects[7] of changes in both the current federal funds rate and expected future federal funds rates since the measure uses the market interest rates at maturities within one year. They refine the measure by orthogonalizing their measure of the component predicted by

[5] Gertler and Karadi (2015) and Miranda-Agrippino and Ricco (2021) employ changes in the current-quarter federal fund future contracts, while Hanson and Stein (2015) and Wu and Xia (2016) use changes in the 1- or 2-year Treasury yield as a sufficient statistic for monetary policy. On the other hand, Gürkaynak et al. (2005a) and Nakamura and Steinsson (2018) estimate the first and second principal components of a set of market interest rates as the measures of monetary policy surprises.

[6] Federal funds futures are also often included in the construction of monetary policy surprises but are not available in Tick Data until 2010. Gürkaynak et al. (2007a) show that Eurodollar futures are the best predictor of future values of the federal funds rate at horizons beyond six months and are virtually as good as federal funds futures at horizons less than six months.

[7] Because the first principal component is essentially equal to a weighted average of the target and path factors, it parsimoniously captures some of the main features of both types of monetary policy surprises.

macroeconomic and financial data preceding the policy announcement.

In this analysis, I first follow Bauer and Swanson (2022)'s approach to measuring the monetary policy shock for the sample period of 1991 to 2018 by using the extended dataset of Gürkaynak et al. (2005a) through 2018. I begin extracting the first principal component of the data X, which include a range of Eurodollar futures contracts (ED1–ED4), in regression (2.1) and normalize[8] it to have a unit standard deviation over the whole sample so that a one-standard deviation changes in the principal component. The first principal component explains about 93% of the variation of assets in X over the sample. Given the principal component as a measure of monetary policy shock, I estimate regressions of the form:

$$Z_t = \alpha + \beta Y_{t-} + \nu_t \tag{2.2}$$

where t indexes FOMC announcements for the sample period from 1991 to 2018, and Z_t denotes the principal factor estimated from the regression (2.1). The vector Y_{t-} consists of seven predictors of macroeconomic and financial data known prior to the announcement t (which are known prior to the announcement, indicated by the time subscript $t-$), including the surprise component of the most recent nonfarm payrolls release, employment growth over the last year, the logarithmic change in the S&P500 from three months before to the day before the FOMC announcement, the change in the yield curve slope over the same period, the logarithmic change in a commodity price index over the same period, the option-implied skewness of the 10-year Treasury yield from Bauer and Chernov (2021), and the three-month moving average of house price growth from two months before the FOMC announcement. The regression residual is denoted by ν_t. Finally, I construct an orthogonal measure of the monetary policy surprise by taking the residuals from the regression (2.2):

$$F_t^{Orth} = Z_t - \hat{\alpha} - \hat{\beta} Y_{t-} \tag{2.3}$$

where Y_{t-} and $\hat{\beta}$ correspond to the predictors and estimated regression coefficients in the regression

[8]Bauer and Swanson (2022) rescales the monetary policy instrument as a one-unit change in the principal component corresponds to one percentage point change in the ED4 rate.

(2.2). The orthogonal surprise F_t^{Orth} is, by construction, uncorrelated with those macroeconomic and financial data observed before the FOMC announcement and thus is more likely to satisfy the assumptions in the existing literature.

Rather than focus on one dimension of monetary policy, Gürkaynak et al. (2005a) estimate the top two factors of the changes in the first and second federal funds and four Eurodollar futures contracts around FOMC announcements by isolating the component of the set that reflects surprises in future rates that are orthogonal to surprises in the current rate. They show that FOMC announcements cause surprises both about the current federal funds rate target and the expected path of the federal funds rate for the next several months, i.e., their "target" and "path" factors. Especially, the latter is influenced by the Fed,s forward guidance[9] and balance sheet policies.

To estimate the unobserved factors, Z_1 (or federal funds rate factor FF) and Z_2 (or forward guidance factor FG), I begin by decomposing X from the regression (2.1), which consists of five columns corresponding to the changes in the current-month and three-month-ahead federal funds futures contracts, the changes in asset price of the second, third, and fourth Eurodollar futures contracts around FOMC announcements, into its principal components after normalizing each column to have zero mean and unit variance. The estimated components, Z_1 and Z_2 correspond to the two elements of FOMC announcements that had the greatest systematic impact on the assets in X over the sample and together explain about 94% of the variation in X. The factors, however, explain only a maximal fraction of the variance of X but do not have a structural interpretation, as discussed by Gürkaynak et al. (2005a) and Swanson (2021). For example, there is no reason why the first principal component should correspond to the surprise change in the federal funds rate or forward guidance since both factors are correlated with the surprises in the current federal funds rate target. Accordingly, I cannot interpret one factor as the change in the federal funds rate target and the other factor as some other dimension of monetary policy.

To address this deficiency and allow for a structural interpretation of the factors, I perform a rotation of the two columns of Z corresponding to the surprise component of changes in the federal

[9] Similarly, Nakamura and Steinsson (2018) show that the effects of their monetary policy shocks reflect, in addition to surprises to the path of interest rates, the effects of Fed announcements on private sector economic expectations.

funds rate and forward guidance, respectively, to yield two new factors. I define them as a F matrix by

$$F = ZU, \tag{2.4}$$

where the two columns of F are still orthogonal, and U is a 2×2 orthogonal matrix. To identify the matrix F, I impose two assumptions[10] below. First, following Gürkaynak et al. (2005a), I impose that changes in forward guidance have no effect on the current federal funds rate. This identifying assumption is justified by defining forward guidance to be the component of FOMC announcements that conveys information about the future path of short-term interest rates above and beyond changes in the target federal funds rate itself. This is the definition of forward guidance (or the path factor) used by Gürkaynak et al. (2005a) and that I also use in this chapter. Second, following Swanson (2021), I normalize the scale of the federal funds rate factor to have a unit standard deviation from January 1991 to December 2008, which corresponds to the period of conventional monetary policy before the Zero-Lower bound (ZLB) period. This scale convention is more intuitive than a full-sample unit standard deviation would be and also facilitates comparison to previous results in the literature. Further, I normalize the forward guidance factor to have a unit standard deviation over the whole sample. Together, these restrictions uniquely identify U, and hence F. Then, I estimate the regression (2.3) for each factor from the regression (2.4) with the vector X_{t-} to measure the orthogonal monetary policy surprises by taking the residuals from each regression. Hence, the orthogonal surprises FF_t^{Orth} and FG_t^{Orth} are, by construction, uncorrelated with the macroeconomic and financial data observed before the FOMC announcement.

As described in Section 2.1, the analysis focuses on the surprise change in three dimensions to explain the response of the market interest rate to FOMC announcements. To estimate the unobserved three factors Z in the regression (2.1), I follow the measure of monetary policy surprise described in Swanson (2021) as the baseline instrument in this analysis. The literature applies a

[10]To estimate three unobserved factors in the regression (2.1), the equation (2.4) requires two more restrictions. Swanson (2021) imposes that changes in LSAPs also have no effect on the current federal funds rate since the FOMC's major LSAP announcements all occurred during the ZLB period. In addition, he assumes the restriction that the LSAP factor is as small as possible in the pre-ZLB period.

factor model to assets with maturities below one year and 2-, 5- and 10-year Treasury yields and estimates the top three factors that explain 94% of the changes in these interest rate responses within a 30-minute window around scheduled FOMC announcements between June 1991 and June 2019. Swanson (2021)[11] takes X to include the first and third federal funds futures contracts, the second to fourth Eurodollar futures contracts, and the 2-, 5-, and 10-year Treasury yields to focus on the assets that are the most closely related to monetary policy. Accordingly, possible interpretation for the three unobserved components of F in the regression (2.4) can be i) the surprise component of the change in the federal funds rate at each FOMC meeting, ii) the surprise component of the change in forward guidance, iii) the surprise component of any Large-Scale asset purchases (LASP) announcements, and iv) any additional dimensions of news about monetary policy or the economy that is systematically revealed in FOMC announcements. Accordingly, in the Three-Factors model, the orthogonal surprises FF_t^{Orth}, FG_t^{Orth}, and $LSAP_t^{Orth}$ are uncorrelated with the macroeconomic and financial data observed before the FOMC announcement.

The results from six distinct variations of the regression (2.2) are presented in Table 2.2. The initial column displays the coefficient estimates β for the sample period 1991-2018, utilizing the One-Factor approach as described in Bauer and Swanson's (2022) framework. The findings support their results, indicating that robust nonfarm payroll employment, a thriving stock market, and high commodity prices are indicative of an unexpected shift towards a more monetary policy tightening. Likewise, when the yield curve inclines upwards (indicating a decline in short-term interest rates compared to long-term rates, typically observed during periods of monetary easing) or when there is negative implied skewness on the 10-year Treasury yield (suggesting that the market is primarily concerned about a reduction in interest rates), it is probable that the Federal Reserve will respond with an unexpected easing of its policy. The remaining five columns in Table 2.2 present outcomes obtained from different estimation techniques. In the second and third

[11] Swanson shows that the first and third federal funds futures contracts provide good estimates of the short-term market expectation of the federal funds rate after the current and three months. In addition, the second through fourth Eurodollar futures contracts provide information about the middle-term market expectation of the path of the federal funds rate over a horizon from about 6 to 12 months ahead. Lastly, the 2-, 5-, and 10-year Treasury yields provide information about interest rate expectations and risk premia over longer horizons.

Table 2.2: Predictive Regressions Using Macroeconomic and Financial Data

	One-Factor	Two-Factors		Three-Factors		
		FF factor	FG factor	FF factor	FG factor	LSAP factor
Nonfarm payrolls	1.65**	1.61***	0.46	1.50***	0.34	0.21
	[0.78]	[0.55]	[1.01]	[0.56]	[0.81]	[0.31]
Empl. growth (12m)	0.07*	0.01	0.12**	0.00	0.09*	-0.00
	[0.04]	[0.03]	[0.06]	[0.03]	[0.05]	[0.05]
Δ log S&P 500 (3m)	1.78	1.50	1.26	1.54	0.60	-0.04
	[1.11]	[1.04]	[1.64]	[1.01]	[1.31]	[0.84]
Δ yield slope (3m)	-0.20	-0.27*	0.02	-0.19	0.06	-0.25**
	[0.13]	[0.15]	[0.20]	[0.13]	[0.15]	[0.12]
Δ log Comm. price (3m)	1.93**	0.37	3.08**	0.38	2.22**	-0.31
	[0.97]	[0.80]	[1.29]	[0.78]	[1.07]	[0.41]
Treasury skewness	0.50**	0.40*	0.36	0.27	0.47**	0.15
	[0.22]	[0.22]	[0.30]	[0.17]	[0.24]	[0.19]
Observations	240	240	240	240	240	240
Adjusted R-squared	0.15	0.10	0.07	0.08	0.06	0.02

The first column shows coefficient estimates β from the regression (2.2) in the sample 1991:2018 by employing One-Factor scheme. Columns [2] and [3] repeat the regression but uses the Two-Factors model, while columns [3] to [6] report results from the Three-Factors model. Robust standard errors are in brackets. *, **, and *** indicate rejection at $\alpha(0.1, 0.05, 0.01)$ significance level, respectively. See text for details.

columns, regression (2.2) is replicated using the same sample but employing the Two-Factors approach, which accounts for federal funds rate factors and forward guidance factors. The final three columns exhibit results obtained from the Three-Factors model. Interestingly, the findings across these methodologies closely align with those in the first column.

In general, the results depicted in Table 2.2 reveal a systematic correlation between high-frequency monetary policy surprises, as measured by various instruments, and publicly accessible macroeconomic and financial data prior to the official announcement of monetary policy. This suggests that the substantial predictability of high-frequency monetary policy surprises identified by previous researchers using different estimation approaches remains evident.

Table 2.3 provides a comparison of the impacts of F_t^{Orth}s derived from regression (2.3) on asset prices in relation to the estimated factor(s) obtained from each estimation approach. The first three rows of Table 2.3 demonstrate the effects of variations in rotated factors derived from

Table 2.3: Effects of monetary policy disturbances on interest rates, 1991 - 2018

	MP1	MP2	ED1	ED2	ED3	ED4	2yrT	5yrT	10yrT	30yrT
Three-Factors										
Federal Funds Rate	8.77***	6.01***	6.16***	5.68***	5.35***	4.58***	3.22***	2.24***	1.03***	0.31*
	[0.50]	[0.58]	[0.40]	[0.35]	[0.42]	[0.35]	[0.31]	[0.24]	[0.18]	[0.18]
Forward Guidance	-0.04	1.10***	2.20***	3.74***	4.82***	5.50***	4.36***	4.53***	3.25***	2.28***
	[0.29]	[0.30]	[0.27]	[0.29]	[0.28]	[0.31]	[0.20]	[0.21]	[0.18]	[0.19]
Large Scale	0.05	1.09***	1.38**	1.73**	1.79***	1.57***	0.12	-1.95***	-3.22***	-3.69***
Asset Purchase	[0.19]	[0.40]	[0.63]	[0.67]	[0.59]	[0.45]	[0.31]	[0.21]	[0.55]	[0.64]
Two-Factors										
Federal Funds Rate	8.27***	5.85***	5.83***	5.44***	5.06***	4.30***	3.02***	2.24***	1.12***	0.45
	[0.39]	[0.47]	[0.36]	[0.30]	[0.38]	[0.33]	[0.35]	[0.35]	[0.29]	[0.28]
Forward Guidance	0.01	0.97***	2.07***	3.26***	4.05***	4.52***	3.33***	3.31***	2.31***	1.58***
	[0.25]	[0.21]	[0.22]	[0.22]	[0.22]	[0.25]	[0.19]	[0.24]	[0.20]	[0.19]
One-Factor										
Principal Component	5.27***	4.42***	5.69***	6.37***	6.72***	6.58***	4.73***	4.22***	2.68***	1.62***
	[0.71]	[0.65]	[0.44]	[0.31]	[0.35]	[0.37]	[0.31]	[0.34]	[0.31]	[0.27]

Coefficients in the table correspond to elements of the structural loading matrix in basis points per standard deviation change in the monetary policy instrument. MP1 and MP2 denote scaled changes in the first and third federal funds futures contracts, respectively; ED1, ED2, ED3, and ED4 denote changes in the first through fourth Eurodollar futures contracts; and 2yr-, 5yr-, 10yr-, and 30yr-T denote changes in 2-, 5-, 10-, and 30-year Treasury yields. Robust standard errors are in brackets. *, **, and *** indicate rejection at $\alpha(0.1, 0.05, 0.01)$ significance level, respectively. See text for details.

the Three-Factors model introduced by Swanson (2021) on differences in market interest rates around FOMC announcements. Additionally, the fourth and fifth rows present the effects derived from the Two-Factors model, while the last row represents the effects from the One-Factor model. It should be noted that as each factor has been rescaled to have a unit standard deviation, the coefficients presented in the table are measured in basis points (bp) per standard deviation change in the monetary policy instrument.

A one-standard-deviation increase in the federal funds rate factor in the first row is estimated to raise the current federal funds rate by about 8.77bp, the expected federal funds rate, and the Eurodollar futures rate at the next FOMC meeting by about 6.01bp, the second through fourth Eurodollar futures rates by 5.68, 5.35, and 4.58bp, respectively, and the 2-, 5-, and 10-year Treasury yields by about 3.22, 2.24, and 1.03bp, respectively. The effects of a surprise change in the federal funds rate are thus largest at the short end of the yield curve and die off monotonically as the maturity of the interest rate increases, consistent with the estimates in Kuttner (2001), Gürkaynak et al. (2005a), and Bauer (2021). The effects of forward guidance in the second row are quite different. By construction, a shock to the forward guidance factor has no effect on the current federal funds rate. At longer maturities, however, the forward guidance factor's effects increase, peaking at a horizon of about one year and diminishing at longer horizons. This is consistent with the estimates in Gürkaynak et al. (2005a) and also Campbell et al. (2012). The effects of LSAPs, in the third row are quite different from the first two. Like forward guidance, a change in the LSAP factor has no effect on the current federal funds rate by construction. Unlike forward guidance and changes in the federal funds rate, the effect of LSAPs is small at short maturities and much larger at the long end of the yield curve. This is consistent with several authors'findings[12] that LSAPs have a substantial impact on longer-term Treasury yields. A one-standard-deviation increase in the LSAP factor causes 5-, 10-, and 30-year Treasury yields to fall about 1.95, 3.22, and 3.69bp, respectively, on average. An increase in LSAPs also causes short-term yields to rise slightly, on average, although this effect is quantitatively small.

The effects of federal funds rate and forward guidance result from the Two-Factors model, in the fourth and fifth rows, are quite similar to those in the first row but slightly a less size. A one-standard-deviation increase in the federal funds rate factor is estimated to raise the current federal funds rate by 8.27bp, the expected federal funds rate at the next three months by 5.85bp, the first through fourth Eurodollar futures rates by 5.83, 5.44, 5.06 and 4.3bp, respectively, and the 2-, 5-, and 10-year Treasury yields by about 3.02, 2.24, and 1.12bp, respectively. Similarly, a shock to the forward guidance factor has no effect on the current federal funds rate, and a one-standard-deviation increase in the forward guidance factor is estimated to raise the first through fourth Eurodollar futures rates by 2.07, 3.26, 4.05, and 4.52bp, respectively, and the 2-, 5-, 10, and 30-year Treasury yields by about 3.33, 3.31, 2.31, and 1.58bp, respectively, which shows that the effects of forward guidance factor increase, peaking at a horizon of one year and diminishing at longer horizons.

On the other hand, the first (principal) component results from the One-Factor model, in the

[12]See Gagnon et al. (2011); Krishnamurthy and Vissing-Jorgensen (2011); Krishnamurthy and Vissing-Jorgensen (2013); Swanson, (2011)

last row, explains the combined effects of changes in both the federal funds rate and forward guidance described in the fourth and fifth rows above. A one-standard-deviation increase in the first component is estimated to raise the current federal funds rate by 5.27bp, the expected federal funds rate at the next 3-month by 4.42bp, the first through fourth Eurodollar futures rates by 5.69, 6.37, 6.72 and 6.58bp, respectively, and the 2-, 5-, 10-, and 30-year Treasury yields by about 4.73, 4.22, 2.68, and 1.62bp, respectively.

In the remainder of this chapter, I use the three measures of high-frequency monetary policy surprises resulting from Table 2.3 to empirically estimate the response of house prices to changes in monetary policy. As described in Section 2.1, the surprise changes in the three dimensions of monetary policy are sufficient to explain the response of the market interest rates to FOMC announcements, so I am interested not only in the shocks to the level of the interest rate itself but also to the slope of the future rate changes. The next section provides a standard theoretical background on the effects of monetary policy shocks on house prices and explains the empirical estimation methodologies.

2.3 Econometric methodology

In this section, I first provide a theoretical primer on the impact of monetary policy shocks on house prices and then describe the empirical estimation method.

2.3.1 Theoretical primer

The basic framework associated with unexpected changes in policy rates to house prices can be explained using a standard business cycle model with households deriving utility from non-durable and housing consumption, as described in Barsky, House, and Kimball (2007). When a central bank raises unanticipated policy rates, the aggregate demand shifts from current consumption to future consumption, which is known as the substitution effect. This can be illustrated through a standard Euler equation:

$$U_t^c = \beta(1 + i_t)E_t\Big[\frac{U_{t+1}^c P_t^c}{P_{t+1}^c}\Big]$$

where U_t^c is the marginal utility of non-durable consumption, P_t^c is its price, and i_t is the risk-free rate. The unexpected increase in the interest rate in period t is met with higher marginal utility (lower consumption) and lower prices in period t.

The effect on house prices depends on how interest rates affect the value of housing γ_t^h, given by the net present value of future real returns from housing services $r_{t+\tau}^h$:

$$\gamma_t^h = \beta E_t[\gamma_{t+1}^h(1 + r_{t+1}^h)].$$

Because houses are illiquid and long-lived durables, their value is insensitive to temporary factors, such as central bank's interest rate changes, i.e.,$\gamma_t^h \simeq \gamma^h$. This means households have much less incentive to smooth house spending relative to spending on non-durables, which in turn has direct implications for how house prices respond to interest rate shocks. Namely, households allocate their non-durable consumption and housing to equate the marginal values of an additional dollar spent so that $U_t^c/P_t^c = \gamma^h/P_t^h$. Since the nominal interest rate increase raises U_t^c/P_t^c, it also lowers house prices P_t^h. And since house spending is lumpier than non-durable consumption, house prices fall by more than non-durable prices. Indeed, using the Euler equation and the constant value of housing, we can obtain the equation linking the risk-free rate and housing prices:

$$(1 + i_t) \simeq \frac{1}{\beta} E_t\Big[\frac{P_{t+1}^h}{P_t^h}\Big]$$

In response to an unexpected nominal interest rate hike, house prices must fall, and their fall is larger than for non-durable consumption prices.

