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House prices, credit and the effect of monetary policy in Norway: Evidence from Structural VAR Models*

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Abstract

This paper investigates the responses of house prices and household credit to monetary policy shocks in Norway, using Bayesian structural VAR models. I find that the effect of a monetary policy shock on house prices is large, while the effect on household credit is muted. This is consistent with a relatively small refinancing rate of the mortgage stock each quarter. Using monetary policy to guard against financial instability by mitigating property-price movements may prove effective, but trying to mitigate household credit may prove costly in terms of GDP and inflation variation.

JEL-codes: E32, E37, E44, E52

Keywords: House Prices, Credit, Monetary Policy, Structural VAR

1 Introduction

This paper aims to quantify the effect of a monetary policy shock on household credit and house prices in Norway. This is motivated by the renewed interest in the role of financial variables in the business cycle and monetary policy transmission mechanism, both in academia and the central bank community. There is little disagreement among observers that the triggers of the recent crisis can be traced back to financial markets.[1] There is, however, no consensus regarding the factors that contributed to the build-up of financial imbalances prior to the crisis. Some point to the liberalisation of credit markets and, as a result, a laxer regulatory regime[2], while others, notably Taylor (2007), argue that an overly expansionary monetary policy played a decisive role.

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[1]Reinhart and Rogoff (2014), Bagliano and Morana (2012), Lall et al. (2009)

[2]E.g. Svensson (2010)

To the extent that imperfections in financial markets lead to inefficiencies, there could be a potential rationale for monetary policy to explicitly target financial variables. However, based on the seminal model developed in Bernanke et al. (1999), which introduced a financial friction due to asymmetric information, Bernanke and Gertler (1999, 2001) argue in a series of papers that there is little gain, in terms of output and inflation stability, from targeting asset prices. Their conclusion is that it is better to react swiftly and firmly should a crisis occur. This view was challenged by Cecchetti et al. (2000), who argue that leaning against movements in asset prices improves overall macroeconomic performance. The perspective in Cecchetti et al. (2000) has gathered increased support and attention after the recent financial crisis and has led to calls on monetary policy to react to movements in credit and asset prices "over and beyond" what is dictated by the medium-term outlook for inflation and real activity (Woodford (2012)). The idea here is that by restricting movements in credit and asset prices in the first place, the risk of non-fundamental movements down the road will be reduced. However, others[3] have gone further, arguing that monetary policy can in itself promote financial instabilities, for example by leading agents to engage in increased risk-taking.

This "over and beyond" strategy has gradually been adopted by Norges Bank. In the Monetary Policy Reports (MPRs)[4] the third criterium for an appropriate interest rate path states that: *"The interest rate should be set so that monetary policy mitigates the risk of a build-up of financial imbalances, and so that acceptable developments in inflation and output are also likely under alternative assumptions about the functioning of the economy."*

Even if a "leaning against the wind" approach to monetary policy is desirable, it is still not obvious that interest rates will be effective in mitigating movements in financial variables. This is a necessary condition for a successful "leaning" policy in the face of monetary policy tradeoffs.[5] In the theoretical literature, there is clearly no consensus on the quantitative effect of monetary policy on asset prices and credit. This is therefore very much an empirical question.

The international VAR literature on this issue is vast, and results vary across different studies. Assenmacher-Wesche and Gerlach (2008) use panel data from 18 OECD countries in a structural VAR and find that the impact of a monetary policy shock on asset prices and credit is modest. However, they do stress the uncertainty and the large cross-country variation in their estimates. Carstensen et al. (2009) do a similar panel data study, but use different variables and a different estimation and identification procedure. In contrast to Assenmacher-Wesche and Gerlach (2008), they find a large impact of monetary policy on house prices, but also stress the cross-country variations.

[3]E.g. Borio and Zhu (2008)

[4]Monetary Policy Report 1/14

[5]See Kohn (2006) for an elaboration of this argument

Most other VAR studies on the subject (eg. Jarocinski and Smets (2008) and Musso et al. (2011)) are based on US or euro area data. Although these papers present a useful benchmark, country-specific factors such as housing construction flexibility, transaction costs, taxes, mortgage market regulation and the proportion of fixed and variable-rate mortgages can lead to differences in the interaction between monetary policy, house prices and credit.[6]

VAR studies on this subject using Norwegian data are more limited. Bjørnland and Jacobsen (2010) find relatively strong effects of monetary policy on real house prices when using a combination of short and long run identification restrictions to identify the monetary policy shock. They also show that the effect is smaller when only using short run restrictions as in Assenmacher-Wesche and Gerlach (2008).

