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# House prices and stock prices:

# Different roles in the U.S. monetary transmission mechanism

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# House prices and stock prices: Different roles in the U.S. monetary transmission mechanism[*]

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## Abstract

We analyze the role of house and stock prices in the monetary policy transmission mechanism in the U.S. using a structural VAR model. The VAR is identified using a combination of short-run and long-run (neutrality) restrictions, allowing for contemporaneous interaction between monetary policy and asset prices. By allowing the interest rate and asset prices to react simultaneously to news, we find different roles for house and stock prices in the monetary transmission mechanism. In particular, following a contractionary monetary policy shock, stock prices fall immediately, while the response in house prices is much more gradual. However, the fall in both house prices and stock prices enhances the negative response in output and inflation that has traditionally been found in the literature. Regarding the systematic response in monetary policy, stock prices play a more important role in the interest rate setting in the short run than house prices. As a consequence, shocks to house prices contribute more to GDP and inflation fluctuations than stock price shocks.

**JEL-codes:** C32, E52, E44.

**Keywords:** VAR, monetary policy, house prices, identification.

# 1 Introduction

The widespread liberalization of financial markets in the 1980s has increased interest in asset price developments, in particular among central banks. This is due to several factors. First, asset prices, such as housing and stock prices, have a central collateral role in the lending sector, making them important sources of macroeconomic fluctuations that an inflation targeting central bank may respond to, see e.g. Bernanke, Gertler, and Gilchrist (1999) and Bernanke and Gertler (1989).[1]

Second, asset prices are forward-looking variables reflecting the expected future return on the asset, which is determined by fundamental variables. If the policymaker is at an informational disadvantage vis-a-vis the private sector, or the fundamentals are not fully observable to the policymaker, asset prices can be helpful as indicator variables since they reflect private sector expectations about the state of the economy.

Finally, asset prices do not only reflect fundamentals, but also frequently include bubble components. Due to the presence of such bubbles, asset prices may influence target variables more than what is reflected by the fundamental part of the asset price. Hence, asset prices can also become distinct indicators of monetary policy (see e.g. Cecchetti, Genberg, Lipsky, and Wadhwani (2000)). However, given the incomplete understanding of asset price determination (i.e. the underlying model), it may be difficult to identify possible bubble components and thus provide adequate monetary policy responses.

In this paper, we analyze the role of two asset prices; house prices and stock prices, in the monetary transmission mechanism in the U.S. using a structural vector autore-

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[1] The recent financial crisis is a case in point. Arguably the crisis began with the collapse of the U.S. housing bubble in 2007/2008, which consequently caused the values of securities tied to real estate pricing to plummet worldwide. This lead to a liquidity crisis in the banking system, stress and collapse in many large financial institutions and eventually a global recession as credit tightened and international trade declined.

gressive (VAR) model. The motivation for including house prices into the model is that it is the most important asset for households in industrialized countries. Unlike other assets, housing has a dual role of being both a store of wealth and an important durable consumption good. A shift in house prices will therefore affect the wealth of homeowners, which may have a bearing on consumption and investment. As the value of collateral changes, this will also affect the availability of credit for borrowing-constrained agents. Finally, increased house prices can have a stimulating effect on housing construction (due to the Tobin's q effect). Hence, a shock to house prices may affect real growth and ultimately consumer prices, making house prices an important forward looking variable that the monetary policymaker may want to monitor.[2]

Furthermore, we also include stock prices in the VAR. We believe stock market wealth may affect household behavior quite analogous to housing wealth, although the marginal propensity to consume out of stock market wealth may be be somewhat smaller than the marginal propensity to consume out of housing wealth, (see e.g. Case, Quigley, and Shiller (2005) and Carroll, Otsuka, and Slacalek (2006)).

A major challenge when incorporating asset prices in the VAR model, though, is how to identify the system, as there is a simultaneity problem when identifying shocks to interest rates and asset prices, as all may respond simultaneously to news. So far, most of the VAR studies that analyze the importance of housing (i.e. Goodhart and Hofmann (2001), Iacoviello (2005) and Giuliodori (2005)), largely ignore this simultaneity by placing recursive, contemporaneous exclusion restrictions on the interaction between monetary policy and house prices.[3]

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[2]Greenspan (2001) also spurred interest in this topic, by suggesting that house prices have gained attention in the formulation of the monetary policy strategy.

[3]Traditional SVAR studies have typically either assumed that house prices are restricted from responding immediately to monetary policy shocks (Goodhart and Hofmann (2001), and Giuliodori (2005)), or that monetary policy is restricted from reacting immediately to innovations in house prices (Iacoviello

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The studies mentioned above have either ignored stock prices, or if included, maintained the recursive order for the VAR, so that stock prices respond with a lag to monetary policy shocks, see e.g. Goodhart and Hofmann (2001). This is equally implausible, and recent studies have found stock prices to play a notable role in the U.S. monetary policy transmission mechanism once allowing for interdependence between monetary policy and stock price fluctuations, see Rigobon and Sack (2003), and Bjørnland and Leitemo (2009).

Here we will include both housing and stock prices into the VAR, while allowing for full simultaneity between monetary policy and these asset prices. Identification is instead achieved by restricting the long run multipliers of the monetary policy shock. In particular, we assume that monetary policy shocks can have no long run effect on neither the level of real stock prices nor on real GDP. These are uncontroversial restrictions, well founded in economic theory (see e.g. Blanchard and Quah (1989) and Bjørnland and Leitemo (2009)).[4] Identified in this way, house prices and stock prices can now respond immediately to all shocks, while the monetary policymaker can consider news in all asset prices, when designing a monetary policy response. This maintains the high degree of interdependence commonly observed in the market between monetary policy and various asset prices. Note that we have not restricted the long run effects of monetary policy shocks on house prices, as we believe this to be a somewhat more controversial issue that we would like to examine rather than impose at the outset.

Our findings suggest different roles for asset prices in the monetary transmission mechanism. In particular, following a contractionary monetary policy shock (that increases the interest rate), stock prices fall immediately, while the response in house prices is more gradual. However, the fall in both house and stock prices enhances the negative response

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(2005)).

[4]However, we will see that our results do not hinge on these specific restrictions, as they can be obtained using sign restrictions instead.

in output and inflation that has traditionally been found in the SVAR literature.

Regarding the systematic response in the interest rate, monetary policy responds less to shocks in house prices than stock prices in the short run, but the relationship is reversed in the long run. Due in part to the delayed monetary policy response to house price shocks, these shocks have a much larger impact on both GDP and inflation than stock price shocks.

The rest of the paper is organized as follows. In Section 2 we explain our structural identification scheme which provides an exact identification. Section 3 presents the empirical results from our structural model. In Section 4 we analyze robustness to our identification strategy and model specification. Section 5 concludes.

# 2    Motivation and identification

The choice of variables in the VAR model reflects the theoretical set up of a New-Keynesian model (i.e. Svensson (1997)). In particular, the VAR comprises annual change of the log of the GDP deflator ($\pi_t$) - referred to hereafter as inflation, log of real GDP ($y_t$), the fed funds rate ($i_t$), the log of real house prices ($ph_t$) and the log of real share prices ($s_t$).[5] In all cases, the fed funds rate is chosen to capture monetary policy shocks; consistent with the fact that the central bank uses interest rate instruments in monetary policy setting. This is in line with Rotemberg and Woodford (1997), who find central bank behavior to be well modeled by a policy rule that sets the interest rate as a function of variables such as output and inflation.