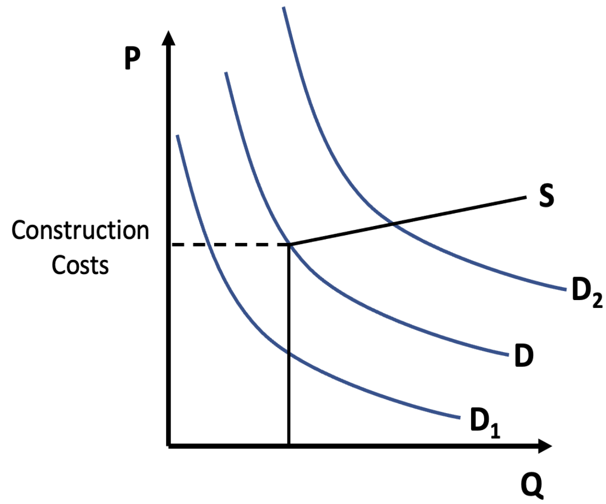
Since buying or selling a house often involves financing, interest rates also influence house prices via the cost of housing debt. Higher interest rates raise mortgage rates and reduce the availability of credit, cooling housing demand, especially from financially constrained households. A large literature that studies the role of housing finance on the transmission of interest rate changes to housing markets includes Iacoviello (2005); Jarocinski and Smets (2008); Williams (2011, 2015); Favara and Imbs (2015); Anenberg and Kung (2017); Garriga, Kydland and Šustek (2017); Greenwald (2018); Garriga, Manuelli and Peralta-Alva (2019); Bhutta and Ringo (2021); Berger, Milbradt, Tourre and Vavra (2021); Wong (2021); Eichenbaum, Rebelo and Wong (2022). Davis and Van Nieuwerburgh (2015) provide a review of the macroeconomic aspects of the housing finance literature.

Besides cooling the demand for housing services, higher current and future interest rates also reflect the risk premium associated with owning a house (Campbell, Davis, Gallin, and Martin, 2009; Favilukis, Ludvigson, and Van Nieuwerburgh, 2017). In addition, higher interest rates can increase the user cost of housing indirectly by raising the expectation of house price depreciation (Glaeser, Gottlieb and Gyourko, 2013; Kuchler, Piazzesi and Stroebel, 2022) or changing property or income tax obligations across different homeowners (Poterba, 1984). A more general review of the literature on housing in macroeconomics is provided by Piazzesi and Schneider (2016).

However, these papers primarily focus on analyzing the overall impact on house prices, overlooking the existence of asymmetric effects between expansionary and contractionary monetary policy shocks. Examining the non-linear relationship between monetary policy and house prices presents a significant challenge. Firstly, the long-lasting nature of housing implies that the housing supply is resistant to downward adjustments, as discussed in Glaeser and Gyourko (2005). Figure (2.1) provides a visual representation of the general framework. The housing market exhibits a kinked supply curve, which is highly elastic when prices reach or exceed construction costs but becomes highly inelastic otherwise. Due to the durability of housing, a negative demand shock, such as the shift from D to D_1, results in a substantial decrease in price but has a limited impact on quantity.

Conversely, when housing is elastically supplied, a positive demand shock represented by the shift from D to D_2 leads to the provision of new housing units at relatively constant costs, resulting in minimal changes in price, as indicated by Figure (2.1). This asymmetric response to positive and negative demand shocks, stemming from the characteristics of the housing demand-supply framework, suggests that an unexpected rise in interest rates would have a more substantial influence on house prices compared to a corresponding decrease in interest rates. This prediction is

Figure 2.1: The nature of housing supply and construction costs



Note: D is the initial demand curve. D_1 is the demand curve after the interest rate increase, while D_2 is the demand curve after the interest rate reduction. The supply curve is given by S. The initial equilibrium is given by the intersection between the original demand curve and the supply curve. The supply curve kinks at the equilibrium point before the shock.

also supported by Aastveit and Anundsen (2018).

Another potential explanation relates to the behavior of lenders and borrowers in different monetary conditions. When the Federal Reserve aims to increase its policy rates, market rates tend to rise accordingly. It is expected that banks would pass on these higher rates to borrowers. However, raising mortgage rates excessively could elevate the likelihood of default among risky borrowers. Indeed, the recent Milliman Mortgage Default Index (MMDI), which measures a lifetime default rate[13] estimated at the loan level for a portfolio of single-family mortgages, revealed that the default risk for loans acquired by government-sponsored enterprises Freddie Mac and Fannie Mae rose to 2.39% in Q1 2022 from 1.90% in Q4 2021, which implies that 2.39% of the loans originated in Q1 are expected to become delinquent (180 days or more) over their lifetimes. From the perspective of lenders, they face a trade-off between the advantage of reducing the burden of debt

[13]For example, if the MMDI is 10%, then we expect 10% of the mortgages originated in that month to become 180 days or more delinquent over their lifetimes.

and the output losses incurred in the event of default (as discussed in Arellano, 2008). Hence, the higher the interest rate, the greater the incentive for borrowers to default. As a result, banks may opt to limit credit availability during periods of high-interest rates, restricting access to credit for certain consumers. This, in turn, leads to a larger decline in housing demand, thereby amplifying the impact of contractionary monetary policy. On the other hand, an expansionary policy does not necessarily stimulate borrowing if economic conditions have weakened demand. Unlike tight monetary policy, declining mortgage rates reduce default risk, making it a less constraining factor for consumers.

2.3.2 Estimation

The baseline framework employed in this study investigates the symmetric role of monetary policy disturbances, as measured by high-frequency instruments from three different approaches, as discussed in Section 2.2. To conduct the analysis, I adopt the local projections method proposed by Jordà (2005). This approach allows for the estimation of the average dynamic effect of a monetary policy shock on house prices on a monthly basis. The methodology involves directly regressing future house prices on the identified monetary policy shock while controlling for other relevant macroeconomic variables.

Let $y_{j,t}$ denote a house market index of the sales price in division j on month t. The house price index utilized in this analysis is sourced from the Federal Housing Finance Agency, specifically from repeat mortgage transactions since January 1975 on single-family properties whose mortgages have been purchased or securitized by Fannie Mae or Freddie Mac. This index represents a weighted repeat sales index, measuring the average price changes in repeat sales or refinancing of the same properties. The index is classified into nine census divisions: Pacific, Mountain, West North Central, West South Central, East North Central, East South Central, New England, Middle Atlantic, and South Atlantic. To account for inflation, I deflate the prices using the headline Consumer Price Index at month t.

Let S_t denote a high-frequency measure of an identified monetary policy surprise in month t.

High-frequency surprises are aggregated at monthly frequency.[14] In three-dimension specification, for instance, S_t is a vector of three factors — FFR_t, FWG_t, $LSAP_t$ — which capture the surprise changes in the federal funds rate, forward guidance, and large-scale asset purchases, respectively. Given the high-frequency instruments measured using different schemes discussed in Section 2, Jordà (2005),s local projection method estimates the average effect of a monetary policy shock on house prices at horizon $t + h$ on the shock in period t. For each horizon $h = 0, 1, ..., H$, I estimate the following empirical specification over the sample period, 1991 to 2018,

$$ln(y_{j,t+h}) = \alpha_h + \beta_{j,h} + \gamma_h S_t + \psi_{j,h}(L) Z_t + \varepsilon_{j,t} \tag{2.5}$$

where $ln(y_{j,t+h})$ is the log of real house prices over h months after the shock in month t in division j, Z is a vector of control variables, $\psi(L)$ is a polynomial in the lag operator, $\beta_{j,h}$ is regional fixed effects over h month, and $\varepsilon_{j,t}$ is the error term, assumed to be heteroskedastic, independent across regions j, and serially correlated. Specifically, the term $\psi(L)$ is a polynomial of order four.[15] The vector of endogenous variables, Z, consists of real industrial production (IP), the unemployment rate, the consumer price index (CPI), the real house price index, the average 10-Year Baa corporate credit spread, the excess bond premium, the 30-Year fixed rate mortgage rate, and the market yield on Treasury bonds at 2-Year maturity.[16] Variables enter the specification in log levels, with the exception of interest rates and credit spreads. Most of the relevant data can be obtained from the Federal Reserve Bank of St Louis database (FRED) and the Federal Housing Finance Agency (FHFA).

By keeping the composition of the variables of interest fixed across the three specifications, I estimate equation (2.5) on a monthly basis for the sample period January 1991 through December 2018 by fixed-effects panel regression method with Newey-West standard errors as described in

[14] Miranda-Agrippino and Ricco (2021) defined an instrument as the sum within the month of all the surprises registered. On the other hand, the monthly instrument of Gertler and Karadi (2015) accounts for the date of the FOMC meeting within the month and weights the surprises by assuming a month duration for each event. In the analysis, I follow Miranda-Agrippino and Ricco (2021)'s approach.

[15] The estimation results are robust to include the contemporaneous value of the control variables to preserve the recursiveness assumption.

[16] I do not employ the federal funds rate since the sample in the analysis includes the zero lower bound period.

Silvia and Giovanni (2019). The main coefficient of interest γ_h gives the average response of house prices at time $t + h$ to the monetary policy shock at time t. The identifying assumption is that the monetary policy shock in t is orthogonal to other variables that influence the housing index over the h-month horizon after the shock. Note that all coefficients are h-horizon-specific. Thus, one constructs the impulse responses as a sequence of the γ_hs estimated in a series of single regressions[17] for each horizon. The linear projections method of estimating impulse responses has several advantages over vector autoregression or other time-series methods applied to aggregate house prices (Hamilton, 2008). First, I use the series on monetary policy surprises estimated using a high-frequency approach. The series are plausibly exogenous, and therefore, I can use them directly in our analysis, bypassing endogeneity concerns. Second, impulse responses are not functions of the structural parameters and hence are less sensitive to model misspecification.

In the following section, I compare the average impacts of three distinct measures of monetary policy surprises on house prices within a local projections framework. Specifically, I analyze these effects while considering the inclusion of controls for the predictability of high-frequency measures, described in Section 2.2. To further address the mechanism behind the house price responses to the monetary policy shocks, Section 2.4 demonstrates that surprises to the expected future interest rates affect house prices by raising long-term interest rates and mortgage rates. To illustrate the credit channel, the dependent variable in the equation (2.5) is substituted with a 2-year treasury yield and a 30-year fixed-rate mortgage for each estimation.

2.4 House price responses to monetary policy shocks

In this section, I make two contributions relative to previous empirical studies. First, the main difference of the analysis is using three different approaches of measures of monetary policy surprises that are orthogonal to macroeconomic and financial data observed before the announcement to predict the effects of monetary policy announcements on real house prices. This chapter demonstrates that monetary surprises resulting from large-scale asset purchases play a significant role in

[17] Section 2.5 examines the estimation of non-linear responses of house prices to the monetary policy shock depending on its direction, i.e., Expansionary monetary policy shock v.s. Contractionary monetary policy shock.

housing market adjustments. Second, to explain the mechanism behind the responses of real house prices, this section considers the effects of monetary policy surprises not only on 2-Year Treasury yields but also on 30-Year Fixed-Rate mortgages. High-frequency measures of the form (2.5) are utilized for each variable.

2.4.1 Baseline responses

The solid black line in each panel in Figure 2.2 illustrates the estimated impulse response of the real house prices to a contractionary one-standard-deviation increase in two different measures: the unadjusted high-frequency monetary policy measure (left panel) and the high-frequency change in monetary policy shocks orthogonalized with respect to economic and financial variables prior to the announcement (right panel). The shaded gray regions represent the corresponding 68% standard-error bands around those point estimates. These responses are estimated using the One-Factor model specification similar to Bauer and Swanson (2022) based on the sample period from January 1991 to June 2018.

Figure 2.2 implies two important findings. Firstly, the responses of real house prices to factors associated with surprises to interest rates less than a year - unadjusted and orthogonal monetary policy shocks - are negative and significant: the real house prices fall by 0.3 and 0.2 percentage points, respectively, within 6-30 months after the shock. By contrast, the speed of convergence of the real house price responses to the unadjusted surprise is comparable to the reactions to the orthogonal surprises. The near-term effect of the contractionary monetary policy shocks causes the real house prices to decline about 0.2 percentage points within 30 months in both panels in Figure 2.2. However, the key difference is that the persistence of the real house price response is much lower in the right panel, reverting to a steady state in less than three years rather than four years. The result is consistent with the finding demonstrated by Bauer and Swanson (2022), which shows that the persistence of the two-year Treasury yield response is much lower if using orthogonalized monetary policy surprises rather than unadjusted surprises. This is intuitive if we think of economic data as being persistent so that the Fed's response to that data leads to an upwardly biased estimate of interest rate persistence. The result implies that faster adjustment in interest rates responses by

Figure 2.2: Responses of real house prices to monetary policy shocks, One-Factor model

Note: The solid black line in each panel depicts the impulse response of the house price index to a one-standard-deviation increase in the unadjusted high-frequency monetary policy measure (left) and the high-frequency change in monetary policy shocks orthogonalized with respect to economic and financial variables prior to the announcement (right). Shaded regions report the associated 68% confidence intervals. Responses are estimated using specifications in the One-Factor model based on the sample from 1991 to 2018. See text for details.

projecting out several economic and financial variables that can be predicted by the market before the FOMC announcement would lead to lower persistent responses of real house prices.

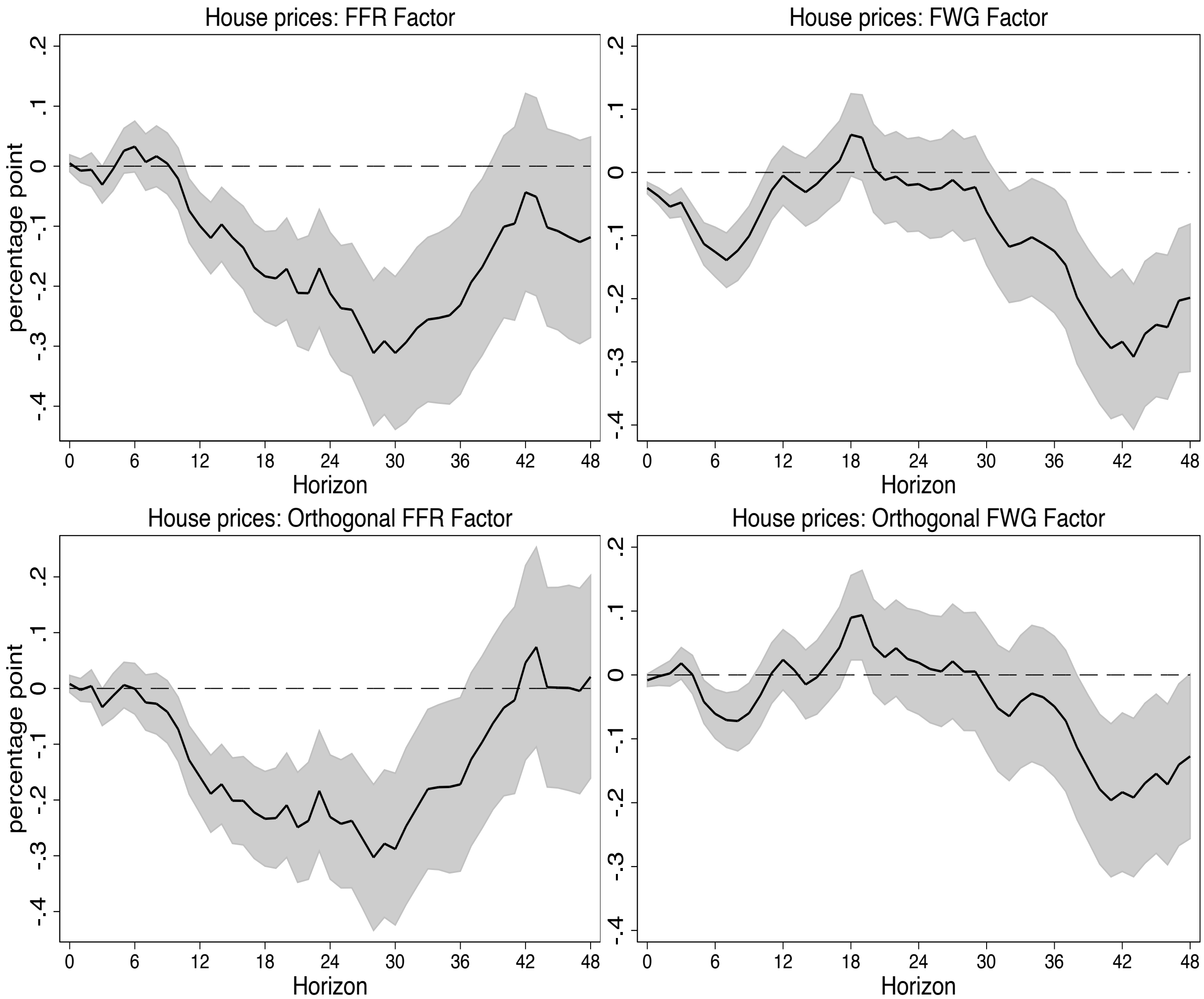
While Figure 2.2 shows the real house prices responses to the monetary surprises identified through the One-Factor model described by Bauer and Swanson (2022), Figure 2.3 reports the responses to two factors - the Federal funds rate factor and Forward guidance factor - estimated through the Two-Factors model following Gürkaynak et al. (2005a) for the baseline full sample from Figure 2.2. The left column in Figure 2.3 provides impulse response functions of the real house prices to a contractionary one-standard deviation in the federal funds rate factor using the unadjusted high-frequency monetary policy surprise (top) and orthogonal monetary policy surprise (bottom). The right column reports results for the same specification but using the forward guidance factor.

One noteworthy aspect of the results from the Two-Factor model is that similar to the observations in the One-Factor model, orthogonal monetary policy shocks continue to exert a strong influence on the persistence of house price responses. In the bottom two panels, the persistence of real house price responses to both the Federal funds rate factor and the forward guidance factor is notably lower, returning to its steady state in less than four years instead of six years. Overall, it is evident that the two figures in the first row, depicting the impulse responses of unadjusted monetary shocks, are generally biased upward when compared to the two figures in the second row, illustrating the impulse responses of orthogonal monetary shocks.

Another point worth noting in Figure 2.3 is that the magnitudes of the real house price responses to the Federal funds rate factor are similar to those of the forward guidance factor, but the timing of the real house price responses differs for each shock. The real house price response to a one-standard-deviation increase in the orthogonal Federal funds rate factor is immediate and significant. The response persists for six months upon impact and then gradually declines, reaching a trough response of approximately -0.3 percentage points about two years and a half after the shock before returning towards a steady state. On the other hand, the real house price responses to the forward guidance factor show limited sensitivity for up to two years following the shock. The response remains at its steady state for two years upon impact and then begins to decline significantly, with a trough response of about -0.2 percentage points within one year, gradually reverting over the subsequent years.

Overall, Figure 2.3 demonstrates that the results remain largely consistent with Figure 2.2. The high-frequency monetary policy measures in Figure 2.3 are constructed using a range of Federal

Figure 2.3: Responses of real house prices to monetary policy shocks, Two-Factors model



Note: The solid black line in each panel depicts the impulse response of the house price index to a one-standard-deviation increase in the federal funds rate factor (left) and forward guidance factor (right). Shaded regions report the associated 68% confidence intervals. Responses are estimated using specifications in the Two-Factors model based on the sample from 1991 to 2018. See text for details.

funds rates and Eurodollar futures with maturities of up to one year. As a result, the responses using the monetary policy shock outlined in Bauer and Swanson (2022) represent a weighted average of the responses to the Federal funds rate and forward guidance factors.

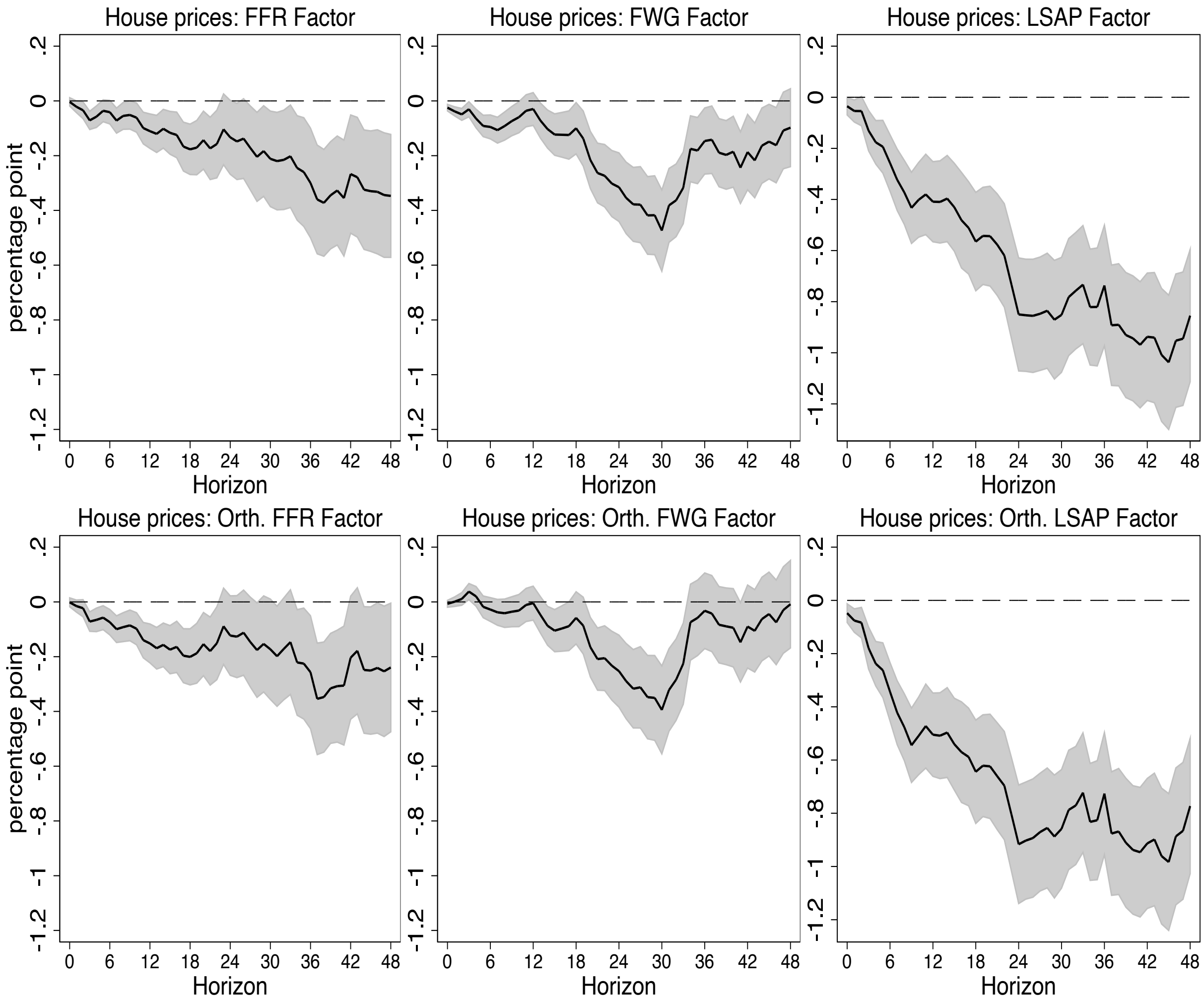
Next, I focus on the key findings of this study. Figure 2.4 presents the estimated responses of real house prices to contractionary one-standard-deviation impulses for three monetary policy shocks, as estimated by the Three-Factors model outlined in Swanson (2021)[18], using data from January 1991 to June 2018. Each panel in Figure 2.4 displays the average impulse response of real house prices to the Federal funds rate factor (left), forward guidance factor (middle), and large-scale-asset-purchase factor (right) using solid lines. The upper three panels illustrate the responses of real house prices to unadjusted monetary policy shocks, while the lower three panels depict the responses to orthogonal monetary policy shocks.