I extend on the VAR model of Bjørnland and Jacobsen (2010) by adding a credit variable to the model. This is motivated by the key role of credit measures in the indicators of financial instability proposed by BIS and Norges Bank.[7] In addition, the inclusion of a credit variable may capture possible multidimensional links between credit, house prices and interest rates. I also identify a monetary policy shock in a large set of competing models and identifying assumptions. Each model has its shortcomings and there are various conflicting views as to which types of assumptions is most plausible. The VAR literature on this topic also shows that results may change drastically depending on the model specifications. Overall, the evidence supports Bjørnland and Jacobsen's finding and suggests that the effect of monetary policy on house prices is quite large. In contrast, for household credit the response to a monetary policy shock seems modest. These results are relatively robust across different identification assumptions, although the effect of monetary policy on house prices is larger when simultaneous effects are allowed for.

The rest of the paper is organised as follows. The next section describes the VAR models and how the monetary policy shock is identified. In Section 3, some data issues are discussed. The results are presented in Section 4, while Section 5 concludes.

2 The VAR Models

The starting point is a reduced form VAR of the following form:

$$y_t = C_0 + C_1 t + A_1 y_{t-1} + ... + A_l y_{t-l} + u_t \tag{1}$$

where y_t is a vector of endogenous variables, C_0 is a constant, $C_1 t$ is a linear time trend, l is the number of lags, A_l are the coefficient matrices on the lags and u_t is a vector of error terms at time t. The variables in the reduced form model include GDP (mainland Norway), inflation, the real exchange rate, real house prices and interest rates as in

[6] See e.g. Calza et al. (2007) and Rubio (2011)

[7] Basel Committee on Banking Supervision (2010), Norges Bank (2013)

Bjørnland and Jacobsen (2010). In addition, real household credit is included.[8] As a robustness measure, Appendix C shows how the results change when GDP, inflation and/or the real exchange rate are replaced by other potentially relevant variables. These alternative models are selected based on out-of-sample forecasting performance.

Table 1: Lag length selection tests

Criteria	LAG 0	LAG 1	LAG 2	LAG 3	LAG 4	LAG 5
Schwarz information criterion (BIC)	-27.3	-28.5	-27.5	-25.9	-25.2	-24.5
Akaike information criterion (AIC)	-27.7	-29.9	-30.1	-29.6	-30.0	-30.4
Hannan-Quinn information criterion (HQ)	-27.5	-29.4	-29.0	-28.1	-28.1	-28.1

Note: In order to perform these tests, one VAR model was estimated for each of the lag orders. The parameters in the VARs are estimated using OLS. For all the tests the "best" model is found by minimising the score stemming from the test

The lag order of the model is based on the tests in Table 1. The BIC and HQ criterion suggest one lag, while the AIC criterion suggests a lag order of five. The VAR model with a lag order of two is second best in all the tests and is therefore used in this paper. I follow the recommendation in Sims and Zha (1999) and estimate the reduced form VAR from a Bayesian perspective using a noninformative prior.[9]

Based on the reduced form Bayesian VAR model, I identify a monetary policy shock using three different identification procedures: Choleski decomposition of the variance-covariance matrix (short run restrictions) as in Sims (1980), a combination of short and long run restrictions as in Bjørnland and Jacobsen (2010) and sign restrictions as in Uhlig (2005).

The identified models have the following form:

$$B_0 y_t = C_0 + C_1 t + B_1 y_{t-1} + ... + B_l y_{t-l} + \varepsilon_t \tag{2}$$

B_0 is the matrix of contemporaneous restrictions, $B_0^{-1} B_l = A_l$ and ε_t is a vector of structural shocks. The monetary policy shock is identified by placing direct restrictions on the B_0 matrix and/or the impulse responses stemming from the structural shock.[10] I use draws from the posterior of the reduced form model to compute the median impulse response from the structural shock and the corresponding 68 percent probability interval. The identification of structural VARs will in general be sensitive to the identification scheme employed. In order to robustify the analysis, I therefore use three different approaches to identification.

The most common way of identifying shocks in the VAR literature is by placing sufficient

[8] The next section describes the data transformations. The data sources are reported in Appendix A

[9] See Appendix B for a detailed description of the prior

[10] Christiano et al. (1999) provides an overview of identification of monetary policy shocks in structural VARs

zero restrictions on the B_0 matrix. To ensure exact identification, these restrictions are placed in a recursive (Choleski) order. One common way of identifying a monetary policy shock is by ordering interest rate last. This is assuming that monetary policy responds to all variables contemporaneously and that the contemporaneous effect of monetary policy is zero for all variables. One problem with this approach is that economic theory usually implies contemporaneous effects of monetary policy, especially on asset prices such as house prices and exchange rates. If these asset prices affect the real economy, theory also suggests that monetary policy should respond contemporaneously to movements in these variables. As discussed in Bjørnland and Jacobsen (2010) this simultaneity issue is one drawback of the Choleski identification scheme. As a robustness check, I use two different ordering assumptions, one where the interest rate is ordered last and one where house prices is ordered last.