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[5]Further details on the data and sources are given in the appendix.

## 2.1 Identification

We first define $Z_t$ as the (5x1) vector of the macroeconomic variables discussed above, where $y_t$, $ph_t$ and $s_t$ are now differenced to be stationary: $Z_t = [\Delta y_t, \pi_t, \Delta ph_t, \Delta s_t, i_t]'$. We model $Z_t$ as an autoregressive process, which when invertible, can be written in terms of its moving average (ignoring any deterministic terms)[6]

$$Z_t = B(L)\nu_t, \tag{1}$$

where $\nu_t$ is a vector of reduced form residuals assumed to be identically and independently distributed with a positive semidefinite covariance matrix $\Omega$. $B(L)$ is the (5x5) convergent matrix polynomial in the lag operator $L$. Following the literature, the innovations $\nu_t$ are assumed to be written as linear combinations of the underlying orthogonal structural disturbances, $(\varepsilon_t)$, i.e. $\nu_t = S\varepsilon_t$. The VAR can then be written in terms of the structural shocks as

$$Z_t = C(L)\varepsilon_t, \tag{2}$$

where $B(L)S = C(L)$. If $S$ is identified, we can derive the MA representation in (2) as $B(L)$ is calculated from a reduced form estimation of $Z_t$. To identify $S$, the elements in $\varepsilon_t$ are normalized so they all have unit variance. With a five variable VAR, we can identify five structural shocks. The three shocks that are of primary interest here are the monetary policy shocks ($\varepsilon_t^{MP}$), house price shocks ($\varepsilon_t^{PH}$) and stock price shocks ($\varepsilon_t^{SP}$). We follow standard practice in the VAR literature and only loosely identify the other two

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[6]This will be discussed further and verified in Section 3.

shocks as inflation (or cost push) shocks (moving prices before output) ($\varepsilon_t^\pi$) and output shocks ($\varepsilon_t^y$).

Ordering the vector of structural shocks as: $\varepsilon_t = [\varepsilon_t^y, \varepsilon_t^\pi, \varepsilon_t^{PH}, \varepsilon_t^{SP}, \varepsilon_t^{MP}]'$, we assume zero restrictions on the relevant coefficients in the S matrix as described below:

$$
\begin{pmatrix} \Delta y_t \\ \pi_t \\ \Delta ph_t \\ \Delta s_t \\ i_t \end{pmatrix} = B(L) \begin{pmatrix} S_{11} & 0 & 0 & 0 & 0 \\ S_{21} & S_{22} & 0 & 0 & 0 \\ S_{31} & S_{32} & S_{33} & 0 & S_{35} \\ S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\ S_{51} & S_{52} & S_{53} & S_{54} & S_{55} \end{pmatrix} \begin{pmatrix} \varepsilon_t^y \\ \varepsilon_t^\pi \\ \varepsilon_t^{PH} \\ \varepsilon_t^{SP} \\ \varepsilon_t^{MP} \end{pmatrix}
$$

We assume standard recursive zero restrictions on the impact matrix of shocks for the traditional macroeconomic variables, see e.g. Sims (1980); Christiano, Eichenbaum, and Evans (1999) and Christiano, Eichenbaum, and Evans (2005), among many others. That is, output and inflation react with a lag to monetary policy shocks, whereas the monetary policymaker might respond immediately to shock to output and inflation, which is consistent with the theoretical set up in Svensson (1997).[7] We further assume a lag in the effect of stock price and house price shocks on inflation and output.[8]

The matrix is, however, two restrictions short of identification since we do not want to restrict monetary policy from responding contemporaneously to shocks in either house prices or stock prices (i.e. $S_{53}$ and $S_{54}$ should be different from zero), or alternatively, house prices and stock prices from responding contemporaneously to monetary policy

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[7]Note that the effects of the monetary policy shocks will be invariant to how output and inflation is ordered. This follows from a generalization of proposition 4.1 in Christiano, Eichenbaum, and Evans (1999), which entails that with a recursive contemporaneous matrix, the impulse responses to a specific shock is invariant to the ordering of variables above the specific shock.

[8]We also assume that house prices do not react simultaneously to a stock price shock.

shocks (i.e. $S_{35}$ and $S_{45}$ should be different from zero). Instead, we impose the restrictions that i) a monetary policy shock can have no long-run effects on the level of real stock prices, and ii) a monetary policy shock has no long-term effect on the level of real output, which are plausible neutrality assumptions. The restrictions can be found by setting the values of the infinite number of relevant lag coefficients in (2), $\sum_{j=0}^{\infty} C_{15,j}$ and $\sum_{j=0}^{\infty} C_{45,j}$, equal to zero, (see Blanchard and Quah (1989)). There are now enough restrictions to identify and orthogonalize all shocks. We write the long run expression of $B(L)S = C(L)$ as $B(1)S = C(1)$, where $B(1) = \sum_{j=0}^{\infty} B_j$ and $C(1) = \sum_{j=0}^{\infty} C_j$ indicate the (5x5) long-run matrices of $B(L)$ and $C(L)$ respectively. The long-run restrictions imply

$$B(1)_{11}S_{15} + B(1)_{12}S_{25} + B(1)_{13}S_{35} + B(1)_{14}S_{45} + B(1)_{15}S_{55} = 0, \tag{3}$$

and

$$B(1)_{41}S_{15} + B(1)_{42}S_{25} + B(1)_{43}S_{35} + B(1)_{44}S_{45} + B(1)_{45}S_{55} = 0. \tag{4}$$

The system is now just identifiable. The zero contemporaneous restrictions identify the non-zero parameters above the interest rate equation, while the remaining parameters can be uniquely identified using the long run restrictions, where $B(1)$ is calculated from the reduced form estimation. Note that (3) and (4) reduce to $B_{13}S_{35} + B_{14}S_{45} + B_{15}S_{55} = 0$ and $B_{43}S_{35} + B_{44}S_{45} + B_{45}S_{55} = 0$ respectively, given the zero contemporaneous restrictions.

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# 3 Empirical results

The VAR model is estimated for the United States using quarterly data from 1983 Q1 to 2010 Q1. Using an earlier starting period will make it hard to identify a stable monetary policy regime, as monetary policy prior to 1983 experienced important structural changes and unusual operating procedures (see Bagliano and Favero (1998), and Clarida, Gali, and Gertler (2000)).

To recall, the VAR comprises the fed funds rate, the annual inflation rate and quarterly growth rates of the following: real GDP, real house prices and real stock prices.[9] The lag order of the model is determined using Schwarz and Hannan-Quinn information criteria and the F-forms of likelihood ratio tests for model reductions. The tests suggested that four lags were acceptable. With a relatively short sample, we use four lags in the estimation. With four lags, the estimated VAR is stable and thus invertible. That is, all eigenvalues of the companion matrix of our baseline VAR have modulus less than one.[10]

Furthermore, vector tests with null hypotheses of neither autocorrelation, heteroscedasticity nor non-normality were not rejected at standard significance levels.[11]

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[9]Inflation is measured by the annual change in the log of the GDP-deflator, and the latter price index is used when deflating house and share prices. We use the Federal Housing Finance Agency house price index (FHFA HPI) and S&P 500 index as measures of house and stock prices, respectively. See the appendix for further details.