The results depicted in the first and second columns of Figure 2.4 exhibit similarities to those presented in Figure 2.3, which are not surprising given the similar specification employed, although there are slight differences in the measurement of high-frequency monetary policy surprises and the inclusion of additional long-term market interest rate variables to decompose the shocks into three factors structurally. Notably, the response of real house prices to a one-standard-deviation increase in the orthogonal Federal funds rate factor gradually declines over three years, reaching a trough response of approximately -0.37 percentage points about three years after the shock before returning to its steady state. Similarly, the response of real house prices to the forward guidance factor shows insensitivity for up to eighteen months after the shock, followed by a significant decline. After thirty months, there is a trough response of about -0.4 percentage points, with an immediate return to the steady state. Hence, Figure 2.4 provides robust evidence that the magnitudes of real house price responses to the Federal funds rate factor are comparable to those of the forward guidance factor, but the timing of the responses differs.

The primary takeaway from Figure 2.4 is that the responses associated with surprises in long-term future interest rates, represented by the LSAP factor, exhibit a negative, long-lasting, and most significant impact compared to the responses to the Federal funds rate and forward guidance factors. The real house prices experience an immediate drop upon impact and subsequently sharply decline by 0.9 percentage points within two years. They remain at approximately that level for several years before reverting back to a steady state. In contrast, the responses to unexpected changes in current and future short-term interest rates, represented by the Federal funds rate and

[18] The contractionary impulse is an increase in the Federal funds rate (FFR) and Forward guidance (FG) factors and a decrease in the Large-Scale asset purchase (LSAP) factor.

Figure 2.4: Responses of real house prices to monetary policy shocks, Three-Factors model



Note: The solid black line in each panel depicts the impulse response of the (log) house price index to a one-standard-deviation increase in the federal funds rate factor (left), forward guidance factor (middle), and negative of large-scale-asset-purchasing factor (right). Shaded regions report the associated 68% confidence intervals. Responses are estimated using specifications in model Three-Factors model based on the sample from 1991 to 2018. See text for details.

forward guidance factors, are negative but less significant than the LSAP factor. The average effect size on real house prices resulting from both the Federal funds rate factor and forward guidance factor is around -0.2 percentage points within four years, considerably smaller than the impact of approximately -0.7 percentage points within four years caused by the LSAP factor. This stronger impulse response to the LSAP factor aligns with intuition if we consider houses as illiquid and high-cost durables, indicating that house prices are more responsive to surprises in the slope of the long-term yield curve rather than the current or short-term level.

2.4.2 The response of market interest rates to monetary surprises

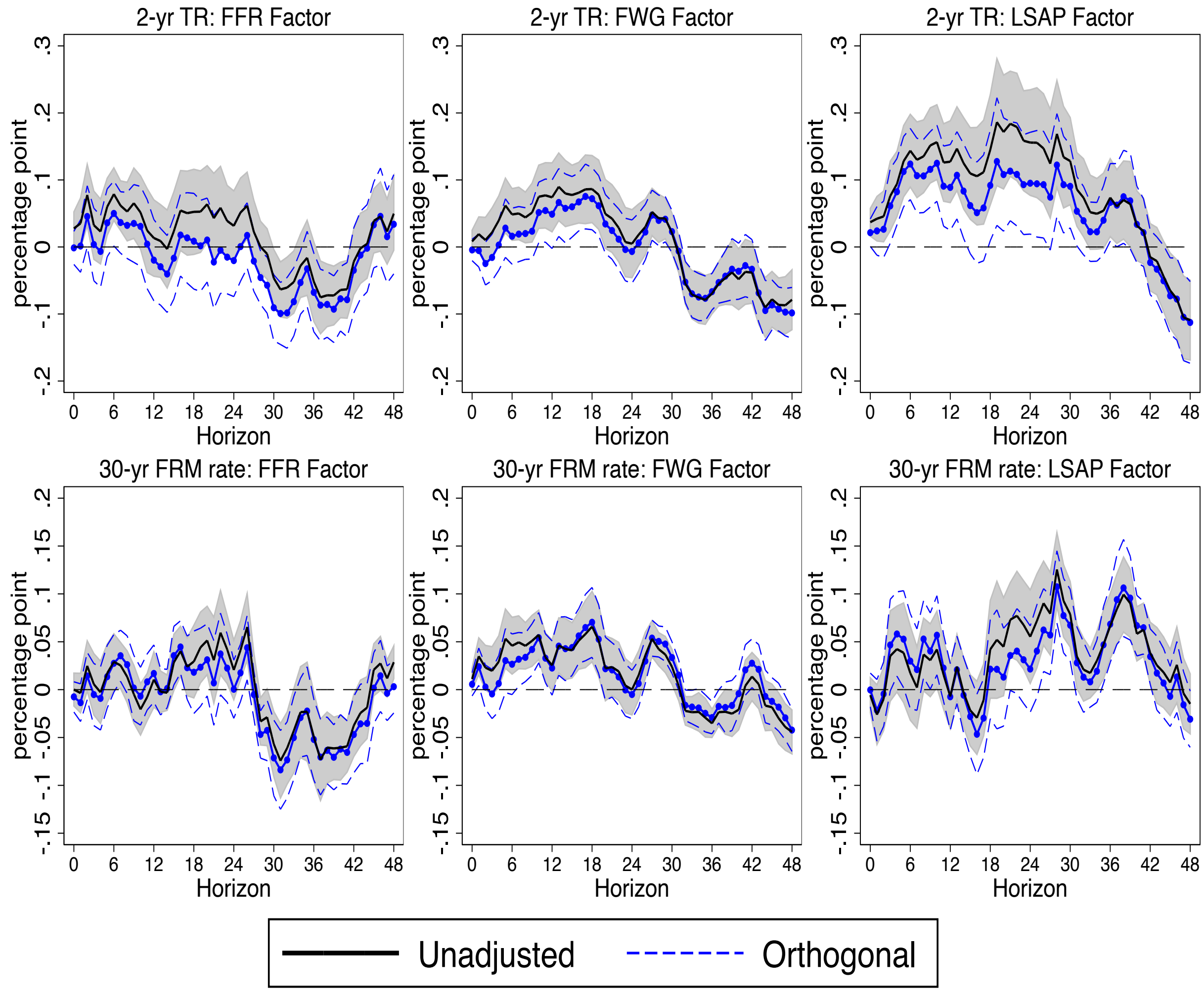
The empirical baseline results from estimating panel local projections in section 4.1 provide that in response to monetary policy tightening surprises, the real house prices fall after the monetary policy announcement. In this section, to obtain a mechanism behind the house price responses, I estimate the same specification as in (2.5), replacing the dependant variable with the 2-year Treasury yield or 30-year fixed rate mortgage, and demonstrate that surprises to the expected future interest rates affect house prices by raising mortgage rates. Higher mortgage rates reduce the availability of credit, cooling housing demand, especially from financially constrained households.

Figure 2.5 provides the responses of two market interest rates. The top three panels illustrate the impulse responses of the market yield on treasury securities with a constant maturity of 2 years to a one-standard-deviation increase in three factors: the federal funds rate factor (left), the forward guidance factor (middle), and the negative of the large-scale-asset-purchasing factor (right). The bottom three display the impulse responses of 30-year fixed-rate mortgage rates. In each panel, the solid black line represents the responses to the unadjusted high-frequency monetary policy measure, while the blue dotted line indicates the responses to the high-frequency change in monetary policy shocks orthogonalized with respect to economic and financial variables prior to the announcement. The shaded regions and blue dashed areas indicate the associated 68% confidence intervals. The responses were estimated using the Three-Factors model[19] specification based on the sample period from 1991 to 2018.

In response to a surprise about long-term future interest rates, captured by the large-scale asset purchasing factor, 2-Year Treasury yields increase by around 0.2 percentage points within six months and remain at that level for several years. In addition, the response to a policy surprise

[19]Appendix Figure A.7 through A.10 provide the responses of 2-Year Treasury yields and 30-Year fixed-rate mortgages to monetary policy surprises using One-Factor and Two-Factors models, and they are all very similar to those in Figure 2.5.

Figure 2.5: Responses of interest rates to monetary policy shocks, Three-Factors model



Note: The first row depicts the impulse responses of the market yield on treasury securities at 2-Year constant maturity to a one-standard-deviation increase in the federal funds rate factor (left), forward guidance factor (middle), and negative of large-scale-asset-purchasing factor (right), while the second row shows the impulse responses of the 30-Year fixed-rate mortgage rates. The solid black line in each panel represents the responses to the unadjusted high-frequency monetary policy measure while the blue dotted line in each panel shows the responses to the high-frequency change in monetary policy shocks orthogonalized with respect to economic and financial variables prior to the announcement. Shaded regions and blue dashed areas report the associated 68% confidence intervals. Responses are estimated using specifications in the Three-Factors model based on the sample from 1991 to 2018. See text for details.

associated with short-term future interest rates, captured by the forward guidance, rises around 0.08 percentage points within one year. By contrast, the response of 2-Year Treasury yields to the level surprise is close to zero, and the estimated coefficients are not statistically different from zero based on 68 percent confidence intervals with robust standard errors. The responses of mortgage rates to monetary surprises, as illustrated in the bottom three panels, also align with the top three panels in Figure 2.5. In response to a surprise about long-term future interest rates, 30-Year fixed-rate mortgages increased by around 0.05 percentage points within six months and reached their peak of about 0.1 percentage points 30 months after the shock. The effects of monetary policy surprise associated with the forward guidance factor are positive and significant. The 30-Year fixed-rate mortgages rise by 0.05 percentage points within one year after the shock. In contrast, the response to the monetary surprise associated with the Federal funds rate factor is not significantly different from zero. The results in Figure 2.5 are consistent with the findings in Hamilton (2008). Based on data from 2006, Hamilton (2008) demonstrates that changes in information about the level and slope of the federal funds rate are positively correlated with 30-year mortgage rates, with slope effects 2.6 times stronger than level effects. Hamilton argues that the mortgage rate response materializes as markets realize the changes in the path of the federal funds rate.

Overall, the empirical results provided in this section can be stylized in three aspects. First, the persistence of real house price responses to orthogonal monetary policy shock is much lower than those to unadjusted monetary policy shock. Second, the average size of the effect on real house prices to Federal funds rate and forward guidance factors are comparatively small (0.3 percentage points on average within 48 months after the shock) and similar to each other, whereas the large-scale asset purchasing factor a stronger impact (one percentage point on average within 48 months after the shock) on real house price dynamics than others. Last, the responses of 2-Year Treasury yields and mortgage rates to monetary surprises align with the baseline results where the real house prices react strongly to surprises about long-term future interest rates and are less sensitive to short-term and current interest rate shocks. Hamilton (2008) and Gorea et al. (2022) suggest monetary surprises affect house prices primarily via mortgage rates. The finding that increases in mortgage rates tend to lower house prices via house financing channels is well documented in the literature. Rising mortgage rates make house financing more expensive by tightening debt-to-income or loan-to-value constraints and lead to lower demand for housing (Anenberg and Kung, 2017; Favilukis et al., 2017; Greenwald, 2018; Garriga et al., 2017; Bhutta and Ringo, 2021). In anticipation of the fall in demand, home sellers lower their prices. Garriga et al. (2019) show that prices respond not only to changes in interest rates but also to changes in expected future financial conditions.

2.5 Non-Linear effects of monetary policy shocks

The analysis presented in Section 2.3 outlines a supply-demand framework for the durable housing market, suggesting that contractionary monetary policy shocks are expected to exert a larger average impact on house prices compared to expansionary shocks. This is attributed to the downward rigidity of the housing supply. In order to examine the empirical validity of these hypotheses, Section 2.5.1 details the baseline empirical specification employed, while Section 2.5.2 documents the empirical findings on the asymmetric effects of monetary policy.

2.5.1 Policy-Dependent model

In this analysis, I employ a reduced-form version of the policy-dependent model, incorporating various high-frequency measures of monetary policy shock, as discussed in Section 2.2. Following a consistent approach, the baseline equation follows the local projection framework introduced by Jordà (2005), as outlined in Section 2.3. This framework enables the estimation of the response of house prices after a monetary policy shock over a period of h months. The advantage of utilizing the local projection approach is its ability to capture the non-linear effects of monetary policy, which would be complex and possibly unfeasible within a standard VAR framework. Furthermore, the parameters of interest, namely the impulse-response functions of house prices following a monetary policy shock, are encapsulated within a single equation in the underlying VAR system, specifically the house price equation.

The empirical specification takes the following form over the period 1991 to 2018: For each $h = 0, 1, ..., H$,

$$ln(y_{j,t+h}) = \alpha_h + \beta_{j,h} + \gamma_h^E S_t^E + \gamma_h^C S_t^C + \psi_{j,h}(L)Z_t + \varepsilon_{j,t} \tag{2.6}$$

where $ln(y_{j,t+h})$ represents the natural logarithm of the house market index h months after the shock occurring in month t in region j, $\beta_{j,h}$ represents the regional fixed effects for the corresponding h month period. $\psi(L)$ denotes a fourth-order lag polynomial, Z represents a vector of control variables that includes the same set of endogenous variables described in Section 2.3.2, and $\varepsilon_{j,t}$ represents the error term, assumed to be heteroskedastic, independent across regions j, and serially correlated.

The vector S_t represents the factors estimated as identified monetary policy surprises aggregated within month t. In the three-dimensional model, S_t comprises three factors: FFR_t capturing surprise changes in the federal funds rate, FWG_t representing surprise changes in forward guidance, and $LSAP_t$ accounting for surprise changes in large-scale asset purchases. On the other hand, in the two-dimensional model, S_t consists of two factors: FFR_t and FWG_t, capturing surprise changes in the federal funds rate and forward guidance, respectively. In the one-dimensional model, S_t corresponds to the principal component estimated using equation (2.1). In particular, the vector S_t^C denotes a variable measuring contractionary shocks, and it is defined as $S_t^C = S_t \times I(S_t > 0)$, where $I(S_t > 0)$ is an indicator function taking the value one for contractionary monetary policy shocks. Expansionary shocks are measured by $S_t^E = S_t \times (1 - I(S_t > 0))$. Neither expansionary nor contractionary shocks if the indicator variable takes a value of zero otherwise.

Maintaining a consistent set of variables of interest across the three specifications, I estimate equation (2.6) on a monthly basis for the period from January 1991 to June 2018. The estimation is conducted using the fixed-effects panel regression method, and Newey-West standard errors are employed. In this specification, γ_h^E represents the average response of house prices h months after an expansionary monetary policy shock at time t, while γ_h^C quantifies the average effect of a contractionary monetary policy shock h months thereafter.

2.5.2 Asymmetric response of real house prices to monetary policy surprises

Note that one of the main purposes of this chapter is to answer the question of whether different monetary policy shocks are equally effective on the responses of real house prices. Based on the specification outlined in the previous section for estimating impulse responses of the real house prices to the monetary policy surprise, first, I provide empirical evidence for the policy-dependent model using the panel local projection method by applying data from January 1991 through June 2018, then describe there is a strong asymmetric response of real house prices in the U.S. housing market depending on the direction of monetary policy, contractionary monetary policy surprise has a more significant effect then expansionary policy shock.

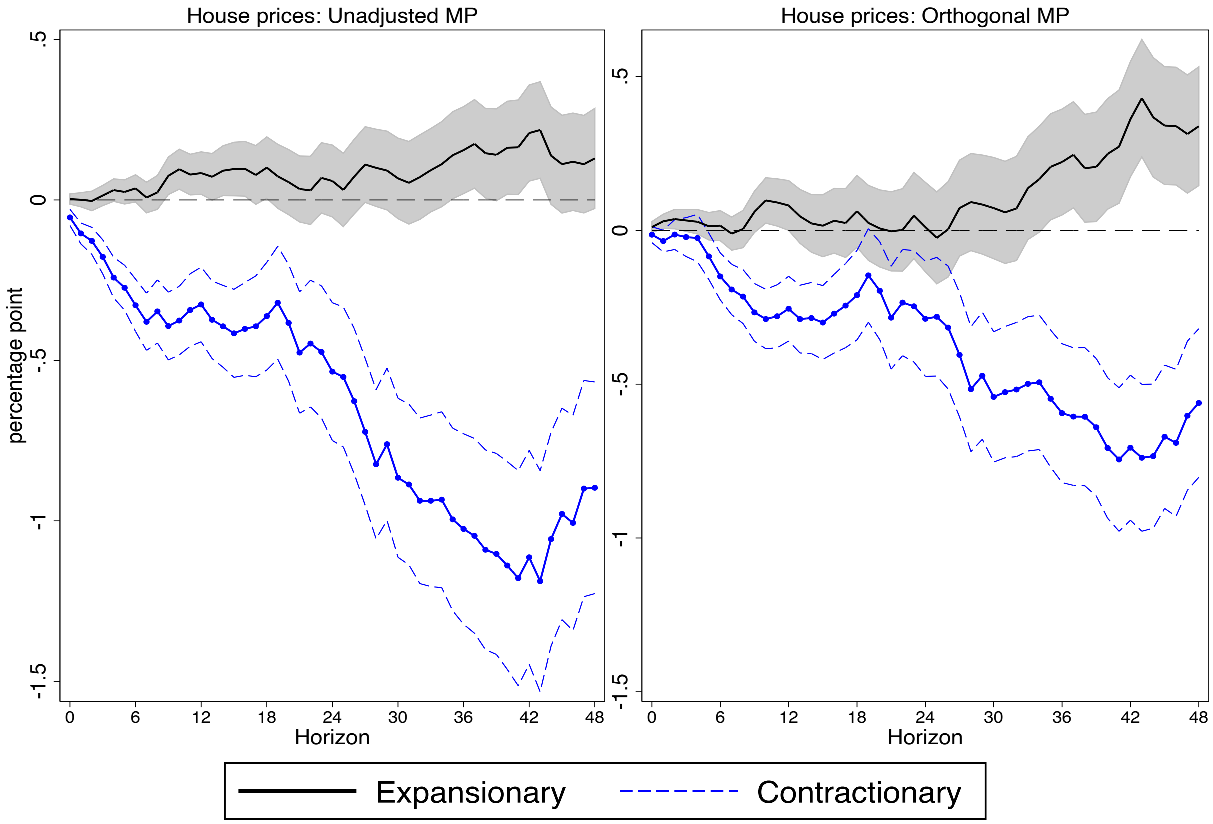
Figure 2.6 presents the impulse response functions of real house prices to high-frequency monetary policy disturbances identified using the One-Factor model. In each panel of Figure 2.6, the solid black line illustrates the impulse response of real house prices to a one-standard-deviation increase in the unadjusted high-frequency expansionary monetary policy shock on the left side. On the right side, it shows the impulse response to the high-frequency change in expansionary monetary policy shocks orthogonalized with respect to economic and financial variables prior to the announcement. The blue dotted line in each panel represents the responses to the contractionary monetary policy shock using the same specification. The shaded regions and dashed blue areas indicate the associated 68% confidence intervals.

The estimated results provide two important findings. Consistent with the conjecture in section 2.3, Figure 2.6 shows that contractionary monetary policy shocks lead to lower house prices. The responses of real house prices to factors associated with contractionary deviations to interest rates less than a year - unadjusted and orthogonal monetary policy shocks - are negative and significant: the real house prices fall by more than 0.5 percentage points within 24-30 months after the shock. In contrast, the responses of real house prices to expansionary monetary policy shock are quantitatively small[20] and close to zero up to 30 months in both cases.

Another point to note is that the convergence speed and the magnitude of the real house price responses to the unadjusted policy surprise are comparable to the responses to the orthogonal policy surprises for each direction of monetary policy. In particular, the effect of the contractionary

[20]In case of the responses to orthogonal monetary policy shock, real house prices increase less than 0.5 percentage points at 42 months after the expansionary shock, which is still comparatively smaller than -0.75 percentage points for the contractionary shock.