To allow for multidirectional simultaneous effects between interest rates and asset prices, I also follow Bjørnland and Jacobsen (2010) and identify the monetary policy shock where the contemporaneous restrictions between the asset prices (house prices and exchange rate) and the interest rate are removed.[11] In order to ensure exact identification of the monetary policy shock, two restrictions on the long run multiplier of the policy shock are added. The long run restrictions imply that monetary policy shocks have no long run effect on the real exchange rate and the level of GDP. Although allowing for simultaneity is an attractive feature of adding long run restrictions, Christiano et al. (2007) find that long run restrictions generate larger confidence intervals than short run restrictions and that impulse responses may be biased.

I also identify a monetary policy shock using sign restrictions as in Uhlig (2005). This amounts to putting restrictions on the sign of the contemporaneous effect of the impulse response to the structural shock for some or all of the variables in the VAR. This procedure does not uniquely pin down the monetary policy shock as there may be several specifications of the B_0 matrix that satisfy the specified sign restrictions. For each draw of the posterior of the reduced form BVAR, the algorithm searches until one draw of the B_0 matrix satisfies the sign restrictions. One advantage of using sign restrictions is that it allows for full simultaneity between interest rates and all the other variables in the VAR, consistent with the DSGE literature. Fry and Pagan (2011), however, point out that sign information is very weak. I therefore have to apply several restrictions to separate the monetary policy shock from other shocks. I follow the recommendation of Fry and Pagan (2011) and use information from DSGE models to find suitable restrictions. For the monetary policy shock, I follow Farrant and Peersman (2006) and impose the restriction that a contractionary policy shock that raises interest rates does not on impact lead to an increase in inflation and GDP and leads to an exchange rate appreciation. I also impose the restriction that a contractionary policy shock does not increase real household credit and real house prices on impact.[12]

[11] See Faust and Leeper (1997) for a further discussion of long run restrictions
[12] These restrictions are consistent with the DSGE model in Iacoviello (2005)

3 Data

The sample period of the (quarterly) data spans from 1994 Q1 to 2013 Q4. I select this period since the process of deregulating the credit market had mostly been accomplished by the mid–1990s (see Steigum (2010)). Moreover, the disinflation process had been completed in Norway in the mid–1990s, even though inflation targeting was not formally introduced until 2001, see Figure 1. A fairly stable monetary policy regime is essential when estimating the effects of a monetary policy shock.

The variables are converted to log differences (except for interest rates, which is in levels). The credit and house price data are plotted in Figure 2. As a preliminary observation it is interesting to note that real house prices growth exhibit large business cycle fluctuations, while real household credit growth seems to be non-stationary. In a Dickey-Fuller test one can reject the null-hypothesis of a unit root for all growth variables except the credit variable.

To deal with the possibility of non-stationarity, I apply a band-pass filter[13] to remove low-frequency movements in real household credit growth, see Figure 3. One interesting observation is that the standard deviation is more than 4 times larger for real house price growth than for the growth rate of the filtered credit series, suggesting that business cycle fluctuations are relatively small for household credit.[14]

4 Results

The median response to a monetary policy shock is larger for house prices than for credit for all the identification procedures. This is also true for all the alternative models in Appendix C. The effect on house prices is larger when simultaneous effects of monetary policy on house prices are allowed for, while the response of credit is relatively small in all the identified models. The monetary policy shocks stemming from the Choleski decomposition introduce a price puzzle and one can therefore question whether this procedure is able to identify a pure monetary policy shock.

4.1 The impulse responses

Figures 4-7 show the median and the 68 percent posterior probability bands of the impulse response to a monetary policy shock in the different structural BVAR models. For all impulse responses the initial interest rate response is normalised to one percentage point.