[10]This doesn't imply that each and all variables in the VAR must be I(0). Generally, in an unrestricted VAR comprising variables that are I(1) and cointegrated, the cointegrating relationships will be implicitly determined, see Hamilton (1994). Moreover, Sims, Stock, and Watson (1990) argue in favor of using VARs in levels as a modeling strategy, as one avoids the danger of inconsistency in the parameters caused by imposing incorrect cointegrating restrictions, yet at the cost of reducing efficiency.

[11]The diagnostic tests were carried out by PcGive 10 (see Hendry and Doornik (2001)). We used RATS for the remaining part of the empirical results. The reported diagnostic tests were: Vector AR 1-5 test: $F(125,285)=1.2368$ [0.0754], Vector Normality test: $\chi^2(10) = 16.582$ [0.0841] and Vector hetero test: $F(600,502) = 0.77491$ [0.9986]. Two impulse dummies for the periods 1984 Q4 (controlling for a very high interest rate (outlier)) and 1987 Q4 (controlling for the stock market crash in October 1987) were also included in the model. The dummies take the value 1 in the relevant quarter and are 0 otherwise. Robustness to the specification is reported below.

## 3.1 The effects of a monetary policy shock

Figures 1 (a-e) plot responses of the interest rate, GDP, inflation, real house prices and real share prices, respectively, to a contractionary monetary policy shock. The responses are graphed with probability bands represented as .16 and .84 fractiles (as suggested by Doan (2004)).[12] To compare across variables, the monetary policy shock is normalized to increase the interest rate with one percentage point the first quarter.

[Figure 1 somewhere HERE]

The figures imply that a contractionary monetary policy shock has the usual effects identified in other international studies: temporarily increasing the interest rate and lowering output and inflation gradually. There is a high degree of interest-rate inertia in the model, as a monetary policy shock is only offset by a gradual reduction in the interest rate. The monetary policy reversal combined with the interest-rate inertia is consistent with what has become known as good monetary policy conduct (see Woodford (2003)).

Regarding the other variables, output falls by almost 0.5 per cent after two quarters, and is reduced by nearly 1 per cent after a year when the effect turns insignificant. The inflation response is initially positive, but the effect is insignificant. The response eventually turns negative and is significant as expected. After 3-4 years, inflation has fallen by nearly 0.4 percentage points, and thereafter the response dies out. A certain increase in consumer prices following a contractionary monetary policy shock is a common finding in the VAR literature, known as the "price puzzle". An interpretation could be that monetary policy reacts systematically to anticipated future inflation, while the signal of future inflation is not adequately captured by the VAR (see Sims (1992)). The puzzle

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[12]This is the Bayesian simulated distribution obtained by Monte Carlo integration with 2500 replications, using the approach for just-identified systems. The draws are made directly from the posterior distribution of the VAR coefficients.

could also be explained by a cost channel of the interest rate, where (at least part of) the increase in firms borrowing costs is offset by an increase in prices (Ravenna and Walsh (2006); Chowdhury, Hoffmann, and Schabert (2006)). The VAR presented here is clearly provided with forward-looking information as two asset prices are incorporated. Moreover, the identification scheme allows for contemporaneous interdependence between monetary policy and asset prices. This could explain why the result displayed in Figure 1c suggests absence of a (significant) price puzzle.

Turning to real house prices, Figure 1d shows that monetary policy has an immediate negative effect on real house prices. The effect is small but significant. Thereafter, house prices are pushed further down, and after three years they have fallen by almost 4 percent. In the long run, though, the effect is insignificant. The persistent effect seemingly supports the reasonableness of not imposing (from the outset) the restriction that monetary policy has no long-run effects on the level of real house prices. Yet the persistent response turns out to be robust to such a long-term restriction, as the response is effectively unchanged when this restriction is imposed.[13]

Are the results plausible? Since a contractionary monetary policy shock also lowers output, one would expect a negative effect on employment and wages. Higher interest rates also raise household interest payments. Thus, household debt servicing capacity will decline when interest payments increase and income is curbed. This can explain the prolonged effect of monetary policy shocks on house prices.

The results for house prices reported here lie somewhere in between those of Iacoviello (2005) and Del Negro and Otrok (2007).[14] The relatively weaker response (in house prices)

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[13]The result can be obtained on request.

[14]The results are, of course, different from Goodhart and Hofmann (2001) and Giuliodori (2005), which use an identification that restricts house prices from responding contemporaneously to a monetary policy shock.

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found in Iacoviello (2005) may be due to the fact that he restricts monetary policy from reacting contemporaneously to shocks in house prices and ignore a possible interaction with stock prices. On the other hand, corresponding results in Del Negro and Otrok (2007) are much larger, as they search for the maximum possible impact when imposing various identification schemes using sign restrictions.

Concerning the other asset price, Figure 1e shows that the monetary policy shock has an immediate negative effect on real stock prices. Stock prices fall by close to 10 percent, but the effect is short lived. This is consistent with what we will see in Figures 7 and 8 using sign restrictions, and with Bjørnland and Leitemo (2009), analyzing the interdependence between U.S. monetary policy and stock prices (only).[15]

Finally, Figure 2 graphs the variance decomposition of real house prices and real stock prices with respect to a monetary policy shock. While monetary policy shocks explain almost 30 percent of the initial variation in real stock prices (which then quickly dies out), the contribution to house prices is less than five percent initially, increasing slowly to 10 percent after 2-3 years, before essentially dying out. Hence, monetary policy shocks contribute more to the variation in stock prices than in house prices in the short term, as the effect on house prices is more delayed.

[Figure 2 somewhere HERE]

## 3.2 The systematic effects of monetary policy

Having examined the variables' dynamic responses to a monetary policy shock, we turn to investigate the reverse causation, namely the (systematic) response in monetary policy to shocks in house prices and stock prices. Our identified asset price shocks will capture non-

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[15]Using a monthly SVAR model augmented with stock prices for the U.S., Bjørnland and Leitemo (2009) find great interdependence between US monetary policy and stock prices in the period 1983-2002.

fundamental asset price variation, that is, sharp increases or decreases in real asset prices at given interest rates and trends in GDP and inflation. Naturally, the interpretation of these shocks being non-fundamental is subject to uncertainty. We also graph the response in GDP and inflation to the same two shocks, in order to investigate to what extent the response in interest rates relate to economic activity. In each of the subsequent figures, we compare the effects of a house price shock and a stock price shock for one variable at the time. That is, Figure 3 plots the effects of a house price shock (left column) and a stock price shock (right column) on the interest rate, GDP and inflation. Due to much higher volatility in stock prices than in house prices, the stock price shock is normalized to increase stock prices 10 percent the first quarter, while the house price shock raises house prices by 1 percent the first quarter. Again, the responses are graphed with probability bands represented as .16 and .84 fractiles.

The figures emphasize that monetary policy responds more slowly to a shock in house prices than in stock prices. As a consequence, the effect of housing on GDP and inflation is allowed to pick up significantly. The effect of a stock price shock on GDP and inflation is instead small, in fact, the effect of the stock price shock on inflation is not even significant.