Figure 2.6: Asymmetric responses of house prices to monetary policy shocks, One-Factors model



Note: The solid black (blue) line in each panel depicts the impulse response of the house price index to a one-standard-deviation increase in the unadjusted high-frequency expansionary (contractionary) monetary policy shock (left) and the high-frequency change in expansionary (contractionary) monetary policy shocks orthogonalized with respect to economic and financial variables prior to the announcement (right). Shaded regions and dashed blue areas report the associated 68% confidence intervals. Responses are estimated using specifications in the One-Factor model based on the sample from 1991 to 2018. See text for details.

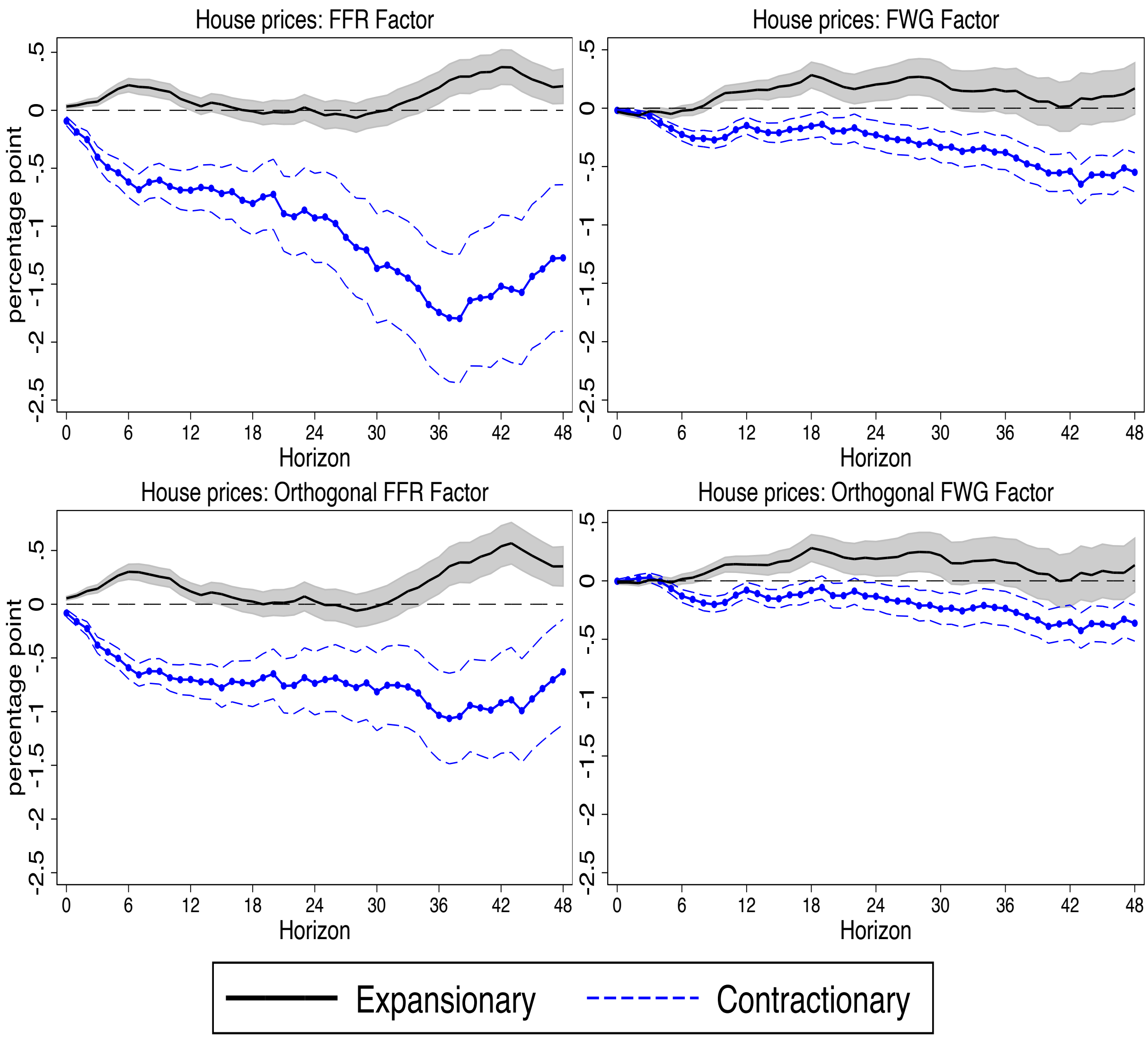
orthogonal monetary policy shocks causes the real house prices to decline about 0.3 percentage points within two years and then gradually decline, with a trough response of about -0.7 percentage points at 42 months. By contrast, the response of the contractionary unadjusted policy surprises leads the prices to decrease around 0.5 percentage points within two years and reach -1.23 percentage points at 42 months. In general, the blue dotted line in the left column is biased downward compared to that in the right column, which implies that the faster adjustment in interest rates responses by projecting out several economic and financial variables that the market can predict before the FOMC announcement would lead to lower persistent responses of real house prices.

While Figure 2.6 shows the real house prices responses to the monetary surprises identified through the One-Factor model, Figure 2.7 reports the responses to two factors - The federal funds rate factor and Forward guidance factor - estimated through the Two-Factors model. The left column in Figure 2.7 provides impulse response functions of the real house prices to one standard deviation in the federal funds rate factor using the unadjusted high-frequency monetary policy surprise (top) and orthogonal monetary policy surprise (bottom). The right column reports results for the same specification but using the forward guidance factor. In each panel, likewise, the solid black line illustrates the impulse response of real house prices to a one-standard-deviation increase in the high-frequency monetary policy shock, while the blue dotted line presents the response to a one-standard-deviation decrease in the policy surprise.

One aspect of the results from the Two-Factor model is that similar to the observations in the One-Factor model, orthogonal monetary policy shocks still strongly affect the persistence of real house price responses. Indeed, the size and persistence of real house price responses to the contractionary policy shocks associated with the Federal funds rate factor and the forward guidance factor are notably lower in the bottom two panels. Overall, Figure 2.7 demonstrates that the results remain largely consistent with Figure 2.6.

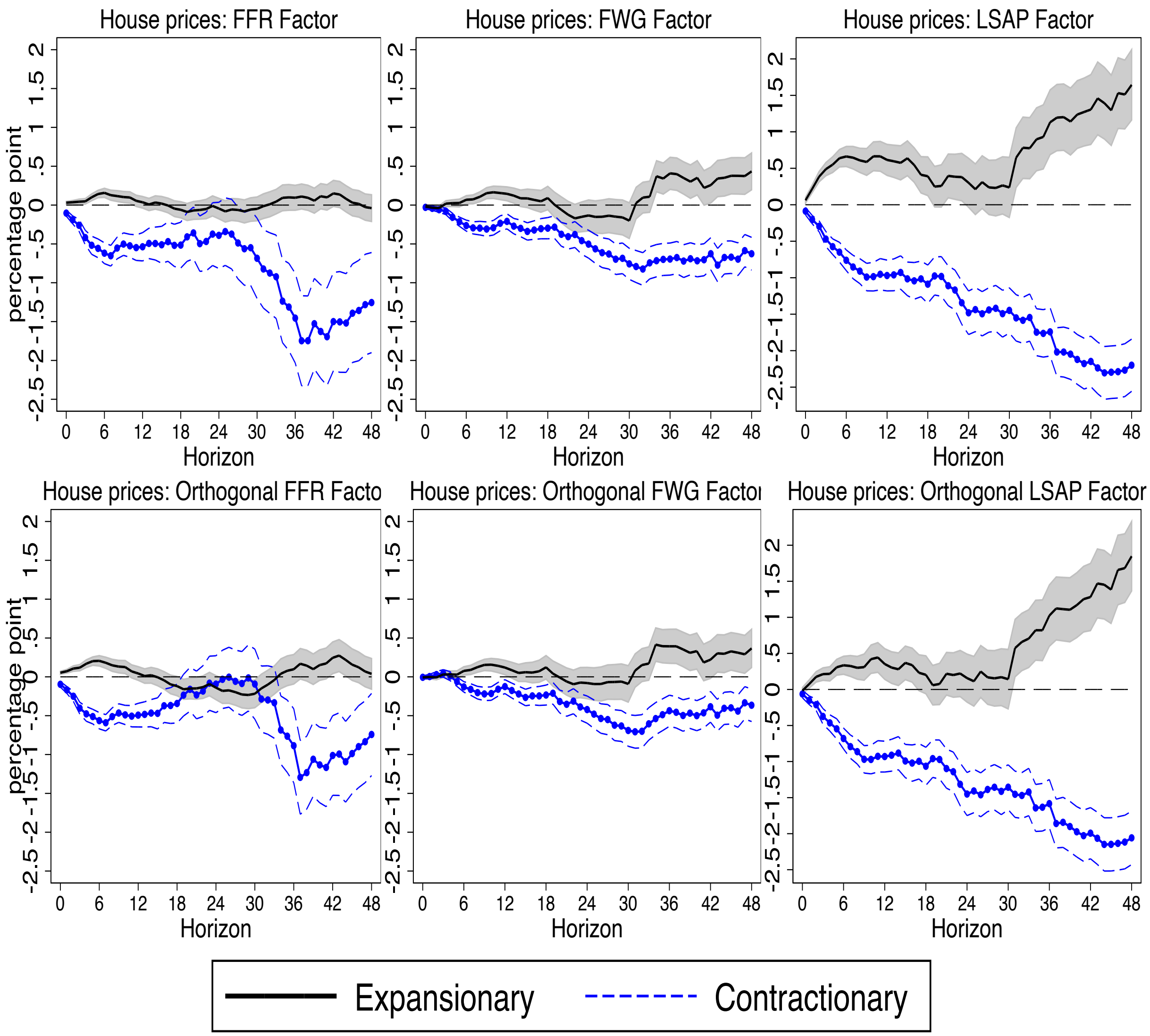
The empirical results remain robust to using alternative monetary policy shock measures. Figure 2.8 presents the estimated responses of real house prices to one-standard-deviation impulses for three monetary policy shocks. In each panel, the solid black line represents the impulse response of log house prices to a one-standard-deviation increase in the federal funds rate factor (left), forward guidance factor (middle), and negative of large-scale asset purchasing factor (right). The blue dotted line in each panel illustrates the response to a one-standard-deviation decrease in policy surprises for each factor. The top three panels display the effects of an unadjusted monetary policy shock, while the bottom three present the impact of an orthogonal monetary policy shock. The shaded regions and dashed blue areas indicate the associated 68 percent confidence intervals

Figure 2.7: Asymmetric responses of house prices to monetary policy shocks, Two-Factors model



Note: The solid black line in each panel depicts the impulse response of the house price index to a one-standard-deviation (positive) increase in the federal funds rate factor (left) and forward guidance factor (right), and the blue dotted line in each panel shows the response to the contractionary policy surprises for each factor. The first row shows the effects of unadjusted monetary policy shock, while the second row shows the effects of orthogonal monetary policy shock. Shaded regions and dashed blue areas report the associated 68% confidence intervals. Responses are estimated using specifications in the Two-Factors model based on the sample from 1991 to 2018. See text for details.

Figure 2.8: Asymmetric responses of house prices to monetary policy shocks, Three-Factors model



The solid black line in each panel depicts the impulse response of the (log) house price index to a one-standard-deviation (positive) increase in the federal funds rate factor (left), forward guidance factor (middle), and negative of large-scale-asset-purchasing factor (right), and the blue dotted line in each panel shows the response to the contractionary policy surprises for each factor. The first row shows the effects of unadjusted monetary policy shock, while the second row shows the effects of orthogonal monetary policy shock. Shaded regions and dashed blue areas report the associated 68% confidence intervals. Responses are estimated using specifications in the Three-Factors model based on the sample from 1991 to 2018. See text for details.

based on robust standard errors.

Interestingly, the key finding taken away in Figure 2.8 is that when examining the magnitude of the impact of each factor shock on real house prices, it can be observed that the response of all real house prices is stronger and more long-lasting in the case of contractionary monetary shocks. For example, looking at the first column, one standard deviation in the contractionary federal funds rate (FFR) factor leads to a decline of approximately 0.5 percentage points in real house prices within six months, gradually decreasing to around 1.5 percentage points after 36 months. However, in contrast, when an expansionary shock occurs, the changes in real house prices are not significantly different from zero for the entire horizon. This pattern is also evident in the case of the forward guidance factor and particularly pronounced when examining the response functions based on the Large-Scale Asset Purchases (LSAP) factor. In fact, looking at the third column, a one-standard-deviation in the contractionary LSAP factor surprise results in a rapid decrease of approximately one percentage point in real house prices within one year, gradually declining further to -2 percentage points after 45 months. On the other hand, when an expansionary shock occurs, real house prices exhibit a relatively muted response for up to 30 months and then show a rapid increase thereafter.

For more direct evidence, I calculate the cumulative responses of real house prices at horizons $h = 12$, 24, and 36. Regarding the Federal funds rate factor, the responses to expansionary shocks are 1.63 percentage points at $h = 12$, 0.57 percentage points at $h = 24$, and 0.37 percentage points at $h = 36$. However, the responses to contractionary shocks are -5.53 percentage points at $h = 12$, -9.03 percentage points at $h = 24$, and -12.57 percentage points at $h = 36$. By examining the cumulative responses at each horizon, it becomes evident that the absolute size of the responses to contractionary shocks is larger, indicating a greater influence of the shocks. Similarly, in the case of the FG factor, the responses to expansionary shocks are 0.94 percentage points at $h = 12$, 1.11 percentage points at $h = 24$, and 2.25 percentage points at $h = 36$. On the other hand, the responses to contractionary shocks are -1.20 percentage points at $h = 12$, -4.60 percentage points at $h = 24$, and -11.59 percentage points at $h = 36$.

The size of the response functions depending on the direction of monetary policy is even more pronounced in the LSAP factor. In the case of the LSAP factor, the responses to expansionary shocks are 3.46 percentage points at $h = 12$, 6.11 percentage points at $h = 24$, and 11.71 percentage points at $h = 36$. In contrast, the responses to contractionary shocks are -7.95 percentage points at $h = 12$, -20.76 percentage points at $h = 24$, and -38.35 percentage points at $h = 36$. Overall, these results clearly demonstrate that the response of real house prices varies significantly depending on the type of monetary policy shock, especially contractionary monetary policy has a significantly stronger effect on house prices than an expansionary monetary policy, which is in line with the findings discussed in Glaeser and Gyourko (2005), Tenreyro and Thwaites (2016), Barnichon and Matthes (2017), and Aastveit and Anundsen (2018).

2.6 Conclusion

This chapter analyzes the measure of high-frequency monetary policy shocks by extending the data of Gürkaynak et al. (2005a) by reviewing three measures of monetary policy surprises, the approach suggested by Bauer and Swanson (2022), Gürkaynak et al. (2005a), and Swanson (2021) to study the effects of monetary policy surprises in housing markets. The empirical results can be stylized in four aspects. First, the persistence of real house price responses to orthogonal monetary policy shock is much lower than those to unadjusted monetary policy shock. Second, the average size of the effect on real house prices to the federal funds rate and forward guidance factors are comparatively small and similar, whereas the large-scale asset purchases factor has a more substantial impact on real house price dynamics than the other two factors. Third, the responses of 2-Year Treasury yields and mortgage rates to monetary surprises align with the baseline results where the real house prices react strongly to surprises about long-term future interest rates and are less sensitive to short-term and current interest rate shocks. Finally, consistent with theoretical premier, the empirical result implies that contractionary shocks have a substantially greater and more persistent impact on real house prices.

The empirical results provided in this chapter also have important implications for central bank communication and the conduct of monetary policy. These suggest that monetary policies adjusting longer-term interest rates, such as quantitative easing, are more effective than shorter-term interest rates at stabilizing real house prices. In addition, the results directly affect the discussion on the trade-offs faced by monetary policymakers regarding real economic and financial stability. As documented in Tenreyro and Thwaites (2016) and Barnichon and Matthes (2017), a reduction in the interest rate is less effective in stimulating the real economy than an interest rate increase in dampening economic activity.

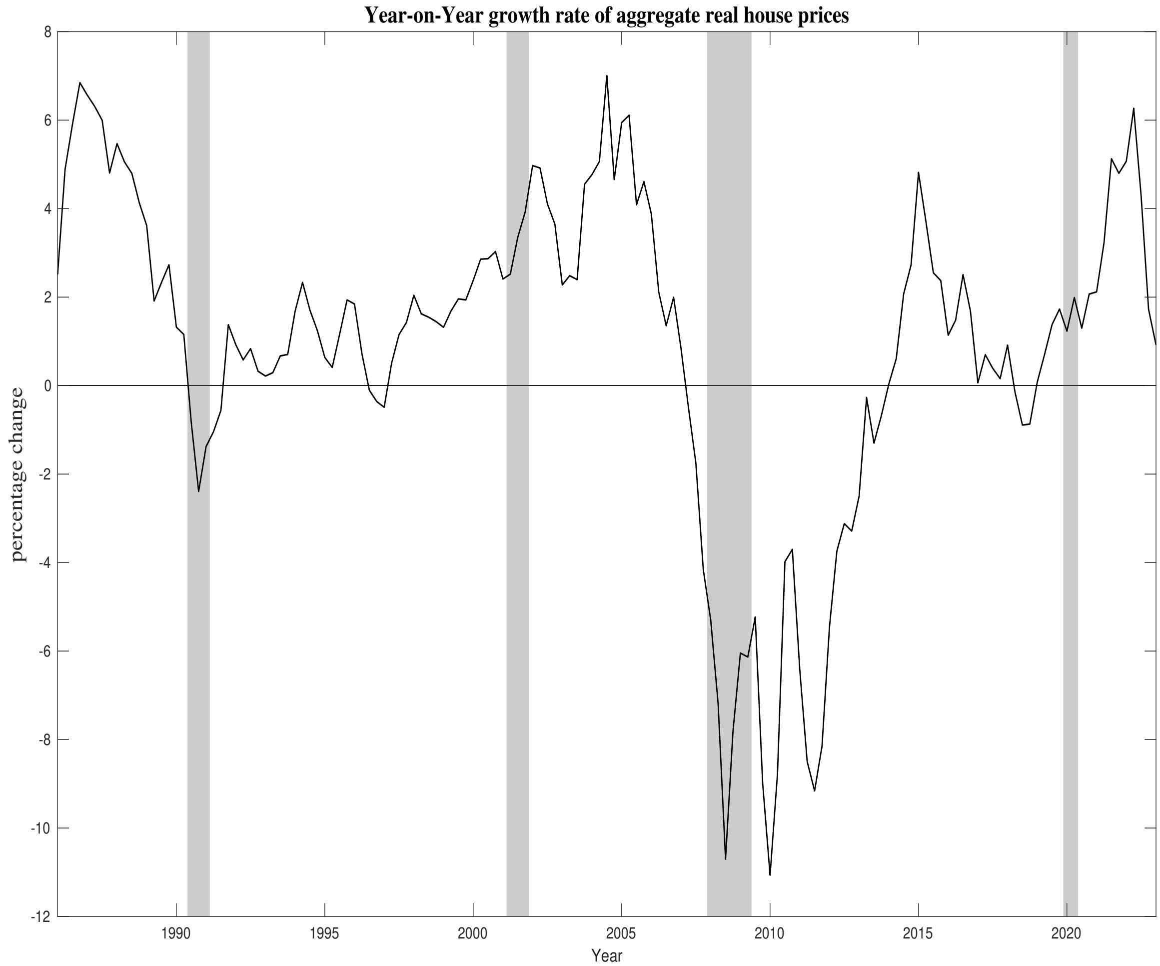
3. THE ROLE OF MACRO-POLICIES IN REGIONAL REAL HOUSE PRICE DYNAMICS

3.1 Introduction

Since the great financial crisis, it became clear that housing was more important than previously recognized. Real house prices in the United States rose by approximately 80% for the period from 1997 to 2006 but lost more than two-thirds of their gain between 2006 and 2012. In the wake of the short but steep COVID-19 recession, house prices have rebounded significantly from the housing crash of the late 2000s. Figure 3.1 shows the Year-on-Year growth rate of aggregate real house prices calculated using the Federal Housing Finance Agency (FHFA) seasonally adjusted purchase-only house price index deflated by the headline Consumer Price Index from 1976 to 2022. As can be seen in the figure, the recent rise in the annualized growth rate of real house prices has reached around 6% in 2021, which amount is compatible with the level in 2005. Recently, the literature has attributed the effects of the Pandemic on the housing market in the United States, discussed in Yoruk (2020), Balemi et al. (2021), Anenberg et al. (2021), and Liu and Su (2021). Indeed, the housing sector has gained much attention in the macroeconomics literature, as house prices have risen at unprecedented levels, hitting the peak increase of 19.3 percent in April 2022. The literature pointed out that this rise was the product of an unusual combination of positive housing demand shocks (a growing share of the population ages from 25 to 40 that typically buys homes), negative housing-supply shocks (a limited increase in the supply of houses for sale) and swift and decisive easing policies to support the economy.