The main difference between the two models with only short run restrictions is the

[13] I remove growth cycles longer than 8 years as suggested in Christiano and Fitzgerald (2003)

[14] This ratio does not change if real house price growth is also filtered using a bandpass filter, as almost all of the variation in real house price growth is business cycle variation

effect of monetary policy on house prices. When house prices is ordered last the effect of monetary policy is amplified, suggesting that there are important contemporaneous effects of monetary policy on house prices. The effect on credit is relatively modest in both models. I also find that a policy shock that raises interest rates leads to an increase in inflation.[15] This puzzle is common in structural VARs and some suggest that this may be due to the cost channel of monetary policy (Chowdhury et al. (2006) and Ravenna and Walsh (2006)). However, Rabanal (2007) and Castelnuovo (2012) argue that it is unlikely that the cost channel dominates the demand channel after a monetary policy shock in a New Keynesian framework. Further Carlstrom et al. (2009) show that standard Choleski assumptions may severely distort the impulse response function and produce a price puzzle, even though this is not the case in the data generating process. The price puzzle may therefore suggest that the Choleski identification assumptions are unable to identify a pure monetary policy shock.

The price puzzle is reduced and the effect of monetary policy on house prices is larger when I introduce long run restrictions on the real exchange rate and GDP and relax the short run restrictions on house prices and the real exchange rate, see figure 7. This is in line with the results in Bjørnland and Jacobsen (2010). For credit the response is small and in line with the models with only short run restrictions. One issue with this model is that even if I remove the short run restrictions between interest rates and exchange rate I still find no significant appreciation of the exchange rate in response to a contractionary policy shock. As predicted by Christiano et al. (2007), the uncertainty bands are wider when the long run restrictions are introduced.

In the model(s) with sign restrictions I remove the price puzzle by construction. I also impose an exchange rate appreciation on impact. The impulse responses stemming from the sign restriction model are broadly in line with the other estimated models in this paper. Allowing for short run effects of monetary policy on credit growth does not seem to change the relatively small movements in credit after a monetary policy shock.

[15] Estimating a monetary policy shock where both the exchange rate and house prices are ordered after interest rates in the Choleski ordering does not change the impulse responses or reduce the price puzzle in this model

Table 2: Response to a monetary policy shock

Paper	Country(ies)	Real house prices	Real credit
This paper: Choleski (interest rate last)	Norway	0-3	0-1
This paper: Choleski (House prices last)	Norway	2-5	0.25-0.75
This paper: Long and short run restrictions	Norway	3-14	0.25-1.25
This paper: Sign restrictions	Norway	2-8	0.5-1.75
Bjørnland and Jacobsen (2010)	Norway	2-4	
Assenmacher-Wesche and Gerlach (2008)	Norway	0.5-3	(-2)-2
Assenmacher-Wesche and Gerlach (2008)	OECD	0.5-2	1-2
Carstensen et al. (2009)	OECD	5-15	
Goodhart and Hofmann (2008)	OECD	2-4	1-3
Jarocinski and Smets (2008)	US	2-4	
Musso et al. (2011)	US	1-3	1-3
Musso et al. (2011)	euro area	0.5-1.5	0.5-1.5
Lasèen and Strid (2013)	Sweden	1	1 (only mean is reported)
Aoki et al. (2004)	UK	0.5-2	

Note: This table shows the maximum impact of a monetary policy shock that lowers interest rates by one percentage point on real house prices and real credit. For other studies the presented numbers are approximations based on visual inspection of graphed impulse responses in the respective paper.

Table 2 compares the impulse responses of real credit and real house prices to similar VAR studies. The response of house prices to a monetary policy shock in the estimated models in this paper is relatively large compared to most international studies, except the Choleski model with interest rate ordered last. This result is not surprising as Figure 8 shows that the Norwegian housing market exhibits more short run fluctuations than the US housing market.

As opposed to real house prices, the response of real household credit to an interest rate shock is relatively small also compared to international studies. The short run fluctuations in credit seem similar or even slightly smaller in Norway compared to the US, suggesting that the spillovers from short run fluctuations in house prices to household credit is smaller in Norway. The small response of credit is supported by the only other VAR study using Norwegian credit data (Assenmacher-Wesche and Gerlach (2008)), which finds no significant effect on real credit after a monetary policy shock.

One feature of the standard DSGE models[16] with financial frictions is that loans are renewed every quarter. The level of credit will therefore adjust relatively quickly in response to movements in asset prices following a monetary policy shock. Gelain et al. (2014) show that credit responds more sluggishly to a monetary policy shock when long-term debt contracts are introduced. Based on a similar argument, Svensson (2013) claims that a monetary policy tightening leads to a higher (not lower) household debt-to-GDP ratio. He therefore argues that leaning against the wind by targeting the household debt-to-GDP ratio, as suggested by eg. Borio and Lowe (2004), is counterproductive.