This is illustrated further in Figure 4 examining variance decompositions. Figures 4a, 4c and 4e plot respectively the variance decomposition of interest rates, GDP and inflation with respect to a house price shock, while Figures 4b, 4d and 4f show the variance decomposition of the same three variables with respect to a stock price shock.

[Figure 3 and 4 somewhere HERE]

While stock price shocks explain almost 30 percent of the initial interest rate variation, house price shocks explain less than 5 percent of the interest rate variation in the first year. Thereafter, the contribution is reversed, so that the effects of stock price shocks decline quickly, while house price shocks increase its contribution, explaining more than

30 percent of the variation in interest rates after 5 years.[16]

Regarding the other variables, house price shocks explain 10 percent of the GDP variation already after one year, increasing to 20-30 percent after 3 years where it stabilizes. The contribution to inflation is practically zero the first year, but thereafter increases quickly, stabilizing around 40-50 percent after 5 years. The contribution of share price shocks to GDP and inflation is on the other hand trivial, explaining less than 5 percent of the variation at all horizons.

Hence, monetary policy responses to shocks in the two asset prices are strikingly different; while a shock to stock prices influences the interest rate setting immediately, a shock to house prices affects monetary policy conduct only slowly. This could indicate that monetary policy has primarily reacted to the indirect effects of house price innovations, i.e. to changes in output and inflation, and not to the initial effect of the shocks. The lack of a swift monetary policy response to the house price shock allows for large and persistent effects on GDP and inflation variation. In contrast, the stock price shock which is followed by an immediate change in interest rates has small or negligible effects on economic activity. Although one should be cautious of letting an estimated VAR provide a basis for counterfactual reasoning, the results at least suggest that if a stronger short-term monetary policy response was in effect following house price shocks, it might have neutralized some of the effects on real activity and inflation.

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[16]Note that, while the effect is not significant at longer horizons, the shocks still account for the total variance of all variables at every horizon, and therefore also provide information about the long-term relative importance of a shock. Consequently, we report variance decompositions over all horizons even though long-run impulse responses are essentially zero as shocks die out.

## 3.3  Historical decomposition

We now turn to the historical decompositions, that attribute the overall variance to different historical periods. Accordingly, Figure 5a portrays the contribution of monetary policy shocks (dotted line) together with actual quarterly percentage growth of real house prices (solid line) in each period. Correspondingly, Figure 5b displays the contribution of the same shocks to the quarterly growth of real stock prices (solid line) in each period.[17]

Figure 5a emphasizes how expansionary monetary policy shocks have contributed to boost house prices in many periods, in particular from mid-2003 to mid-2006. This is consistent with results found in Chauvet and Huang (2010), who argue that the uncertainty surrounding the end of the 2001 recession led the Federal Reserve to keep interest rates low during the recovery period in 2002-2004, which worked as a seed for the markedly strong run-up of house prices in the 2000s. Concerning the effect of monetary policy on real stock prices, Figure 5b illustrates that the volatility of stock prices is quite high relative to the contributions from monetary policy shocks, yet the two series are fairly correlated.[18] Expansionary monetary policy shocks contributed positively from end-2002 to mid-2004, confirming the significance of monetary policy shocks in the first half of the 2000s.

[Figures 5 and 6 somewhere HERE]

Finally we focus on the reverse causation. In particular, Figure 6a shows the contribution of house price shocks to the fed funds rate in each period, while Figure 6b displays the contribution of stock price shocks to the fed funds rate. Clearly, due to the delayed but persistent effects of housing on monetary policy (see Figure 3), house price shocks

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[17]While variance decompositions highlight the relative importance of shocks on average, the historical decomposition clarifies the time varying contributions from shocks to variables' fluctuations.

[18]Correlation coefficient of 0.42.

have contributed to increase the interest rate since the mid 1990s and until the recent financial crisis. Hence, without the house price shocks, monetary policy would have been even more expansionary in this period (in particular after the 2001 recession). This illustrates that house price developments may have had a substantial effect on the business cycle and (therefore) monetary policy.

The impact of shocks to real stock prices on monetary policy is exhibited in figure 6b. The stock market "dot-com bubble", covering roughly the period 1995-2000, clearly contributed contractionarily to monetary policy in the latter half of the 1990s. On the other hand, negative stock price shocks contributed to reduce the interest rate from Q2 in 2001 and until 2006 Q2, and again from 2008 Q1. This emphasizes the importance of stock prices as early warnings of recessions.

# 4 Robustness

We now report robustness tests of our preferred model with regard to the responses of interest rates, house prices and stock prices (the results for the other variables can be obtained on request). We first examine robustness to the chosen identification and then to model specifications.

## 4.1 Sign restrictions

We test for a possible interaction between U.S. monetary policy and house and stock prices using sign restrictions. We do this by including house prices and stock prices into two separate VAR models, each consisting of GDP, inflation and interest rates. As in the baseline model, the VAR is identified assuming a recursive order for GDP, inflation and interest rates. To identify asset prices, we now impose the restriction that house and

stock prices must react non-positive on impact following a contractionary monetary policy shock. This assumption is consistent with the findings in Del Negro and Otrok (2007) regarding house prices, and in Rigobon and Sack (2004) and Bernanke and Kuttner (2005) concerning stock prices. However, the restriction is in place for one period only, allowing house prices and stock prices to move in any direction after that. More importantly, we do not impose any restrictions on the converse relationship, i.e. whether monetary policy is responding to shocks in asset prices, which is the focal question of this paper.

Figure 7a portrays the impulse response of house prices to a monetary policy shock using the VAR model where we included real house prices. Figure 7b then displays the response in stock prices to the same monetary policy shock, except that that real house prices is replaced with real stock prices in the VAR. In both cases, the monetary policy shock is normalized to increase the interest rates by one percentage point the first quarter. Finally, Figure 8a and 8b graph the response of interest rates from a shock to house prices and to stock prices respectively (again using the two different SVARs). Note that as above, the stock price shock is normalized to increase stock prices by 10 percent the first quarter, while the house price shock is normalized to increase house prices by one percent initially. The reported median responses are graphed with probability bands represented as .16 and .84 fractiles.[19]

[Figures 7 and 8 somewhere HERE]

The figures confirm the results presented so far. A contractionary monetary policy shock reduces both house prices and stock prices on impact, although the contemporaneous response is much larger for stock prices than for house prices. Following the initial

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[19]We apply a Bayesian numerical inference method, similar to Uhlig (2005). The approach can be separated in two stages. In the first step, draws are made for the posterior distribution of the reduced form VAR coefficients. Conditioned on each of these draws, the second part involves a procedure with orthogonal draws for the contemporary matrix, where only draws that fulfill the imposed sign restrictions are kept.

reaction, the response of stock prices dies out quickly, while house prices continue to decline gradually for four to five years, until the effect dies out. Hence, monetary policy has a much more persistent and delayed effect on house prices than on stock prices. This confirms the plausibility of the restrictions imposed above.

Turning to systematic monetary policy, as found above, there is clearly a significant interest rate response following a shock in house prices (Figure 8a) or stock prices (Figure 8b). Judging by the median response, the interest rate increases for a few quarters following both shocks, before the effect dies out.

Hence, using either long-run or sign restrictions, there is clear evidence of simultaneity between monetary policy and house prices/stock prices, although monetary policy shocks have a more delayed effect on real house prices than on real stock prices.