Another point to note on the house price dynamics is that the fluctuation was even more dramatic in some regions or cities, with areas experiencing the most rapid price growth during the boom and also having the largest price declines during the bust. Associated with the studies about the regional heterogeneity in the housing market of the United States (U.S.), Del Negro and Otrok (2007) used a Bayesian dynamic factor model (DFM) to deduce the importance of the common component in the FHFA house price movements relative to state- or region-specific shocks, esti-

Figure 3.1: Annualized growth rates of real house prices from 1976 to 2022



Note: Shaded areas denote NBER-dated recessions.

mated on quarterly state-level data from 1986 to 2005. They found that, while movements in house prices have been mainly driven by the local component, the period of 2001 to 2005 was different in the sense that the overall increase in house prices was a national phenomenon, though "local bubbles" were important in some states. Align with the context of trying to explain the movement in overall U.S. house prices based on macroeconomic shocks, a recent study by Plakandaras et al. (2018) employed a Bayesian time-varying parameter VAR (TVP-VAR) covering the period of 1830 to 2016. Based on a model which identified (permanent) technology, price and financial(money) shocks, and (temporary) housing market-related demand/supply shocks, the authors found that technology shocks dominate in driving the U.S. housing market. This finding further corroborates the analysis of conditional volatilities and correlations with macroeconomic shocks. Interestingly, these results are in line with those obtained earlier by Iacoviello and Neri (2010) from a micro-founded dynamic stochastic general equilibrium (DSGE) model of the U.S. economy, which incorporated an explicit housing sector. Motivated by the findings of the existing literature, this chapter targets to address the question of whether the heterogeneous variation in house prices across the states in the U.S. reflects a national phenomenon or rather a regional-specific housing market, aiming to revisit the work of Del Negro and Otrok (2007), based on expanded quarterly data covering for the Covid period from 1975 to 2022 and what extent to which the national component can account for the variation in real prices in the U.S. housing market over the period.

The rest of the chapter is structured as follows. Section 3.2 introduces the statistical methodology to estimate the common component of fluctuations from the regionally specific fluctuation and describes the data used in the analysis. Section 3.3 presents the empirical results. Section 3.4 concludes and suggests political implications.

3.2 Models and data

This section describes a statistical model to distinguish the common component of fluctuations from state or region-specific fluctuations. In this step, I avoid making too many prior assumptions on the drivers of common fluctuations, letting the common factor be latent instead of prespecifying a number of regressors.

3.2.1 Specification of the dynamic factor model

In the prototypical dynamic factor model, all co-movement among variables in the data set is captured by a set of K latent variables, F_t. Let Y_t denote an $(N \times 1)$ vector of observable data. The dynamic factor model for this set can be written as,

$$Y_t = \Lambda F_t + \epsilon_t, \quad \text{where} \quad \epsilon_t = \Psi(L)\epsilon_{t-1} + u_t \tag{3.1}$$

with $E_t(u_t\, u_t') = \Omega$, and

$$F_t = \Phi(L) F_{t-1} + v_t \tag{3.2}$$

with $E_t(v_t\, v_t') = I_K$. Vector ϵ_t is an $(N \times 1)$ vector of idiosyncratic shocks that captures movement in each observable series specific to that time series. Each element of ϵ_t is assumed to follow an independent AR(q) process; hence $\Psi(L)$ is a block diagonal lag polynomial matrix, and Ω is a covariance matrix that is restricted to be diagonal. The latent factors are denoted by the $(K \times 1)$ vector F_t, whose dynamics follow an AR(p) process. The $(N \times K)$ matrix Λ contains the factor loadings, which measure the response of each observable variable to each factor.

3.2.2 An application of Multi-Level dynamic factor model to State-Level house prices

The parameters and factors of the model 3.1 and 3.2 can be estimated using non-parametric approaches via Bayesian methods[1], as in Kose et al. (2008). The model is used to differentiate the fluctuation in real house price indexes that are common across all states from those that are region- or state-specific. Specifically, the model supposes that the observable variables ($y_{n,t}$, $n = 1, ..., N, t = 1, ...T$), the demeaned growth rates in real state-level house price indexes, depending on a number of latent factors, which capture co-movement at the national (f_t^0), at the regional (f_t^r) level, as well as on state-specific shocks, $\epsilon_{n,t}$. The form of the dynamic factor model can be written as follows:

$$y_{n,t} = \lambda_n^0\, f_t^0 + \sum_{r=1}^{R} \lambda_n^r\, f_t^r + \epsilon_{n,t}, \tag{3.3}$$

where λ_n^r represents the exposure of state n to factor r. The model imposes the natural restriction that $\lambda_n^r = 0$ if state n does not belong to region r. The law of motions for the factors and for the state-specific shocks are given by an AR(q) and AR(p) process:

$$f_t^s = \phi_1^s f_{t-1}^s + \cdots + \phi_q^s f_{t-q}^s + u_t^s, \quad u_t^s \sim \mathrm{N}(0,1), \text{ for } s = 0, \cdots, R, \tag{3.4}$$

$$\epsilon_{n,t} = \phi_{n,1}\epsilon_{n,t-1} + \cdots + \phi_{n,p}\epsilon_{n,t-p} + u_{n,t}, \quad u_{n,t} \sim \mathrm{N}(0, \sigma_n^2). \tag{3.5}$$

[1]The Bayesian approach allows (but does not require) the imposition of restrictions on the factor loadings such that the model has a multi-level structure.

where the variance of the innovations u_t^s is normalized to one.

A key identification assumption that allows disentangling the factors from one another and from the state-specific shocks is that all innovations are mutually independent. Intuitively, the factor model disentangles the co-movement (f_t) and idiosyncratic fluctuations ($\epsilon_{n,t}$) apart. In order for this decomposition to be meaningful, the innovations to these different components need to be orthogonal:

$$E[u_t^s u_{n,t}] = 0, \quad \text{for all } s, n, t, \tag{3.6}$$

$$E[u_{n,t} u_{m,t}] = 0, \quad \text{for all } n, m, t. \tag{3.7}$$

If the innovation to the idiosyncratic components were correlated across series or with the factors, they would cease to be "idiosyncratic". One attempt to satisfy this assumption is to include local factors in the analysis, that is, to explicitly capture possible sources of co-movements across states. Likewise, I assume that innovations across factors are also orthogonal:

$$E[u_t^s u_t^r] = 0 \quad \text{for all } s, r, t, \tag{3.8}$$

otherwise, the distinction between national and regional factors would again lose its meaning.

An important question for this chapter is whether the widespread, but not homogeneous, fluctuation in real house prices reflects a national phenomenon or rather in the regional- or state-specific housing market. To answer this question, once the estimates of common factors are extracted from the statistical model, the analysis further decomposes movement in $y_{n,t}$ into fluctuations due to each of the three components, national, regional, and state-specific idiosyncratic component. Two statistics are used. The statistic ν_t computes the variance of fluctuations due to the national factor as the fraction of the sum of the variance of all three components across state n for each time t:

$$\nu_n(t_0, t_1) = \frac{\sum_{t=t_0}^{t_1} (\lambda_n^0 f_t^0)^2}{\sum_{t=t_0}^{t_1} (\lambda_n^0 f_t^0)^2 + \sum_{t=t_0}^{t_1} (\lambda_n^r f_t^r)^2 + \sum_{t=t_0}^{t_1} (\epsilon_{n,t})^2}. \tag{3.9}$$

This variance decomposition quantifies the relative importance of the national factor for the house price and is derived for each time t across the states n.

3.2.3 Description of the data

Most of the data can be obtained from the Federal Reserve Bank of St Louis database (FRED), Federal Housing Finance Agency (FHFA), and the Bank for International Settlements (BIS). The housing price index (1980=100) is published by the FHFA and captures changes in the value of single-family houses. It is a weighted repeat-sales index, meaning that it measures average price changes in repeat sales or refinancings on the same properties. The price information is obtained from repeat mortgage transactions on single-family properties whose mortgages have been purchased or securitized by Fannie Mae or Freddie Mac since January 1975. This chapter uses quarterly all-transaction indexes, which are built on the purchase-only index by adding prices from appraisal data obtained from the Enterprises. Although only non-seasonally adjusted housing price indexes (HPI) are available, and it has been criticized for its construction, it is the best data available to the public at the state level. The HPI data are deflated using the headline Consumer Price Index (CPI), which can be obtained from FRED. In summary, the real house prices consist of 47 years (188 quarters) of data, from 1976q1 to 2022q4, for the 48 contiguous U.S. states.

The regional specification outlined in 3.3 and 3.4 is defined by geography based on the U.S. Census Division. The model includes five geographical[2] regions. The first three regions are the Northeast, which includes the New England and Middle Atlantic divisions; the Mid-West region, which includes the East- and West-North-Central divisions; the West region, which includes the Mountains and the Pacific divisions. Further, the South is divided into two separate regions, Oil producing and Non-oil producing. The oil-producing region in the South includes the West-South-Central division (Arkansas, Louisiana, Oklahoma, and Texas); on the other, the non-oil-producing region includes South Atlantic and the East-South-Central (i.e., Alabama, Kentucky, Mississippi, and Tennessee).

[2]The analysis tests other specifications with nine regions based on the U.S. Census Division and obtained robust results.

3.3 Empirical results

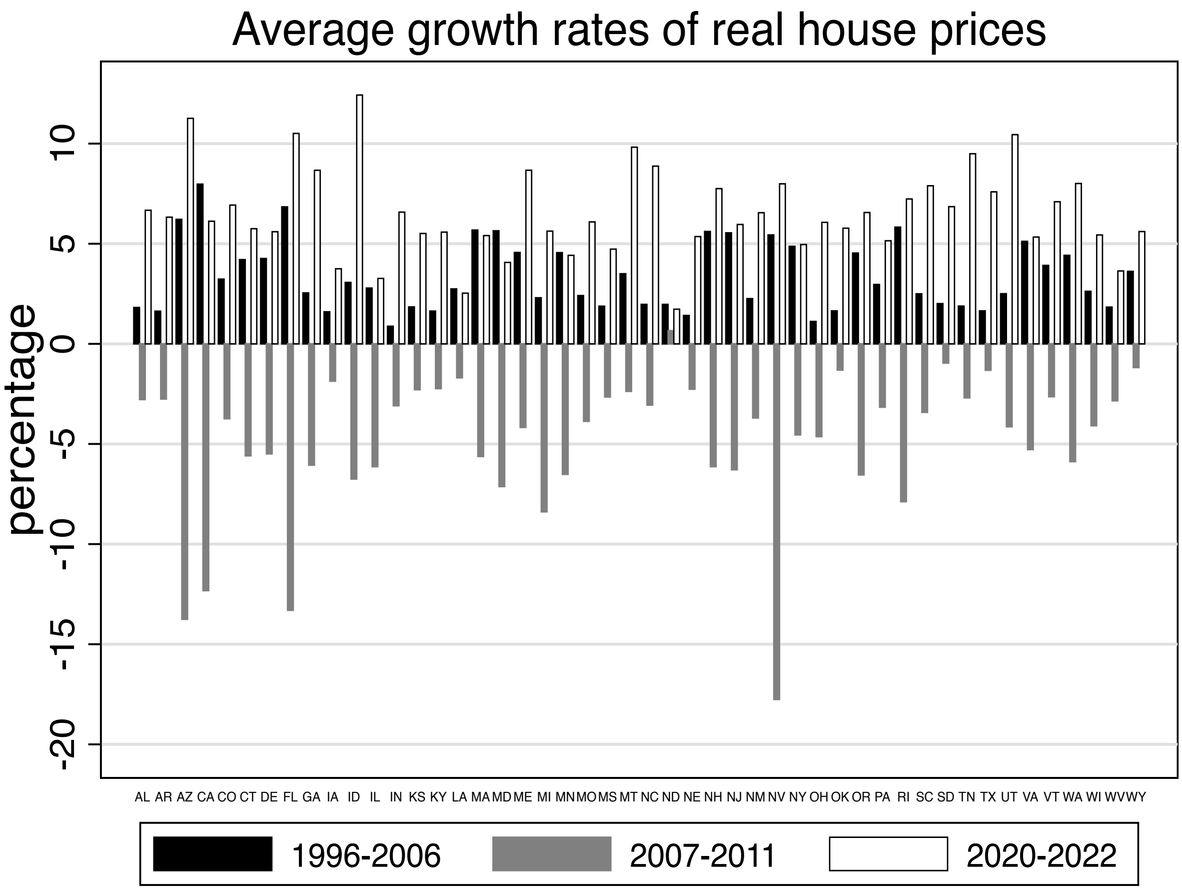
This section describes two sets of empirical results. The first set of results provides empirical findings on the state heterogeneity in the U.S. housing market across five different periods, as defined as period 1: 1986-1995; period 2: 1996-2006; period 3: 2007-2011; period 4: 2012-2019; and period 5: 2020-2022. The second set of results describes the relative importance of national versus regional or state-specific shocks in driving movements in real house prices across U.S. states over the past 47 years. This section documents that there is a large degree of heterogeneity over time in regard to the relative importance of the national factors. While local factors have remained important, the increase in house prices that occurred in recent years during the period of Covid-19 is mainly driven by the national phenomenon.

3.3.1 Heterogeneity in real house price dynamics across U.S. states

The white bars in Figure 3.2 show the annualized average growth rates from the first quarter of 2020, the beginning of the Covid-19 period, to the last quarter of 2022 in the FHFA real house price indexes, deflated by the headline CPI inflation, for the 48 contiguous U.S. states. Although real house prices have shown an increase of over 10% per year in several states, notably Arizona, Florida, Idaho, and Utah, during the COVID period, overall, it can be observed that there has been an average price increase of approximately 6.5% for three years across all states. Instances of overall rise or fall in real house prices in the U.S. housing market can be found in several past periods. In particular, following the onset of the global financial crisis, from 2007 to 2011, the annualized average growth rates of real house prices generally experienced an average decrease of 5 percent, as can be seen in the light gray bars of Figure 3.2.

On the other hand, Figure 3.3 exhibits a different pattern compared to Figure 3.2. The dark bars in Figure 3.3 show the annualized average growth rates from the first quarter of 1986 to the last quarter of 1995. In this ten-year period, house price indexes increased more than 2% per year in some states, especially Illinois, Michigan, Oregon, and Wyoming. Notably, the rise in house prices had been very uneven across the nation, with some states, like Maine, Minnesota, Nebraska,

Figure 3.2: Real house price dynamics across U.S. states, Three periods

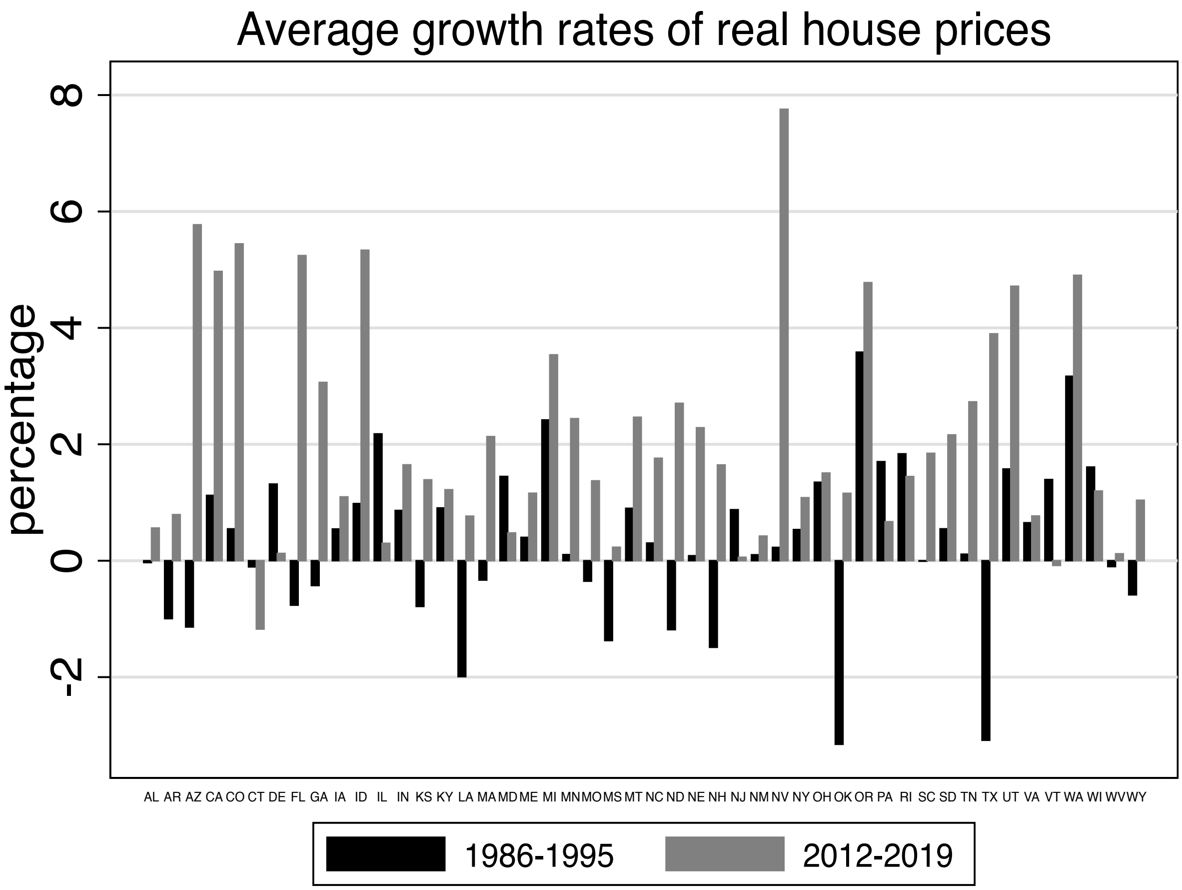


Note: The figure shows for each of the 48 contiguous states the annualized average growth rates in real house prices for the 1996–2006 period (dark bars), the 2007-2011 period (light gray bars), and the 2020-2022 period (white bars).

Nevada, North Carolina, and Tennessee, growing less than 0.5% per year. Interestingly, during this period, the annualized average growth rates take on positive values in 30 U.S. states, while 18 states experience negative values. This regional heterogeneity in the U.S. housing market occurred to be pronounced during the period from 2012 to 2019 as well.

As a result, Figure 3.2 and 3.3 provide evidence that the fluctuations in real house prices in the U.S. are generally a national phenomenon, but at times, the rates of growth vary significantly across regions. Particularly during the periods of 2020-2022 and 2007-2011, the growth rate of

Figure 3.3: Cross-state heterogeneity



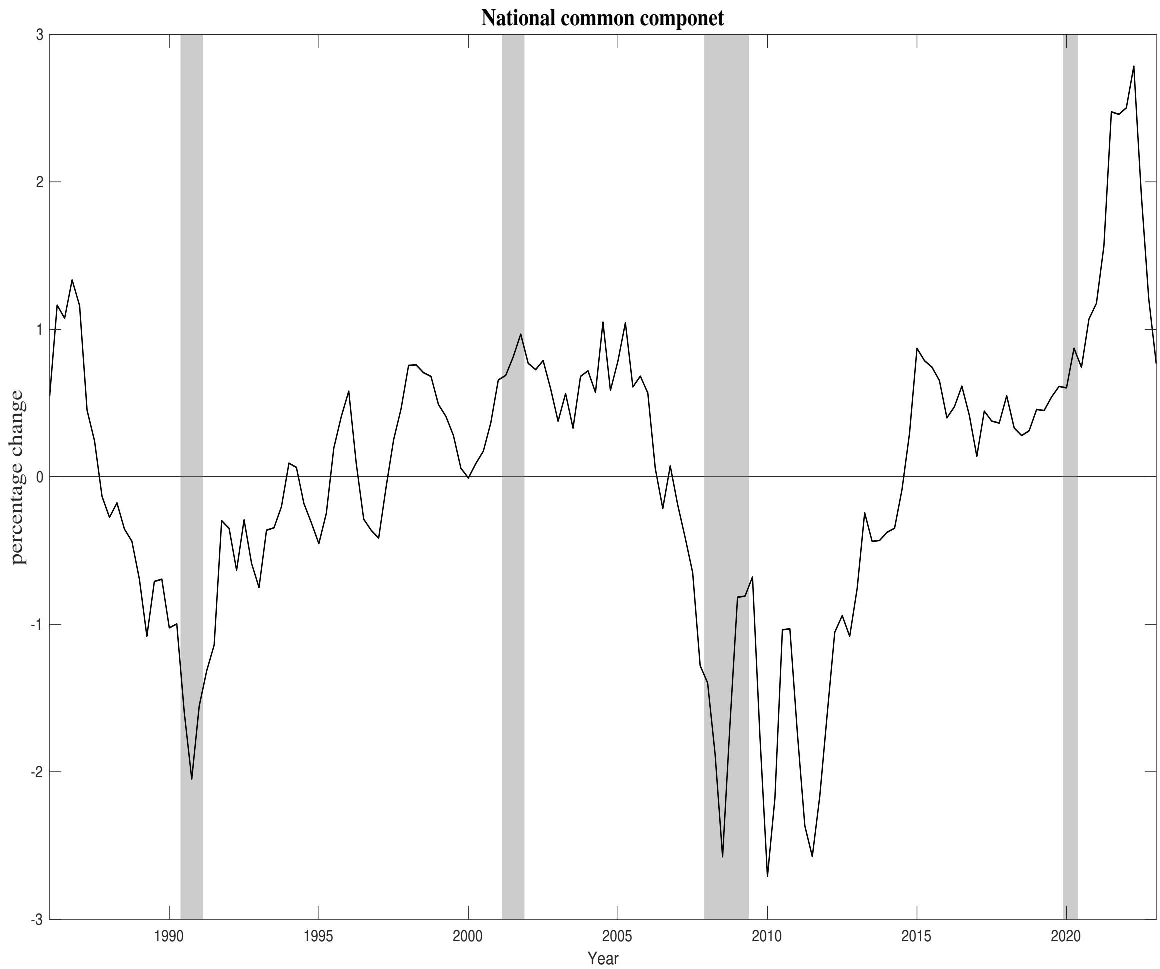
Note: The figure shows for each of the 48 contiguous states the annualized average growth rates in real house prices for the 1986–1995 period (dark bars) and the 2012-2019 period (light gray bars).

average house prices can be largely attributed to the national component rather than the regional or state-specific component. To examine this in more detail, next, I investigate the degrees of co-movement in house prices across states.

3.3.2 National factor versus local factor

Based on the statistical specification described in Section 3.2, this chapter decomposes movements in the growth rates of real house prices into national and regional-specific factors. Figure 3.4 shows the estimated common components across all regions and states, defined as the national

Figure 3.4: Common component across all regions and states, National factor

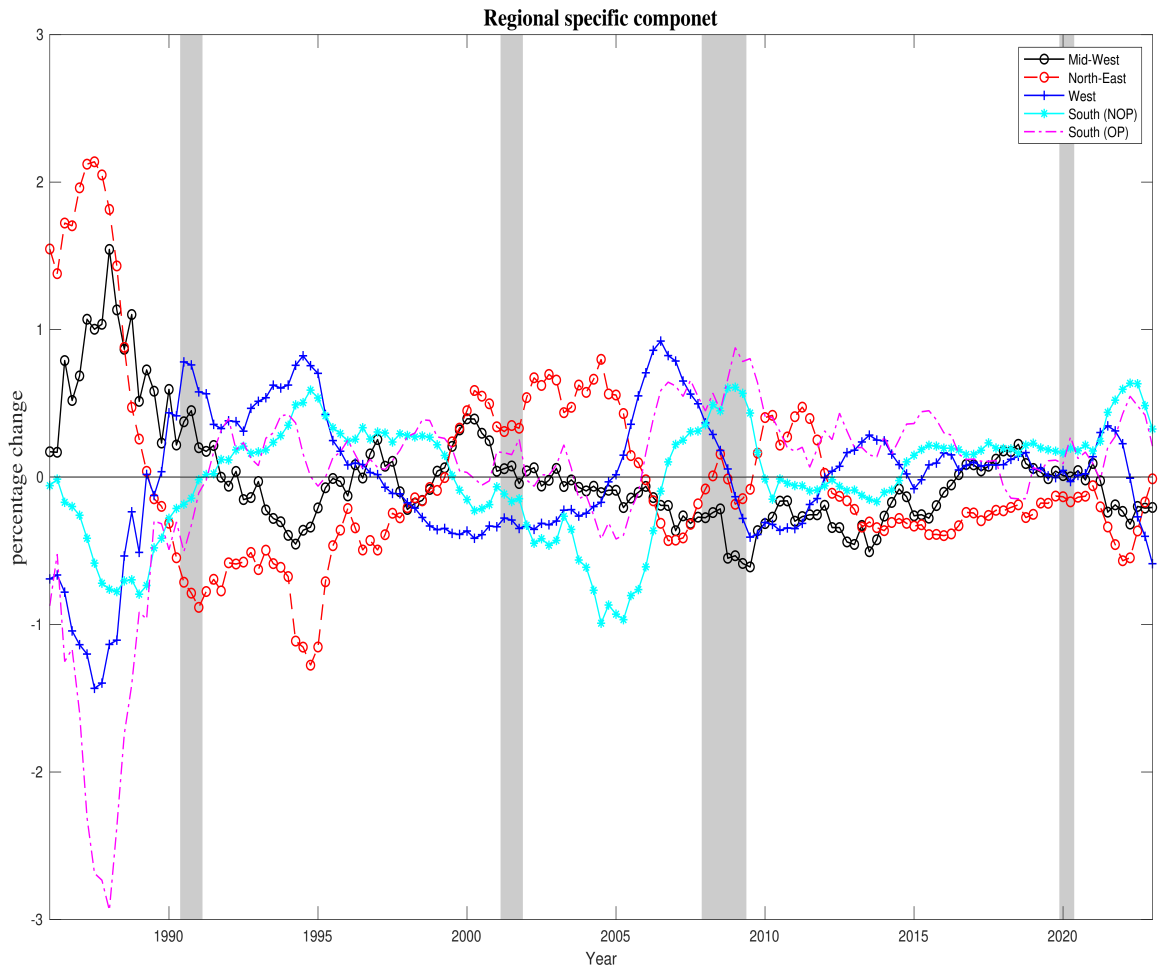


Note: Shaded areas denote NBER-dated recessions.

factors, that is, the component f_t^0 of equation 3.3. On the other hand, Figure 3.5 illustrates the estimated five regional components of real house prices, that is, the f_t^r components of equation 3.3.

Figure 3.4 and 3.5 imply an important finding. The historical movements in common (national) components estimated in equation 3.3 are highly correlated with those in the annualized growth rates of real house prices depicted in Figure 3.1. This is intuitive if we think that movements in the U.S. price index could either be driven by movements in the common component or by large shocks in states or regions that have a large weight in the index. Indeed, a key issue in the debate is

Figure 3.5: Local components across all states, Regional factors

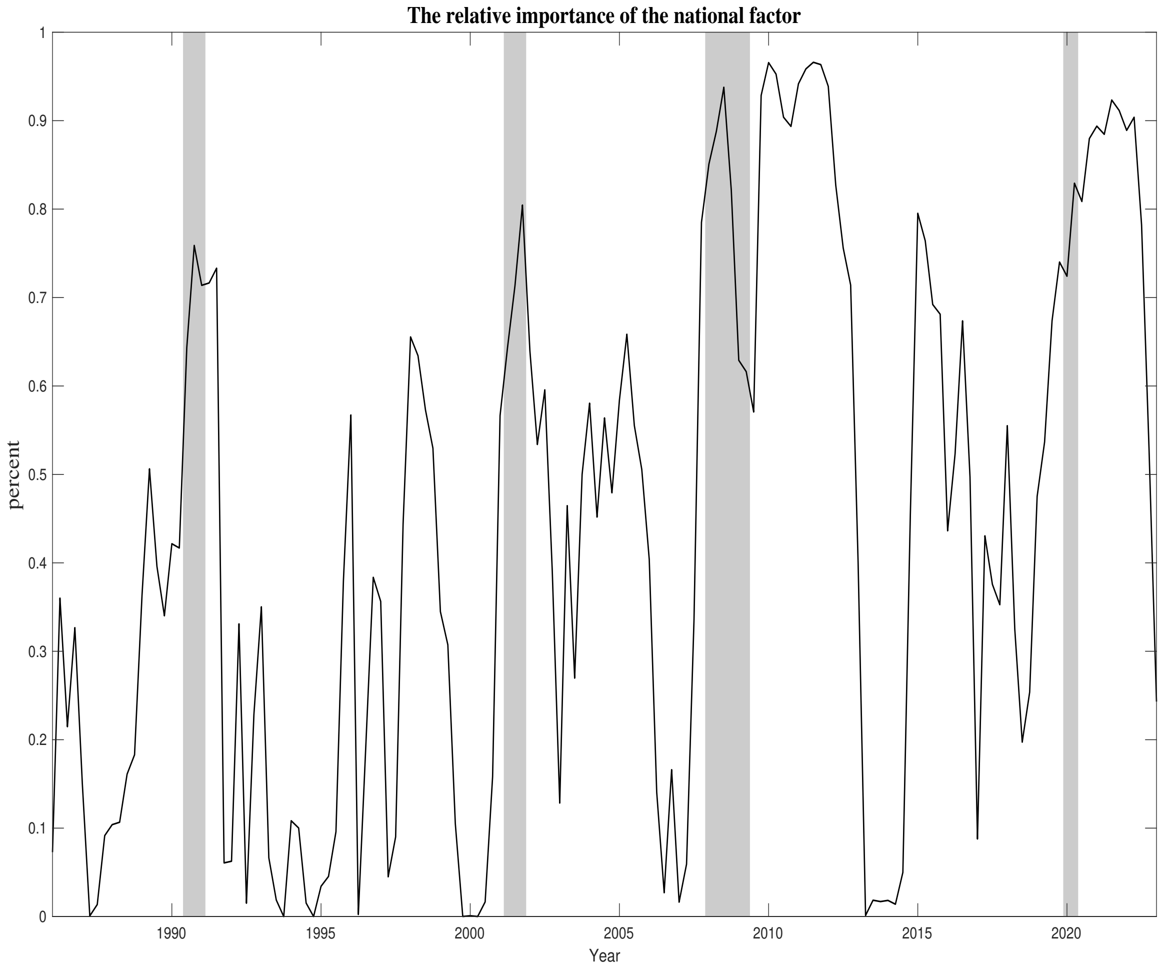


Note: Shaded areas denote NBER-dated recessions.

whether the increase in the national index reflects a national phenomenon or local phenomenon in a number of very highly populated (and therefore highly weighted) states, like Florida or California. The fact that the estimated national factor and the U.S. price index have moved in sync, especially in the last two years, suggests that the recent housing boom is a national phenomenon.

Another point to note is that the regional factors described in Figure 3.5 show a period of relatively high volatility in the fluctuations. The period coincides with the early part of the sample, from the first quarter of 1976 to the late 90s. A possible reason that can explain the difference between the period and others is the role played by regional and state-specific factors, as shown

Figure 3.6: The relative importance of the national factor



Note: Shaded areas denote NBER-dated recessions.

by Figure 3.6. The figure shows the variance of fluctuations due to the national factor as the fraction of the sum of the variance of all three factors across all states for each time, as described in equation 3.9 of Section 3.2. In the early part of the sample, the statistics associated with the relative importance of national factors are comparatively less than in other periods. Indeed, the regional components account for 48% of the variation in real house price dynamics over this period. Consequently, the empirical finding suggests that regional and state-specific (local) factors played a significant role in this period, which can imply that regional and state-specific factors are behind most of the volatility in real house prices from 1976 to the late 1990s.

In contrast, in the recent episode, it can be clearly seen that the relative importance of a common component is comparatively larger than in the first period. In particular, Figure 3.6 shows that the national factor accounts for 87% of the variation[3] of real house price dynamics over the period 2007-2011 and 85% of the variation of the prices over the period 2020-2022 on average.

3.4 Conclusion

This chapter examines a multi-level dynamic factor model using a non-parametric estimation method with a Bayesian approach to assess the relative importance of national and regional components in FHFA real house price fluctuations, particularly in relation to regional and state-specific shocks. The dataset comprises state- and quarterly-level data spanning from the first quarter of 1976 to the last quarter of 2022. The findings suggest that the national factor significantly contributes to the variation observed in recent periods. Notably, national factors played a dominant role in the overall change in real house prices since 2000, particularly during the Covid-19 period. Conversely, fluctuations in house prices prior to 2000 were primarily driven by local (regional or state) factors, indicating that regional factors were the main drivers of volatility during that earlier period.

The empirical findings presented in this chapter have important implications for policy. The characteristics of the regional housing market are likely to be influenced by local factors specific to each geographic market rather than by nationwide policies that are uniform across the nation. However, if the recent surge in house prices is a nationwide phenomenon, it raises the possibility that policy measures may be contributing to this trend.

[3] National factor accounts for 37% variation of real house price dynamics over the period 1986-1995, 47% for 1996-2006, and 61% for 2012-2019 on average.

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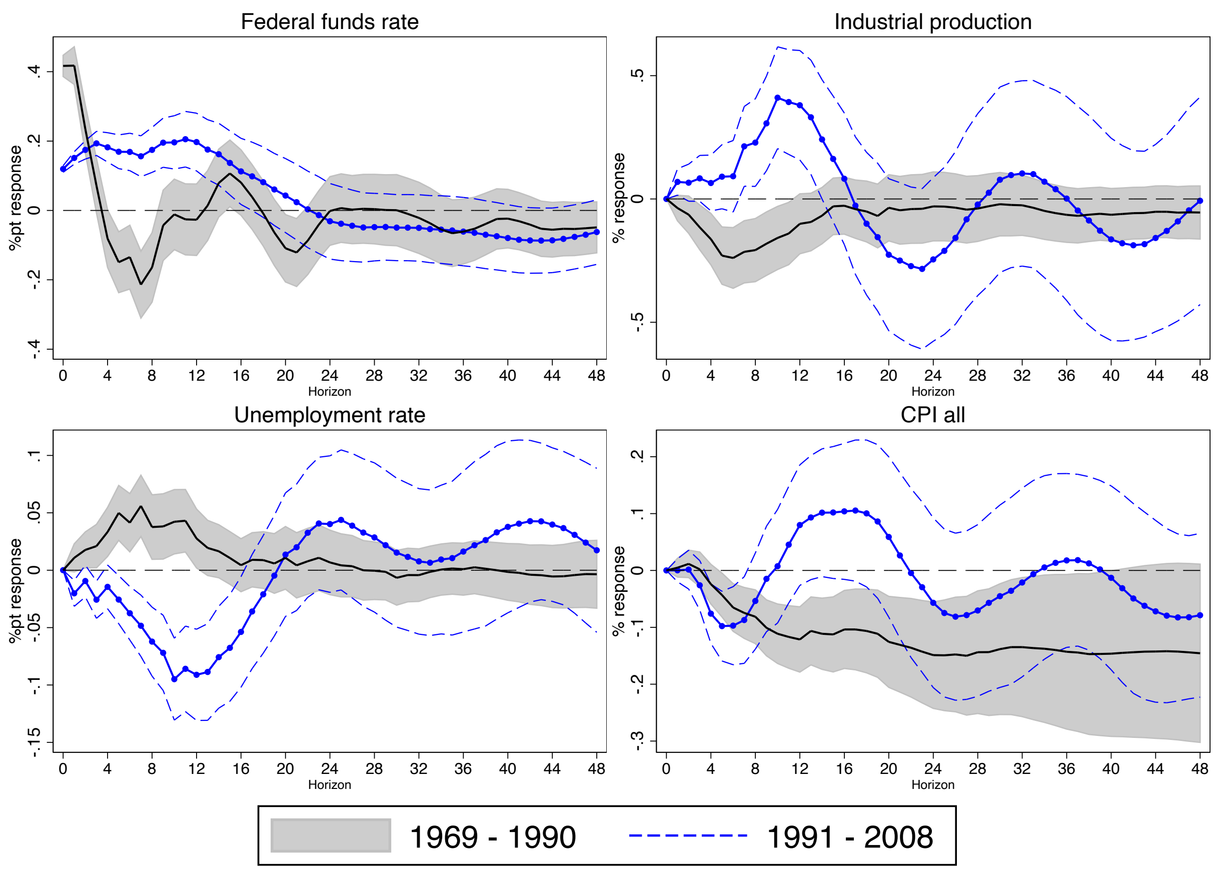
APPENDIX A

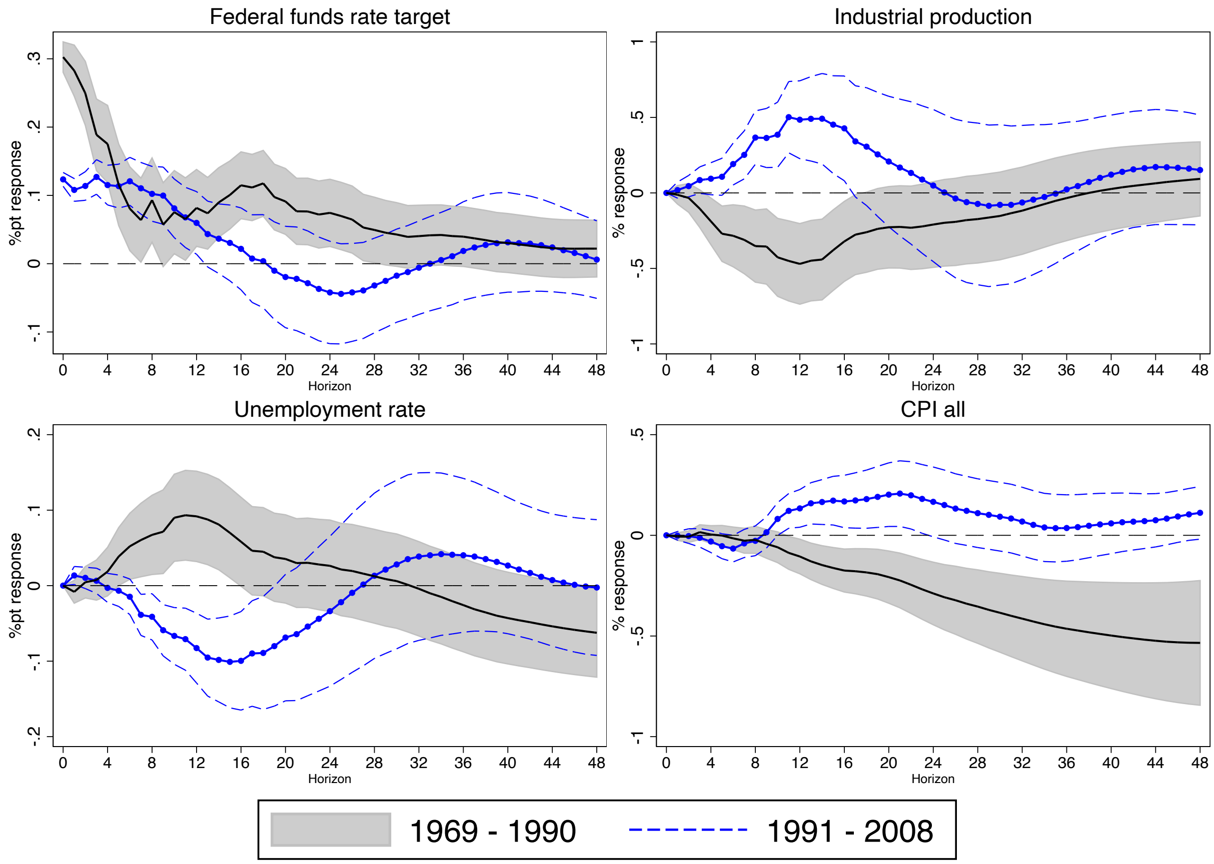
SUPPLEMENTARY TABLES AND FIGURES

Figure A.1: Christiano et al. (1999): SVARs identification



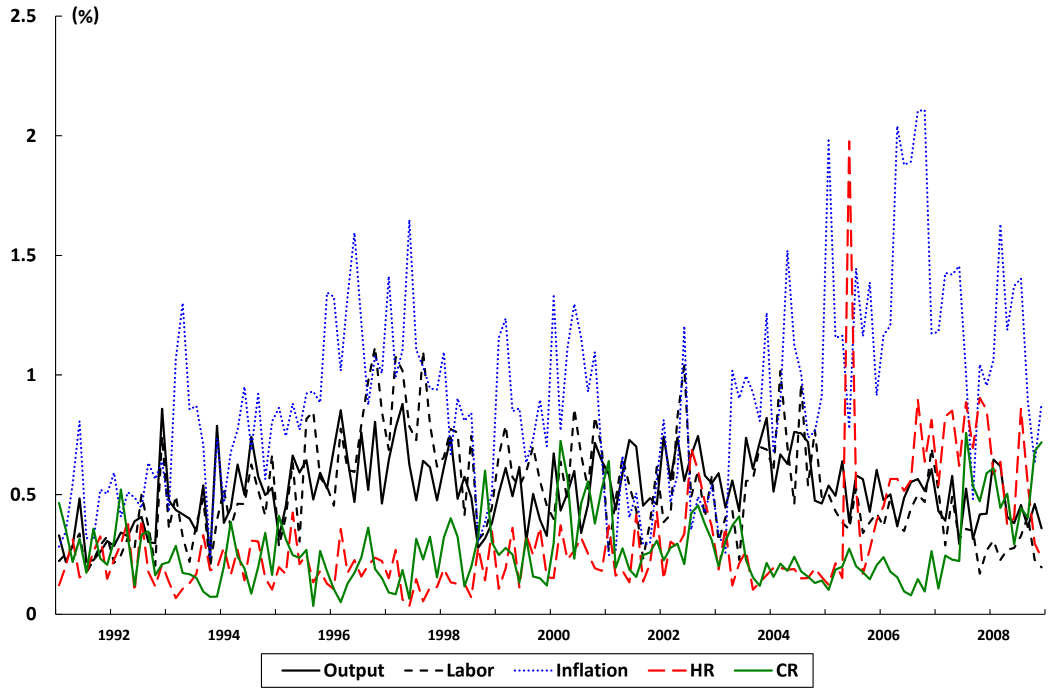
Note: The solid black line in each panel depicts the impulse response function of the specified variable (Federal funds rate, real industrial production, the unemployment rate, and headline CPI) to 100 basis point changes in the standard deviation of monetary policy shock for 1969 - 1990. The blue dotted line in each panel shows the response function of the specified variable to 100 basis point changes in the standard deviation of monetary policy shock for 1991 - 2008. Shaded bands and blue dashed lines denote the associated 90% confidence intervals for the system.

Figure A.2: Coibion (2012): Hybrid-SVARs with R&R monetary shock



Note: The solid black line in each panel depicts the impulse response function of the specified variable (Federal funds rate, real industrial production, the unemployment rate, and headline CPI) to 100 basis point changes in the standard deviation of monetary policy shock for 1969 - 1990. The blue dotted line in each panel shows the response function of the specified variable to 100 basis point changes in the standard deviation of monetary policy shock for 1991 - 2008. Shaded bands and blue dashed lines denote the associated 90% confidence intervals for the system.

Figure A.3: Frequency of word count for each group, FOMC transcripts, 1991 - 2008



Note: Each line shows the series of frequency (%) for each group to the total number of words expressed at each FOMC meeting over the period February 1991 through December 2008; Black-Solid line represents the group "Output"; Black-Dashed line represents the group "Labor"; Blue-Dotted line shows the group "Inflation"; Red-Dashed and Green-Solid line illustrate the frequency of terms that are related to housing and credits, respectively.