## 4.2 Alternative model specifications

Figures 9 and 10 report robustness to the following stepwise changes: First, we let the estimation period start in 1987 (1987 Q3) and end just before the financial crisis (2006 Q4), so as to analyze the Greenspan effect in a more stable monetary policy regime [*1987-2006*].[20] Second, we use six lags in the VAR instead of our preferred four lags [*6 lags*]. Third, we remove the two impulse dummies (1984 Q4 and 1987 Q4) we have used in the VAR [*No impulse dummies*]. Fourth, an impulse dummy for 2008 Q3 is also included to control for a possible break in the variance due to the impact of the financial crisis [*Controlling for Lehman*].[21]

Finally, we include two robustness tests that are specific to stock prices and house

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[20] Alan Greenspan took office in August 1987.

[21] As an alternative, we included a step dummy in order to control more broadly for the Great Recession. The step dummy is zero prior to 2008 Q3, and takes the value 1 thereafter. Also in this case we obtain responses that are fairly similar to the baseline finding, although slightly weaker at longer horizons.

prices respectively. That is, we test robustness by adding an impulse dummy, 2001 Q3, to control for the stock market turmoil corresponding to 9/11 [*Controlling for 9/11*]. Then we add a dummy for the period 2001-2004, to examine if the link between monetary policy and house prices may have been different in this period when interest rates were kept exceptionally low. Again see Chauvet and Huang (2010) who argue that the uncertainty surrounding the end of the 2001 recession led the Federal Reserve to keep interest rates low during the recovery period in 2002-2004, which differed from monetary policy conduct in other early stages of expansion [*Controlling for 2001-2004*]. While these two dummies may potentially affect the whole system, we focus the discussion and report the results of the first test only to stock prices and the second test only to house prices.

[Figure 9 and 10 somewhere HERE]

Figure 9 and 10 illustrate that the robustness tests are supportive of our main conclusions. However, two findings should be pointed out. First, we note that the systematic response in monetary policy to a house price shock is much smaller in the period 1987-2006, when Alan Greenspan was chairman (Figure 10a). The monetary policy response to stock prices, though, is much the same. Hence, monetary policy responded much more to variations in stock prices than to house prices in the Greenspan era (Figure 10b).

Second, adding a dummy in the period 2001-2004, produces even larger monetary policy responses to a house price shock (Figure 10a). As pointed out by Chauvet and Huang (2010), the interrelationship between monetary policy and the housing cycle has changed since the 2001 recession. When including a dummy for this period (accounting for an altered relationship), we obtain a stronger systematic monetary policy response for the whole period on average. However, while this implies that monetary policy has responded less to housing and more to other factors in the period 2001-2004, the effect of monetary policy shocks on house price was basically unchanged (Figure 9a).

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## 4.3 Impulse responses using Cholesky decomposition

Finally, we ask what we have gained by using our preferred specification rather than the Cholesky decomposition. An exercise that allows us to test the implications of our own suggested decomposition would be to impose a recursive contemporaneous Cholesky ordering of all shocks, thereby restricting asset prices and monetary policy from responding simultaneously to news. Using the same ordering of the variables as in the baseline case above (where house prices and stock prices are ordered above the interest rate), the Cholesky decomposition will imply that asset prices prices cannot respond contemporaneously to a monetary policy shock. Similar restrictions were used in both Goodhart and Hofmann (2001) and Giuliodori (2005).

[Figure 11 and 12 somewhere HERE]

In Figures 11a-b we compare the results for house prices and stock prices using our structural decomposition with the findings from the Cholesky decomposition. The solid line is our baseline impulse response using the structural VAR while the dotted line is the impulse response from the Cholesky decomposition. The results emphasize that the effects of monetary policy shocks on both housing and stock prices would be much smaller using the Cholesky decompositions than our preferred identification scheme. In fact, the stock price response has the wrong sign when using the Cholesky decomposition. Hence, accounting for interdependence between monetary policy, housing and stock prices seems important.

Figures 12a-b investigate the implication for GDP and inflation by using the same Cholesky decomposition. In addition, we also perform an exercise where we exclude the asset prices from the VAR, and ask to what extent the responses in GDP and inflation will depend on the inclusion of these financial variables. Hence, the figures compare our

baseline SVAR results with (i) a VAR model with only three domestic variables, identified using the Cholesky decomposition with the ordering: output, inflation and the interest rate and (denoted *Cholesky, 3 variables*) (ii) our original baseline VAR, but now identified using the Cholesky decomposition, where house prices respond with a lag to monetary policy shocks (denoted *Cholesky, 5 variables*).

Figure 12a emphasizes that using either the three or the five variable VAR with the Cholesky decomposition, output responds very little following a contractionary monetary policy shock and, in fact, with the wrong sign. Only when we include all asset prices and use our structural identification scheme, does GDP respond significantly negative for a prolonged period. The same holds for inflation in figure 8b, although here all models imply an eventual decline in inflation. Hence, we have shown that by adding just a few series of relevant financial variables and using an identification procedure that allows for contemporaneous interaction between monetary policy and asset prices, enhance the negative response in output and inflation that has traditionally been reported in other studies.

# 5    Concluding remarks

In this paper, we analyze the role of house prices and stock prices in the monetary transmission mechanism in the U.S. The quantitative effects of monetary policy shocks are studied through structural VARs. Contrary to recent studies, we allow for full interdependence between monetary policy and both housing and stock prices. Identification is achieved by imposing a combination of short-run and long-run restrictions.

By allowing for simultaneity between monetary policy and house and stock prices, we find different roles for asset prices in the monetary transmission mechanism. In particular,

following a contractionary monetary policy shock (that raises the interest rate), stock prices fall immediately, while for house prices, the response is more gradual. However, the fall in both house prices and stock prices enhances the negative response in output and inflation that has traditionally been found in the literature. Regarding the systematic interest rate response, monetary policy responds by less to shocks in house prices than in stock prices in the short run, but the relationship is reversed in the long run. Due in part to the delayed monetary policy response to house price shocks, house prices have a much larger impact on both GDP and inflation than stock prices.

# 6  Appendix - Data

The following data series are used:

- $y_t$ Log of real GDP, s.a. Source: OECD Economic Outlook

- $\pi_t$ Inflation, measured as annual change in the log of the GDP deflator. Source: OECD Economic Outlook

- $ph_t$ Log of real house prices, s.a. House prices deflated by GDP deflator. House price index from the U.S. Federal Housing Finance Agency (FHFA HPI). Source: Thomson Reuters

- $s_t$ Log of real stock prices. Stock prices deflated by GDP deflator. Standard & Poor's 500 used as stock price index. Source: Thomson Reuters