Figure A.4: Greenbook forecasts for key background factors, March 2006

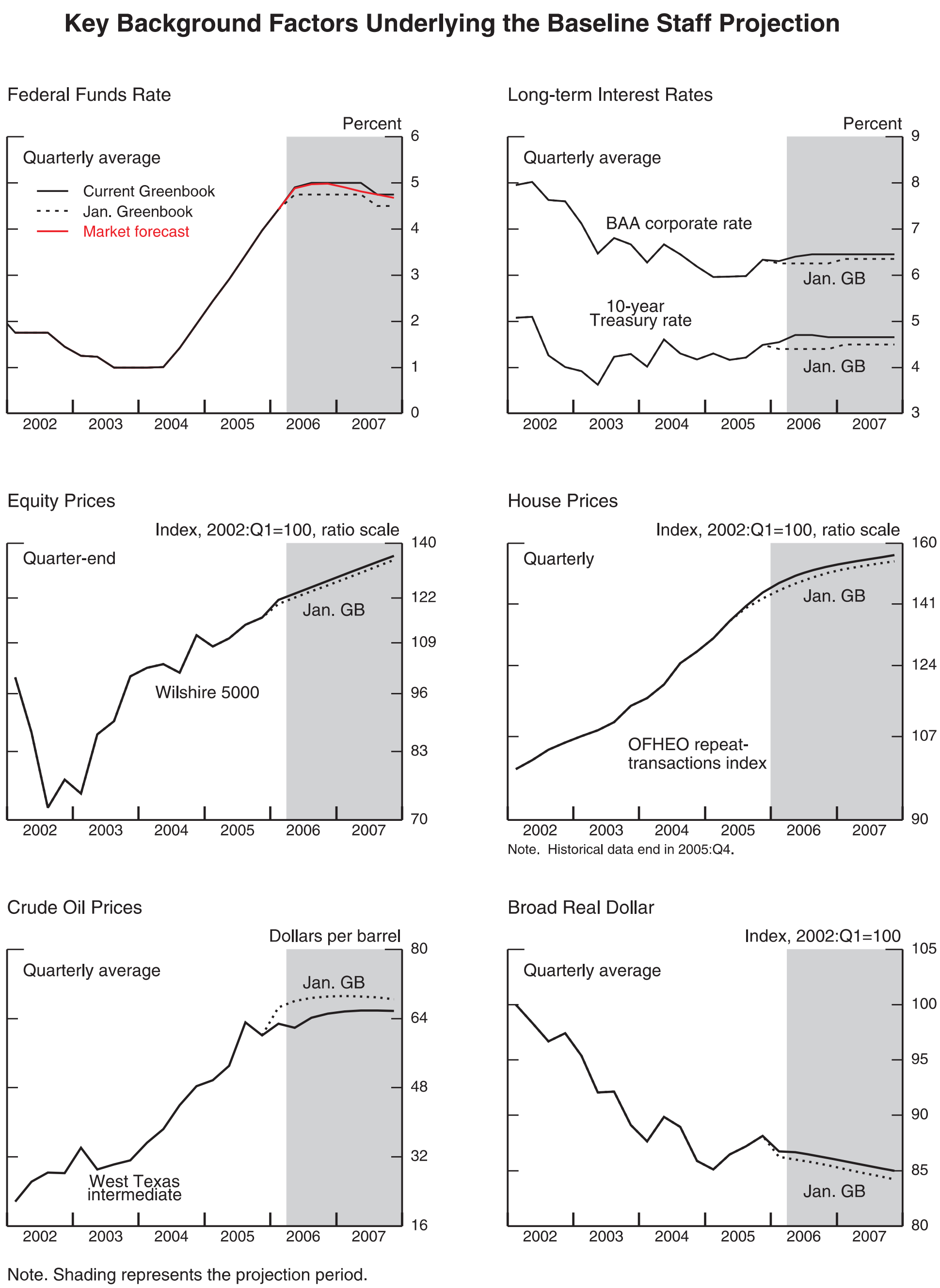
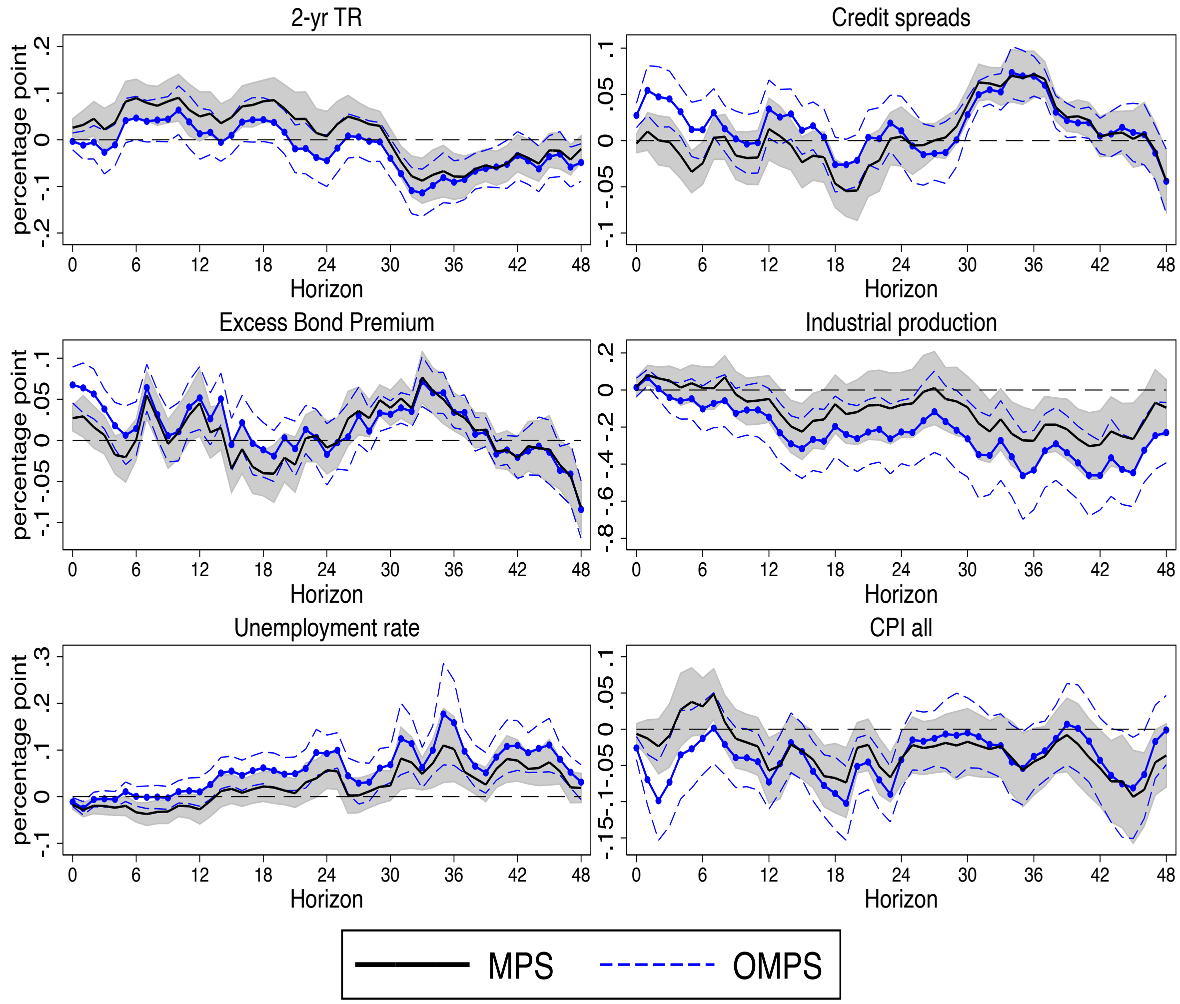
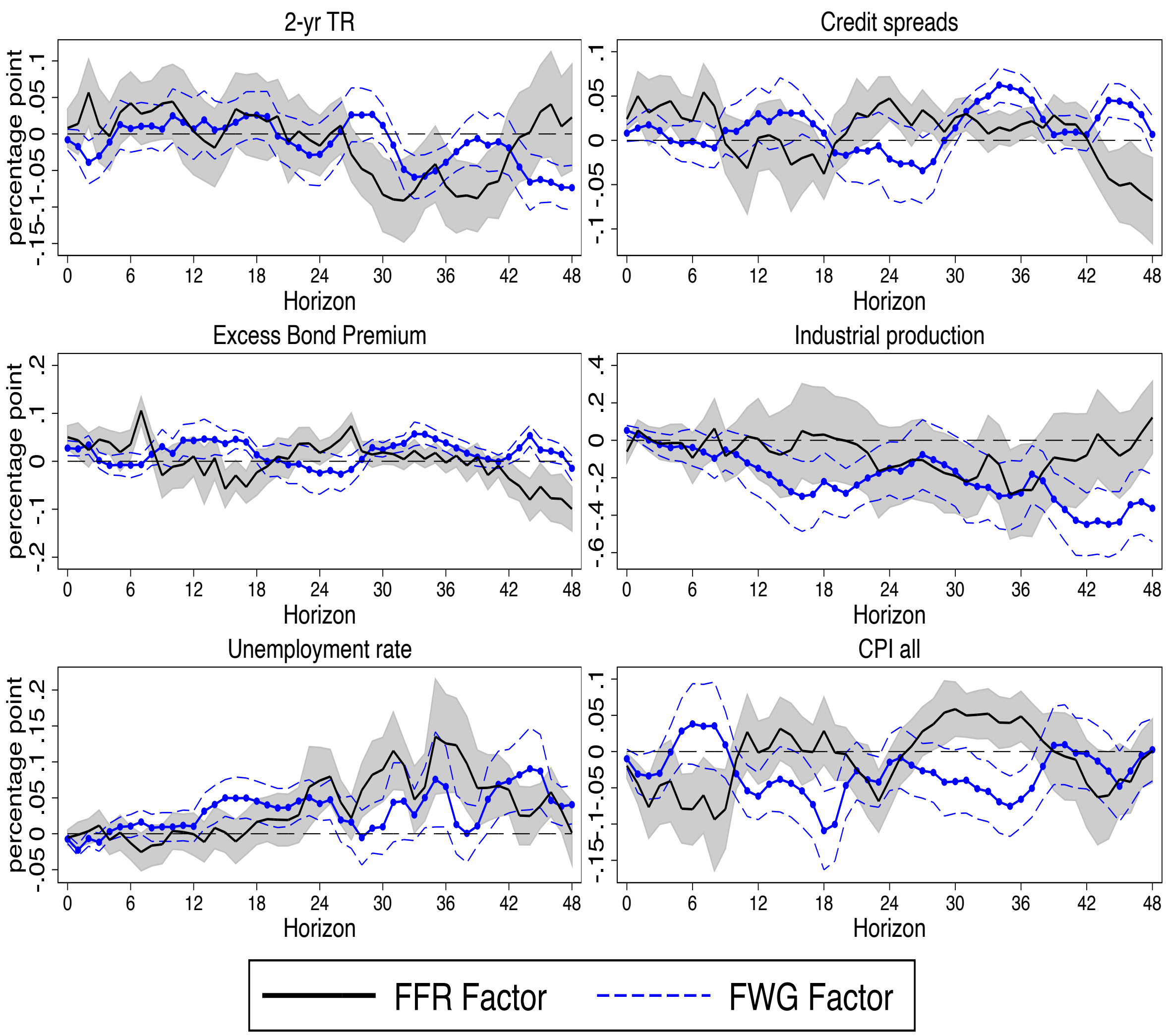


Figure A.5: Local projection with high-frequency monetary policy surprise, One-Factor model



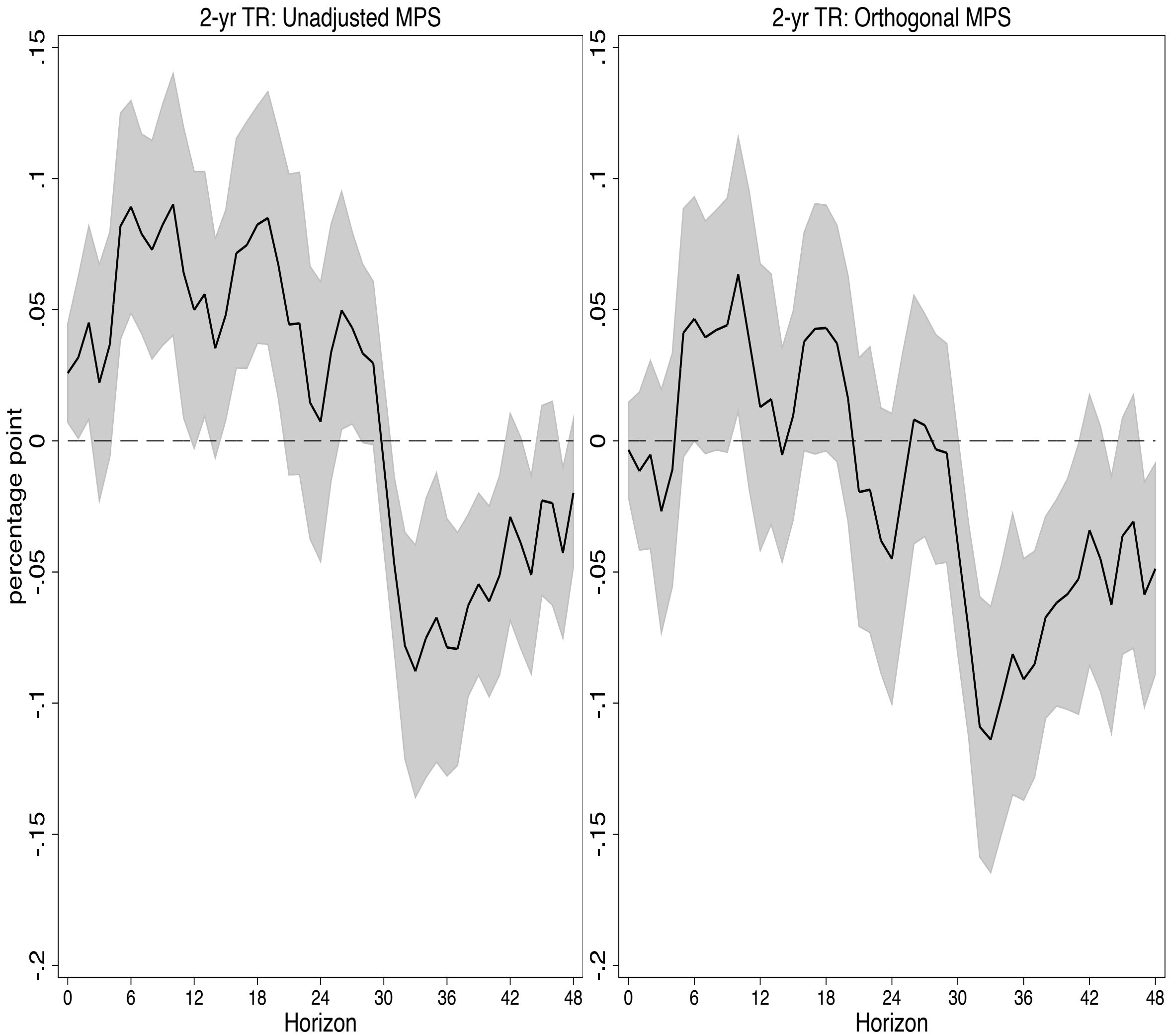
Note: The solid black line in each panel depicts the impulse response functions of real macroeconomic variables to a one-standard-deviation increase in the unadjusted high-frequency monetary policy shock, and the blue dotted line in each panel shows the same response functions to the high-frequency change in monetary policy shocks orthogonalized with respect to economic and financial variables prior to the announcement. Shaded regions and dashed blue areas report the associated 68% confidence intervals. Responses are estimated using specifications in the One-Factor model based on the sample from 1991 to 2018.

Figure A.6: Local projection with high-frequency monetary policy surprise, Two-Factors model



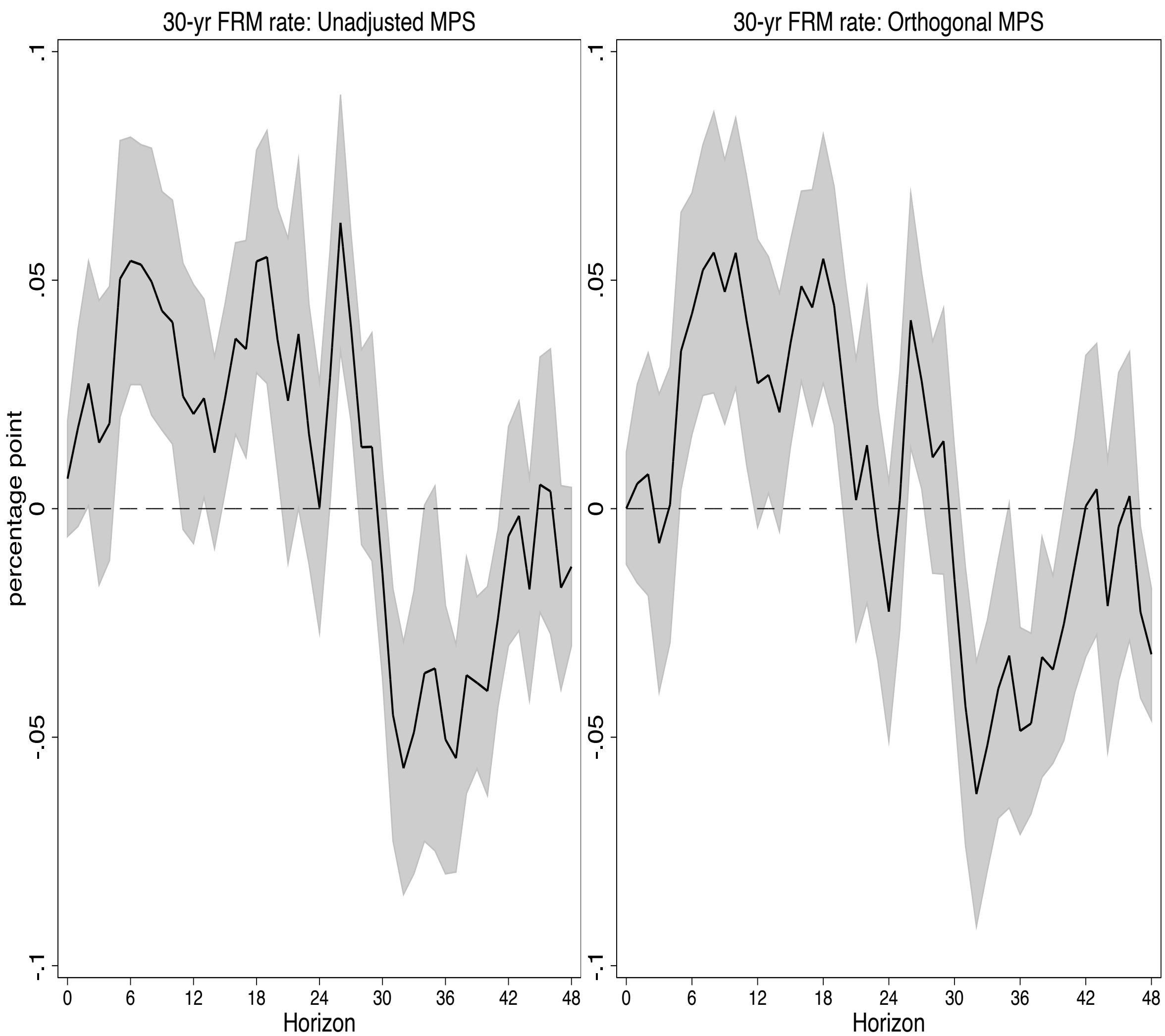
Note: The solid black line in each panel depicts the impulse response functions of real macroeconomic variables to a one-standard-deviation increase in the orthogonal Federal funds rate factor, and the blue dotted line in each panel shows the same response functions to the high-frequency change in the orthogonal forward guidance factor. Shaded regions and dashed blue areas report the associated 68% confidence intervals. Responses are estimated using specifications in the Two-Factors model based on the sample from 1991 to 2018.