- $i_t$ Fed funds effective rate. Source: Thomson Reuters

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Figure 1: *Responses to a monetary policy shock*
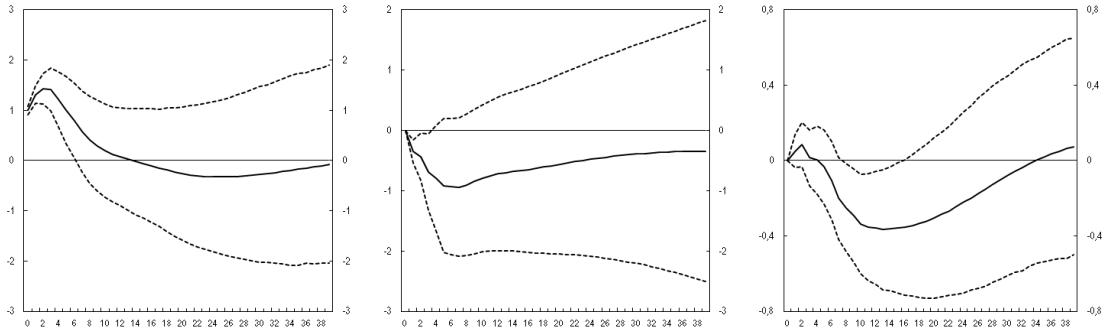


(a) Interest rate (pp)

(b) GDP (pct)

(c) Inflation (pp)
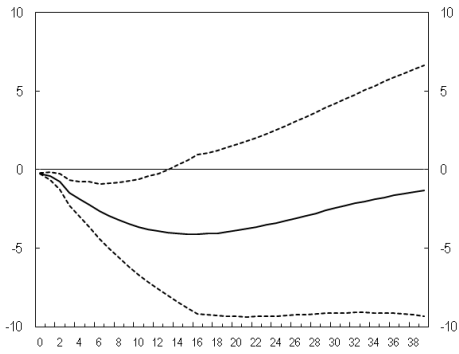
(d) Real house prices (pct)
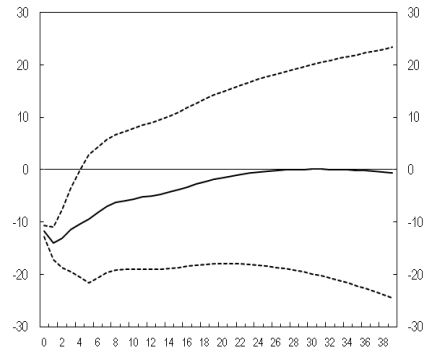
(e) Real stock prices (pct)

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Figure 2: *Variance decomposition (pct) to a monetary policy shock*



(a) Real house prices
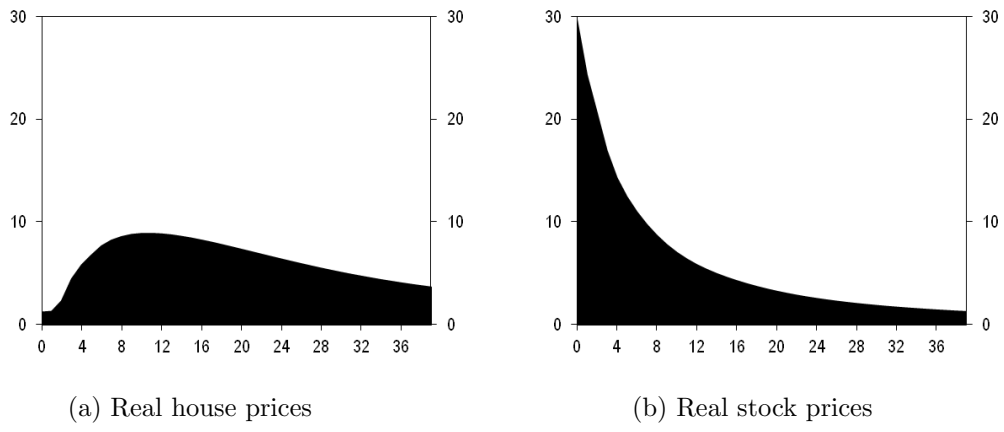
(b) Real stock prices

Figure 3: *Responses to a house price shock (left) and a stock price shock (right)*
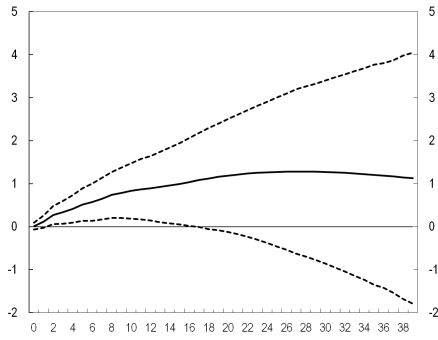


(a) Interest rate (pp): House price shock
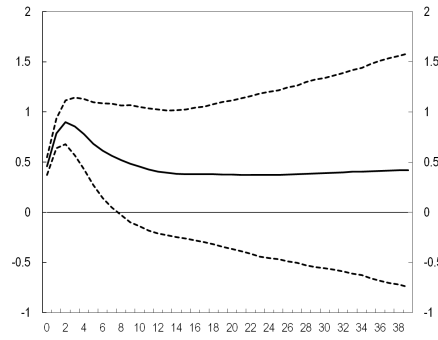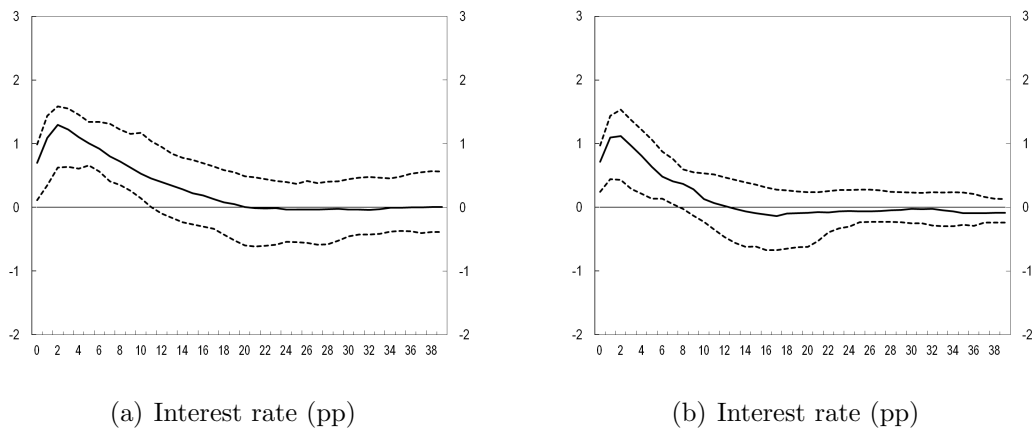
(b) Interest rate (pp): Stock price shock
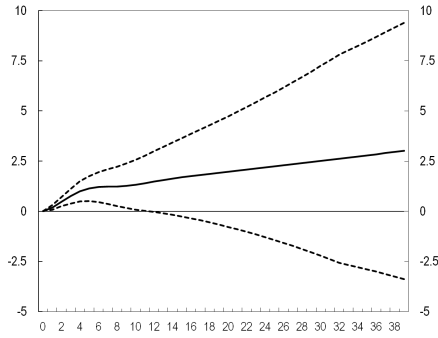
(c) GDP (pct): House price shock
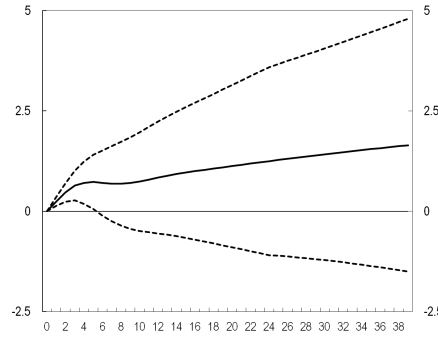
(d) GDP (pct): Stock price shock
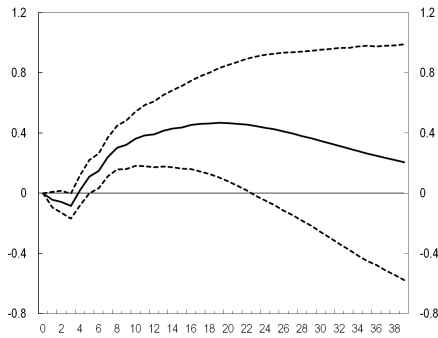
(e) Inflation (pp): House price shock
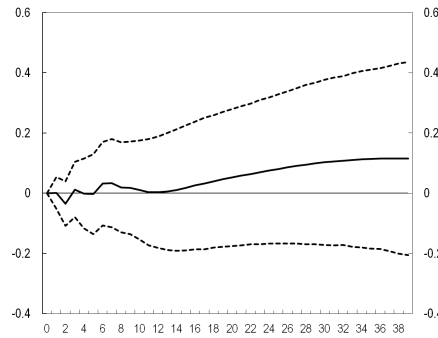
(f) Inflation (pp): Stock price shock