Figure A.7: Responses of 2yr-TR. to monetary policy shocks, One-Factor model



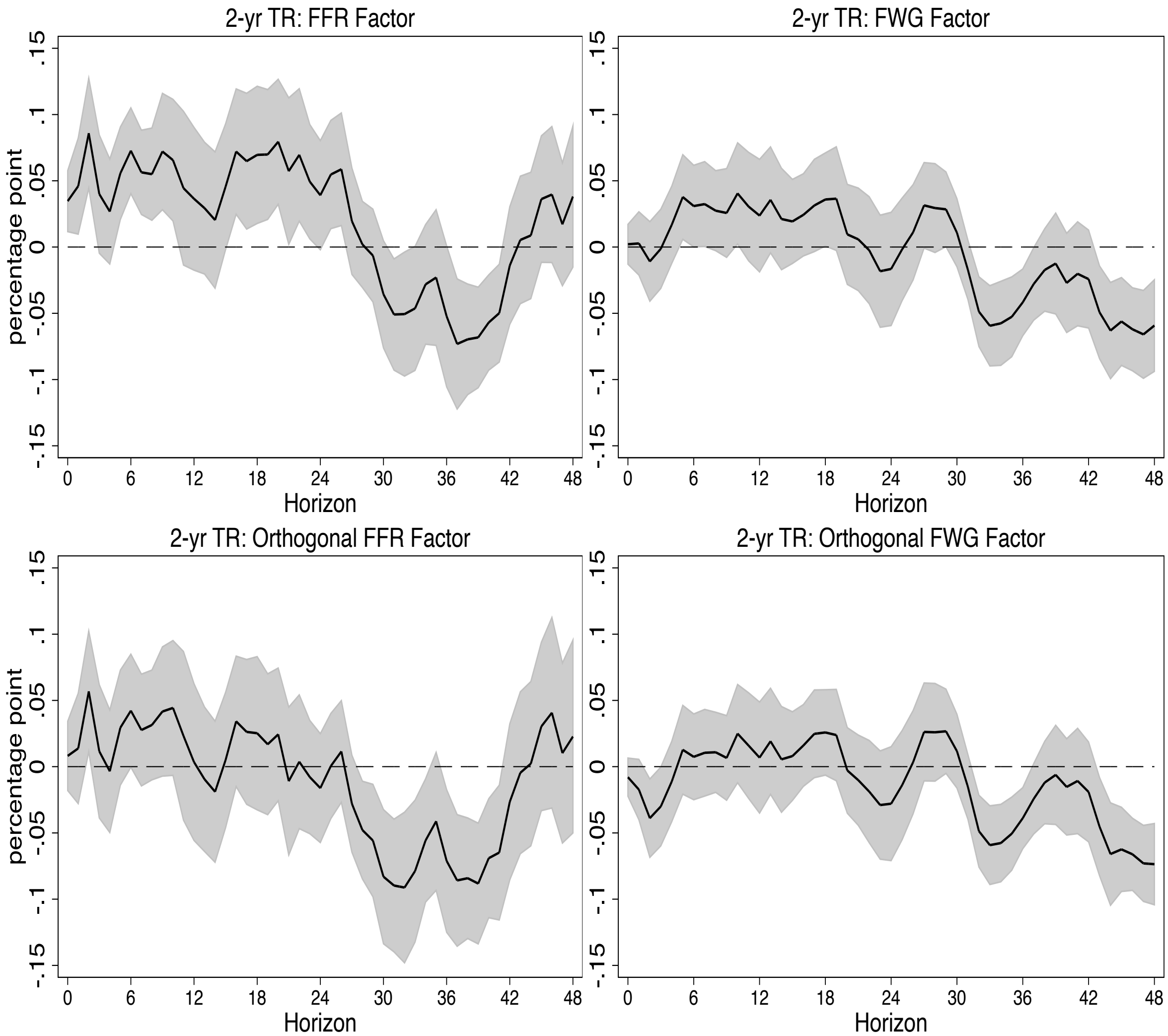
Note: The solid black line in each panel depicts the impulse response of the market yield on treasury securities at 2-Year constant maturity to a one-standard-deviation increase in the unadjusted high-frequency monetary policy measure (left) and the high-frequency change in monetary policy shocks orthogonalized with respect to economic and financial variables prior to the announcement (right). Shaded regions report the associated 68% confidence intervals. Responses are estimated using specifications in the One-Factor model based on the sample from 1991 to 2018.

Figure A.8: Responses of 30yr-FRM. to monetary policy shocks, One-Factor model



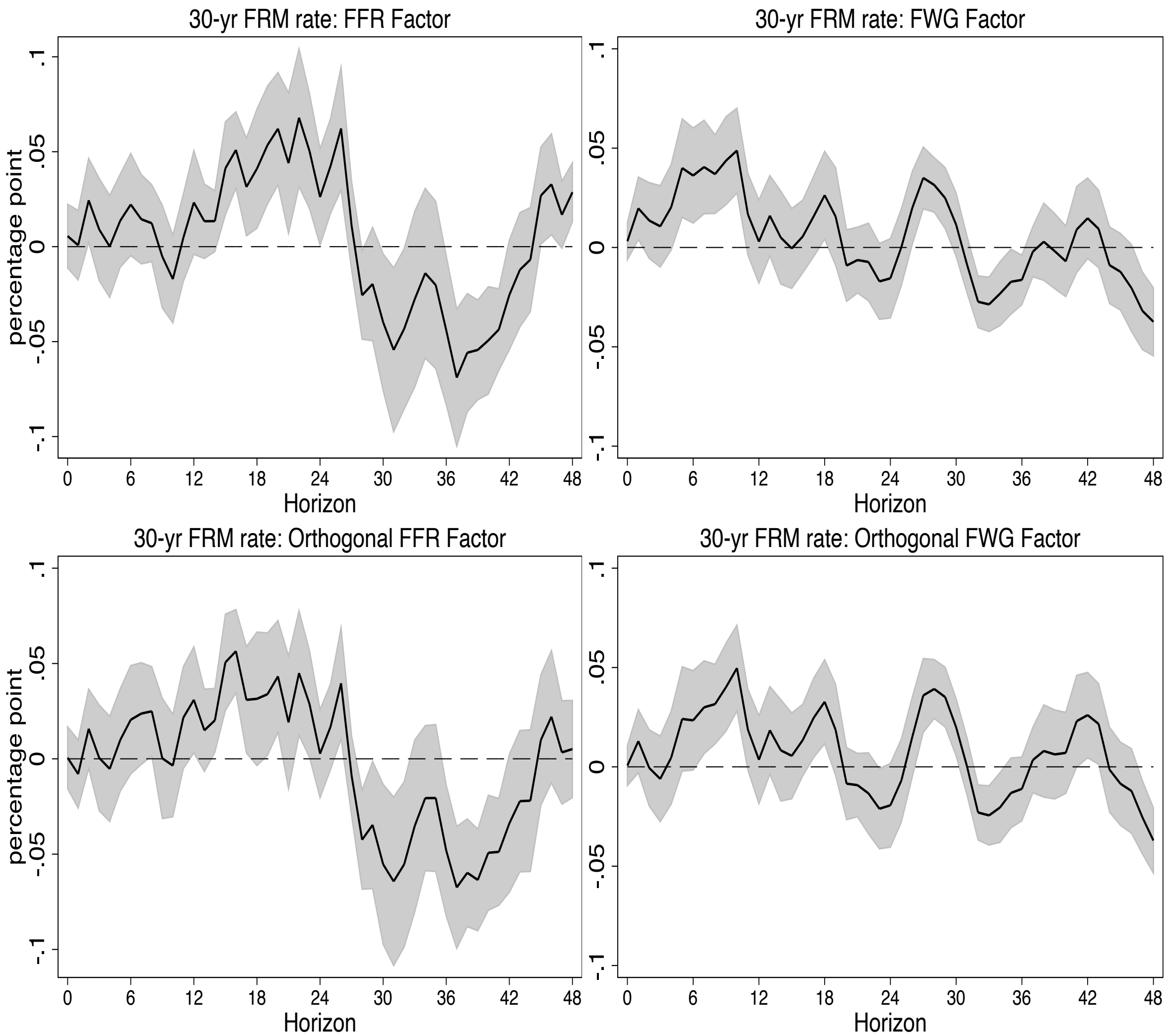
Note: The solid black line in each panel depicts the impulse response of the 30-Year fixed-rate mortgage rates to a one-standard-deviation increase in the unadjusted high-frequency monetary policy measure (left) and the high-frequency change in monetary policy shocks orthogonalized with respect to economic and financial variables prior to the announcement (right). Shaded regions report the associated 68% confidence intervals. Responses are estimated using specifications in the One-Factor model based on the sample from 1991 to 2018.

Figure A.9: Responses of 2yr-TR. to monetary policy shocks, Two-Factors model



Note: The first row depicts the impulse responses of the market yield on treasury securities at 2-Year constant maturity to a one-standard-deviation increase in the unadjusted federal funds rate factor (left) and forward guidance factor (right), while the second row shows the impulse responses to a one-standard-deviation increase in the high-frequency change in monetary policy shocks orthogonalized with respect to economic and financial variables prior to the announcement. Shaded regions areas report the associated 68% confidence intervals. Responses are estimated using specifications in the Two-Factors model based on the sample from 1991 to 2018.

Figure A.10: Responses of 30yr-FRM. to monetary policy shocks, Two-Factors model



Note: The first row depicts the impulse responses of the 30-Year fixed rate mortgage to a one-standard-deviation increase in the unadjusted federal funds rate factor (left) and forward guidance factor (right), while the second row shows the impulse responses to a one-standard-deviation increase in the high-frequency change in monetary policy shocks orthogonalized with respect to economic and financial variables prior to the announcement. Shaded regions areas report the associated 68% confidence intervals. Responses are estimated using specifications in the Two-Factors model based on the sample from 1991 to 2018.

Table A.1: Frequency of terms expressed by the group across the sample

Group	Full sample: 91-08		Pre-period: 91-99		Post-period: 00-08	
	/ total	/ all groups	/ total	/ all groups	/ total	/ all groups
Output	0.52	20.18	0.5	20.51	0.54	19.85
	[0.15]	[5.226]	[0.17]	[4.397]	[0.125]	[5.954]
Labor	0.51	19.45	0.54	21.48	0.48	17.43
	[0.218]	[6.612]	[0.238]	[5.711]	[0.193]	[6.866]
Inflation	0.91	33.52	0.81	33.09	1	33.95
	[0.407]	[10.036]	[0.317]	[8.054]	[0.463]	[11.73]
Housing	0.3	11.23	0.2	8.85	0.4	13.61
	[0.245]	[7.001]	[0.092]	[4.676]	[0.301]	[8.083]
Credits	0.39	15.62	0.36	16.08	0.42	15.16
	[0.194]	[8.329]	[0.165]	[8.53]	[0.217]	[8.158]
All groups	2.63		2.4		2.85	
	[0.612]		[0.581]		[0.561]	
Total terms	19431	521	15549	373	23314	670
Observations	144		72		72	

APPENDIX B

HIGH-FREQUENCY INSTRUMENTS AND THE ROLE OF REAL HOUSE PRICES

The empirical literature on monetary policy has also relied on the incorporation of external high-frequency instruments, which are likely to provide direct measures of structural policy disturbances. For example, Gürkaynak, Sack, and Swanson's (2005) market surprises have been used in Gertler and Karadi (2015), Miranda-Agrippino and Ricco (2021), and Bauer and Swanson (2022) as measures of monetary policy shocks. The use of monetary policy surprises is particularly appealing in these applications because they focus on market interest rate changes within a narrow window of time around FOMC announcements. This approach plausibly rules out reverse causality and other endogeneity problems. For instance, FOMC decisions are made an hour or two before the announcement, indicating that the FOMC could not have been reacting to changes in financial markets in a sufficiently narrow window of time around the announcement. Therefore, the asset price changes are clearly caused by the announcements themselves rather than vice versa. Additionally, surprises are also typically considered unpredictable, with any publicly available information that predates the FOMC announcement. This view is supported by the standard argument that financial market participants would be able to trade profitably on that predictability and drive it away in the process. Hence, monetary policy surprises are plausibly exogenous with respect to all macroeconomic variables that are publicly known before the FOMC announcement itself, and this is where the tight window comes in places. This characteristic makes them a valid instrument for the effects of monetary policy in structural VARs and local projections, as discussed in Stock and Watson (2018).

However, a few recent studies have questioned whether monetary policy surprises possess the desirable properties that the literature has typically assumed. For instance, Miranda-Agrippino and Ricco (2021) described that the Fed's internal Greenbook forecasts contain substantial information that is correlated with the high-frequency monetary policy surprise around the subsequent FOMC announcement. Cieslak (2018) and Bauer and Swanson (2022) have documented substantial predictability of monetary policy surprises with publicly available macroeconomic or financial market information that predates the FOMC announcement. This empirical evidence highlights the exogeneity issue, which can be addressed by removing the component of the monetary policy surprises that is possibly predictable, as recommended by Miranda-Agrippino and Ricco (2021) and Bauer and Swanson (2022).

In this paper, the main argument provides empirical evidence that monetary policy decisions systematically respond to changes in house prices by revisiting the narrative approach proposed by Romer and Romer (2004). To this end, Appendix B tests whether house prices can be used as a predictable component in policy surprises, which are measured by a high-frequency instrument. Specifically, Table B.1 examines the correlation with real house prices as a proxy for the Fed's internal forecasts for the leading indicators of monetary policy shocks. Meanwhile, Table B.1 focuses on the role of house prices as a publicly available measurement of macroeconomic (or financial) variables that possibly predict upcoming monetary policy surprises.

Table B.1 displays the estimated coefficients and relative significance level of the projection of high-frequency market surprises in the fourth Federal funds futures (FF4), the three-month ahead monthly fed funds futures as proposed by Gertler and Karadi (2015), over the 3-month moving average of house price growth prior to the FOMC meeting, Greenbook forecasts, and revisions to forecasts for output, inflation, and unemployment. In particular, I employ the movements in the fourth Federal funds futures contracts that are registered within a 30-minute window around the time of the FOMC announcements, as suggested by Gürkaynak et al. (2005). The regressions were conducted on all surprises registered between 1990 and 2008 at the frequency of FOMC announcement dates. The first column corresponds to a regression similar to those in Romer and Romer (2004) and reports results analogous to those in Miranda-Agrippino and Ricco (2021), using Greenbook forecasts for output and inflation relative to the previous quarter and up to three quarters ahead, nowcasts for the unemployment rate, and forecast revisions for output, inflation, and unemployment relative to the previous quarter and up to two quarters ahead. The results indi-

Table B.1: Projection of high-frequency market-based surprises

	[1]	[2]	[3]	[4]
House Prices		-0.019		-0.003
		[0.019]		[0.019]
Forecasts				
Output				
h = -1	0.003	0.000	-0.004	-0.004
	[0.004]	[0.004]	[0.003]	[0.004]
h = 0	0.008	0.011	0.009*	0.009*
	[0.006]	[0.007]	[0.005]	[0.005]
h = 1	0.001	0.004	0.002	0.001
	[0.008]	[0.009]	[0.006]	[0.007]
h = 2	-0.002	-0.002	0.002	0.002
	[0.008]	[0.009]	[0.005]	[0.006]
Inflation				
h = -1	-0.013*	-0.014*	-0.011*	-0.012*
	[0.007]	[0.008]	[0.006]	[0.007]
h = 0	0.013*	0.017*	0.011	0.013*
	[0.008]	[0.009]	[0.007]	[0.007]
h = 1	-0.036**	-0.037**	-0.013	-0.017
	[0.015]	[0.017]	[0.013]	[0.015]
h = 2	0.030**	0.026	0.013	0.015
	[0.014]	[0.018]	[0.012]	[0.016]
Unemployment				
h = 0	0.001	0.001	-0.005	-0.005
	[0.006]	[0.006]	[0.005]	[0.005]
Forecasts Revisions				
Output				
h = -1	-0.011*	-0.010*	-0.007	-0.008
	[0.006]	[0.006]	[0.005]	[0.005]
h = 0	0.000	0.002	0.000	0.001
	[0.008]	[0.008]	[0.006]	[0.007]
h = 1	0.004	0.000	0.009	0.008
	[0.011]	[0.012]	[0.010]	[0.010]
h = 2	0.001	0.006	-0.008	-0.001
	[0.010]	[0.011]	[0.009]	[0.010]
Inflation				
h = -1	-0.002	-0.001	0.001	0.005
	[0.010]	[0.009]	[0.010]	[0.009]
h = 0	-0.005	-0.004	-0.003	-0.002
	[0.010]	[0.010]	[0.009]	[0.010]
h = 1	0.040*	0.037	0.023	0.022
	[0.020]	[0.022]	[0.022]	[0.024]
h = 2	-0.025	-0.013	-0.001	0.002
	[0.025]	[0.026]	[0.023]	[0.026]
Constant	-0.031	-0.027	0.001	0.006
	[0.048]	[0.051]	[0.040]	[0.045]
Observations	178	160	152	141
Adjusted R-squared	0.080	0.064	0.114	0.095

Note: Projection of high-frequency market-based surprises on Greenbook forecasts and real house prices. The dependent variable is the 30-minute adjustment in the price of the fourth federal funds future around the FOMC announcements in sample 1990:2008. The first two columns use all announcement dates, and the last two are the dates of scheduled FOMC meetings only. Robust standard errors are in brackets. *, **, and *** indicate rejection at $\alpha(0.1, 0.05, 0.01)$ significance level, respectively.

cate that high-frequency surprises are correlated with the central bank's private forecasts, although the interpretation of individual coefficients is limited due to the multicollinearity of forecasts for the same variable at different horizons. Overall, the results imply that the Fed's private information is primarily related to the bank's assessment of the short-term macroeconomic outlook. In column 2, I repeat the same analysis by adding house prices to evaluate the role of house prices as a predictive component of monetary policy. The estimated results suggest that house prices have an insignificant coefficient at any significance level, indicating that high-frequency surprises in the fourth Federal funds futures possibly capture the effects of demand shocks of house prices through the financial market.

A potentially important concern is related to the role of unscheduled meetings, during which the FOMC makes urgent discussions in times of particular economic distress. These unexpected meetings, which gather market attention, may actually be responsible for the information channel. In my sample period, unscheduled meetings occurred 26 times, most frequently during the Great Recession. Columns 3 and 4 address this concern by repeating the regression in columns 1 and 2, respectively, using market surprises registered around scheduled FOMC meetings only, and the results are found to be robust.

Table B.2 estimates regressions of the form:

$$mps_t = \alpha + \beta X_{t-} + \varepsilon_t \tag{B.1}$$

where t indexes FOMC announcements for the sample period from 1988 to 2019 and mps_t denotes a measure of the monetary policy surprise as proposed by Bauer and Swanson (2022).[1] The vector X_{t-} consists of seven predictors of macroeconomic and financial data known prior to the announcement t (which are known prior to the announcement, indicated by the time subscript $t-$), including the surprise component of the most recent nonfarm payrolls release, employment growth

[1] To construct high-frequency monetary policy surprises, various methods are used by different authors. For instance, Kuttner (2001) uses the change in the current-month federal funds futures contract, Gertler and Karadi (2015) use the change in a farther-ahead federal funds futures contract, and Gürkaynak et al. (2005) and Nakamura and Steinsson (2018) use a range of federal funds and Eurodollar futures contracts. In this section, I adopt the approach of Bauer and Swanson (2022) and use the first four quarterly Eurodollar futures contracts, ED1-ED4.

Table B.2: Predictive Regressions Using Macro and Financial Date

	[1]	[2]	[3]	[4]	[5]	[6]
Nonfarm payrolls	0.09**	0.11**	0.11*	0.11*	0.08*	0.11*
	[0.04]	[0.05]	[0.06]	[0.06]	[0.05]	[0.06]
Empl. growth (12m)	0.01**	0.01	0.00	0.00	0.01	0.00
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.01]
Δ log S&P 500 (3m)	0.08	0.14*	0.11	0.12	0.15*	0.23**
	[0.06]	[0.08]	[0.07]	[0.07]	[0.08]	[0.10]
Δ Slope (3m)	-0.01	-0.01	-0.01	-0.011	-0.01	-0.01
	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
Δ log Comm. price (3m)	0.12**	0.09	0.09	0.09	0.22***	0.20**
	[0.05]	[0.06]	[0.07]	[0.06]	[0.07]	[0.10]
Treasury skewness	0.03***	0.04***	0.04***	0.04***	0.05**	0.06
	[0.01]	[0.01]	[0.01]	[0.01]	[0.02]	[0.04]
Moving avg (3m). House prices		-0.01		-0.01		0.01
		[0.01]		[0.01]		[0.02]
Observations	322	249	218	218	216	143
Sample	1988:1-2019:12	1988:1-2019:12	1994:1-2019:12	1994:1-2019:12	1988:1-2007:6	1988:1-2007:6
Adjusted R-squared	0.15	0.14	0.15	0.15	0.17	0.17

Note: Columns [1] and [2] show coefficient estimates β from the regression B.1 in sample 1988:2019. Columns [3] and [4] repeat the regression but begins the sample in 1994, while columns [5] and [6] report results for a sample period that stops in June 2007. Robust standard errors are in brackets. *, **, and *** indicate rejection at $\alpha(0.1, 0.05, 0.01)$ significance level, respectively. See text for details.

over the last year, the logarithmic change in the S&P500 from three months before to the day before the FOMC announcement, the change in the yield curve slope over the same period, the logarithmic change in a commodity price index over the same period, the option-implied skewness of the 10-year Treasury yield from Bauer and Chernov (2021), and the three-month moving average of house price growth from two months before the FOMC announcement. The regression residual is denoted by ε_t.

The results from six different versions of the regression B.1 are reported in Table B.2. The first and second columns consider the baseline measure of the monetary policy surprise described in Bauer and Swanson (2022) over the full sample of 322 FOMC announcements from 1988 to 2019. The results are consistent with their findings, where strong nonfarm payroll employment, a strong stock market, and high commodity prices predict a hawkish monetary policy surprise, while house prices do not have a significant role in this context. The other four columns of Table B.2 report results for alternative estimation samples. The third and fourth columns repeat regression B.1 with the same specification but start the sample in 1994 when the FOMC began explicitly announcing its monetary policy decisions. The results of this sample are very similar to the first and second columns. The last two columns report results for a sample period that stops in June 2007, before the financial crisis, and the zero lower bound period, again with similar estimates.

Overall, the results in Tables B.1 and B.2 confirm the substantial predictability of high-frequency monetary policy surprises found by previous authors for different samples. The former implies that there is strong evidence that the Fed's internal forecasts are correlated with the subsequent monetary policy surprises, while Table B.2 shows monetary policy surprises measured by high-frequency instruments are systematically correlated with macroeconomic and financial data that are publicly available before the monetary policy announcement. However, the results associated with house prices in each table show that the predictive power of house prices for policy surprises is marginal. A possible explanation for the predictability results associated with house prices is that a good predictor should have a parsimonious and robust relationship to the Fed's monetary policy rule and a variable of the most recent release measured on an intra-daily basis prior to the FOMC announcement. For this analysis, I used a three-month moving average of house price growth two months prior to the FOMC announcement as a proxy for predictor variables, which is publicly available from the FHFA data archive. Since the predictor's timing was constructed on a monthly basis instead of a daily basis, the predictive power of house prices employed in this analysis for high-frequency monetary policy surprises may not be strong enough to result in a statistically significant estimate. I will leave further exploration of these findings to future studies.