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Figure 4: *Variance decomposition (pct) to a house price shock (left) and a stock price shock (right)*
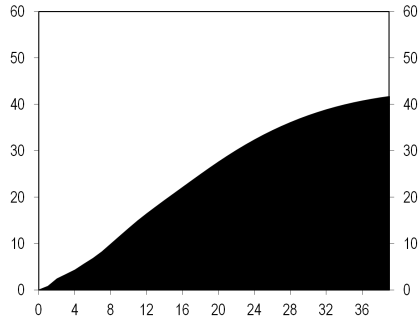


(a) Interest rate: House price shock
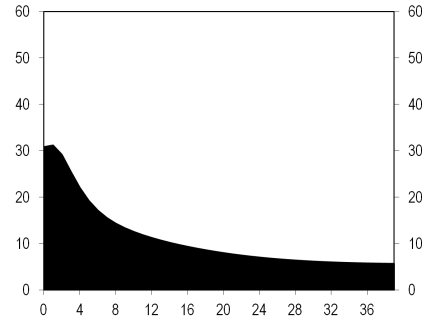


(b) Interest rate: Stock price shock
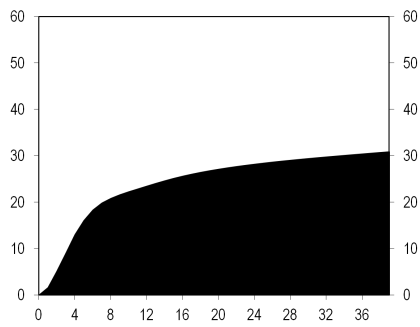


(c) GDP: House price shock
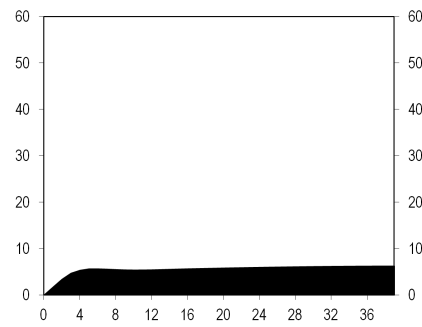


(d) GDP: Stock price shock
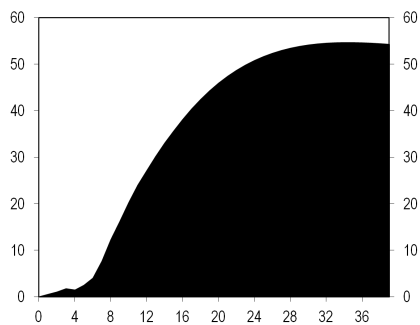


(e) Inflation: House price shock
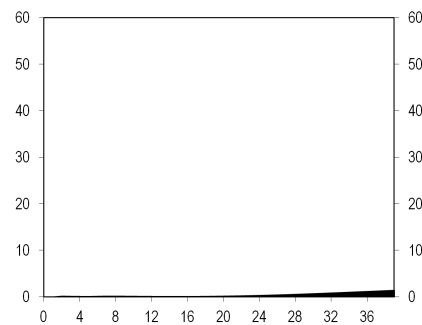


(f) Inflation: Stock price shock

Figure 5: *Contribution from monetary policy shocks to house price growth (left) and stock price growth (right)*



(a) Real house price growth (pct)

(b) Real stock price growth (pct)
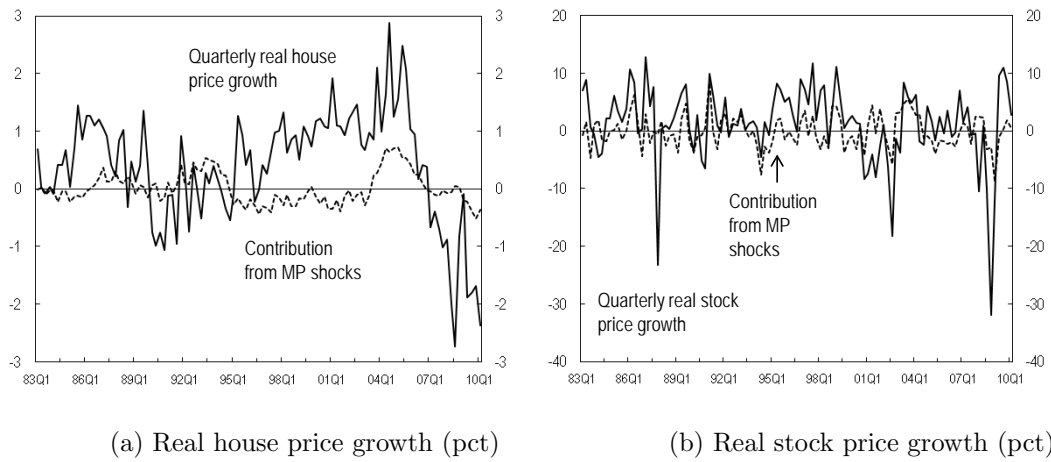
Figure 6: *Contribution from house price shocks (left) and stock price shocks (right) to the Fed funds rate*



(a) Interest rate (pp)

(b) Interest rate (pp)
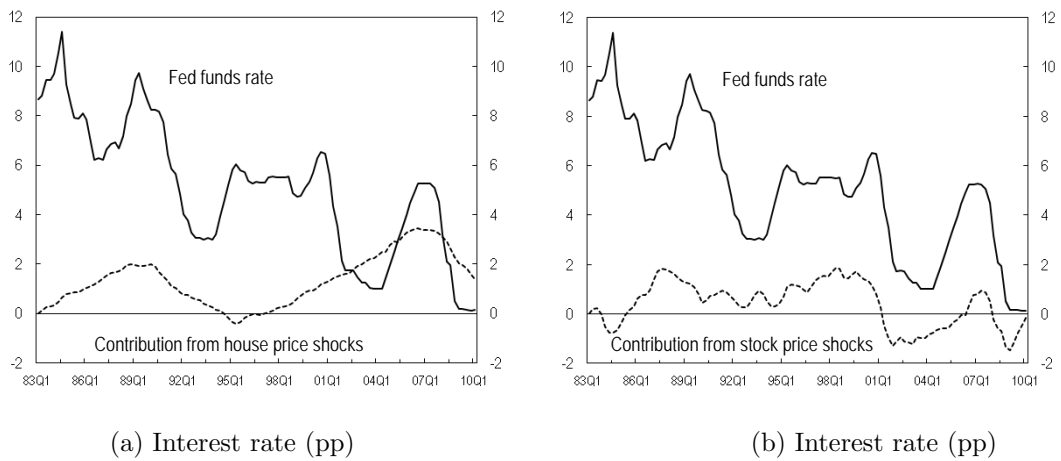
Figure 7: *Responses to a monetary policy shock, sign restrictions*



(a) Real house prices (pct)

(b) Real stock prices (pct)
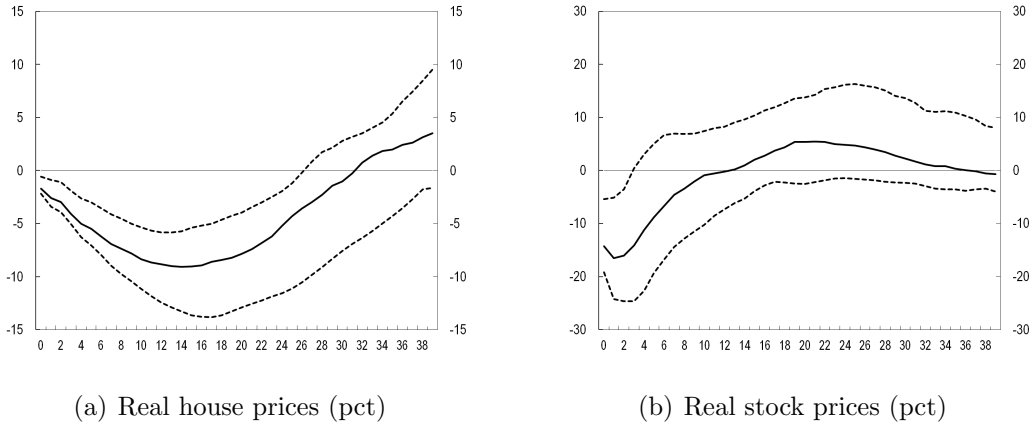
Figure 8: *Response to a house price shock (left) and a stock price shock (right), sign restrictions*



(a) Interest rate (pp)

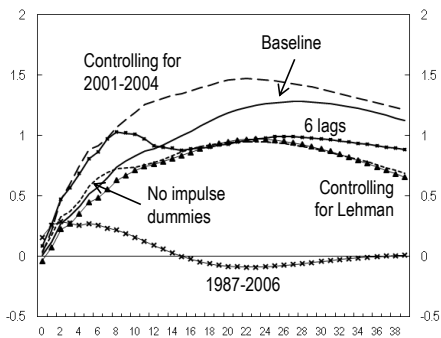(b) Interest rate (pp)

Figure 9: *Robustness: Response to a monetary policy shock*
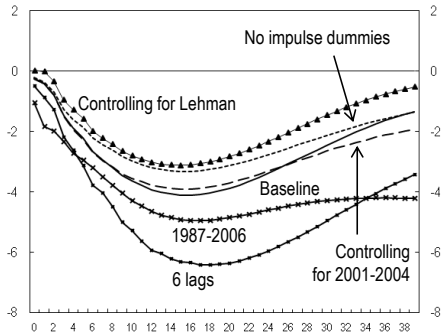


(a) Real house prices (pct)
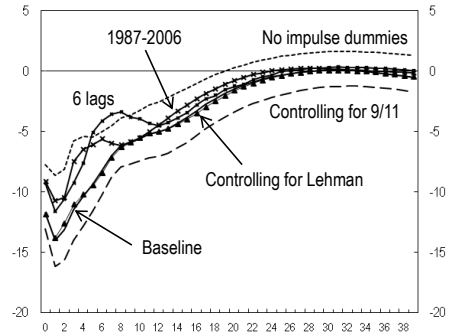
(b) Real stock prices (pct)

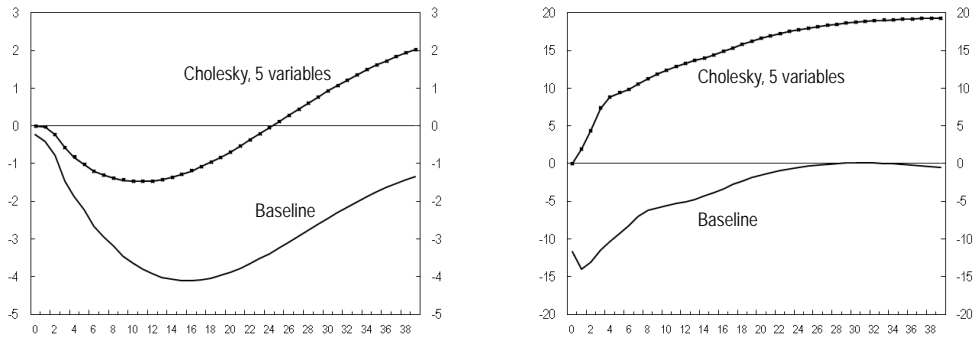Figure 10: *Robustness: Response to a house price shock (left) and a stock price shock*



(a) Interest rate (pp)
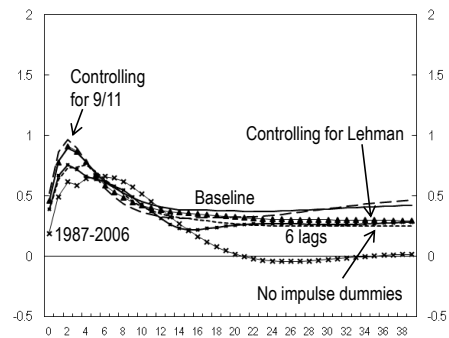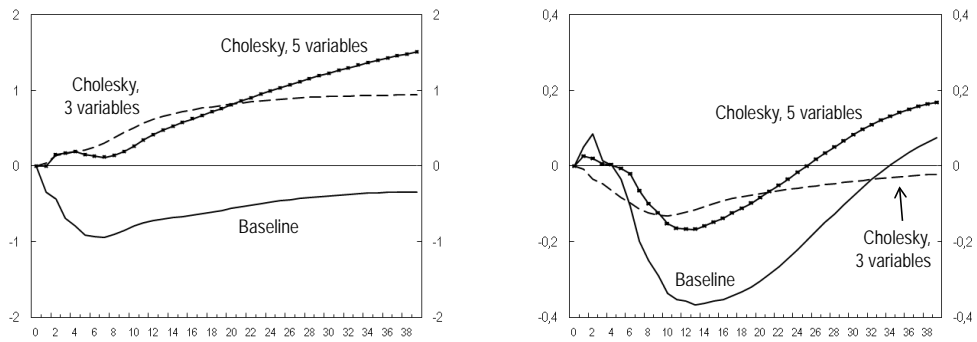
(b) Interest rate (pp)

Figure 11: *Response to a monetary policy shock: Cholesky versus structural VAR*



(a) Real house prices (pct)

(b) Real stock prices (pct)

Figure 12: *Response to a monetary policy shock: Cholesky versus structural VAR*



(a) GDP (pct)

(b) Inflation (pp)

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