[16]See e.g Iacoviello (2005)

Figure 9 shows how the household debt-to-GDP ratio responds to a contractionary monetary policy shock in the different structural BVAR models. All the models show a slight rise in this relationship after a monetary tightening, although the rise is not significant in all the models. These results partially support the claim in Svensson (2013) that a monetary policy tightening leads to a higher, not lower, household debt-to-GDP ratio.

5 Conclusions

This paper presents an empirical analysis of the effect of monetary policy shocks on house prices and credit using several estimated Structural Bayesian Vector Autoregression models. Overall the results in this paper support the finding in Bjørnland and Jacobsen (2010) that house prices react fairly strongly to a monetary policy shock in Norway. This strong effect is robust for most of the estimated models and relatively large compared to similar SVAR-studies using US, EURO or OECD data. For household credit the estimated effect of monetary policy is modest across all the models also compared to other studies.

Based on the results in this paper, it is not clear that using household debt-to-GDP ratio as an indicator in a "leaning against the wind" approach to monetary policy will be successful. However, the results seem to suggest that interest rates have a large impact on real house prices and that using real house prices as an indicator in a monetary policy framework might prove more effective. The modest response of real credit to movements in interest rates and house prices suggests that the refinancing rate of the mortage stock is relatively slow in Norway. A strategy to stabilise house prices at their fundamental value in the business cycle will in the long run also stabilise household debt if household credit is mainly used for housing. Using the household debt-to-GDP ratio as an indicator in a monetary policy framework may on the other hand generate large swings in inflation, house prices and the real economy.

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Appendix A: Data

Nominal interest rate Norway: Three-month money market rate (NIBOR). *Source: Norges Bank*

Prices Norway: Seasonally adjusted consumer price index adjusted for tax changes and excluding energy products (CPI-ATE). *Sources: Statistics Norway and Norges Bank*

Domestic Prices Norway: Seasonally adjusted consumer price index domestic sources adjusted for tax changes and excluding energy products. *Sources: Statistics Norway and Norges Bank*

Prices Abroad: Trade-weighted consumer price index for 25 trading partners. *Sources: Ecowin and Norges Bank*

Real house prices: Seasonally adjusted nominal house prices deflated by the CPI-ATE. *Sources: Statistics Norway, Eiendomsmeglerforetakenes forening (EFF), Finn.no, Eiendomsverdi and Norges Bank*

Real household credit: C2 for households chained and break-adjusted deflated by the CPI-ATE and adjusted for population growth. *Sources: Statistics Norway and Norges Bank*

GDP mainland Norway: Seasonally adjusted GDP mainland Norway (volumes) from national accounts adjusted for population growth. *Source: Statistics Norway*

Household consumption: Seasonally adjusted household final consumption (volumes) from national accounts adjusted for population growth. *Source: Statistics Norway*

Residential investment: Seasonally adjusted gross investment in housing (volumes) from national accounts adjusted for population growth. *Source: Statistics Norway*

Real exchange rate: Trade-weighted nominal exchange rate index (I-44) for 44 trading partners adjusted for relative prices in Norway and abroad. *Sources: Thomson Reuters, Statistics Norway, Ecowin and Norges Bank*

Hours worked: Total hours worked in mainland Norway from national accounts adjusted for population growth. *Source: Statistics Norway*

Population: Population from 16 to 74. *Source: Statistics Norway*

Output gap: The percentage deviation between GDP for mainland Norway and projected potential GDP for mainland Norway estimated by Norges Bank. See Hagelund and Sturød (2012) for a more detailed description of the output gap estimation. *Source: Norges Bank*

Interest rates abroad: Trade-weighted 3-month nominal money market interest rate for four trading partners (SWE, USA, EUR and GBR) *Sources: Thomson Reuters and Norges Bank*

Population US: Working-age population. *Source: Bureau of Labor Statistics*

Prices US: Consumer price index (CPI). *Sources: OECD, Main Economic Indicators (database)*

Real house prices US: Residential property prices, existing houses adjusted for CPI. *Source: Federal Housing Finance Agency (FHFA)*

Real household credit US: Credit to households and NPISHs provided by all sectors adjusted for CPI and population growth. *Source: BIS*

Appendix B: Bayesian estimation and priors

I use an uninformative version of the natural conjugate priors described in Koop and Korobilis (2009). For simplicity, assume equation 1 is rewritten in the following form:

$$Y = XA + E \tag{3}$$

where X now includes all regressors in equation 1, i.e. lagged endogenous, the constant and the time trend and E has a variance-covariance matrix Σ. Since $A = (C_0 \quad C_1 \quad A_1 \quad A_2)'$ equation 3 can be written in the following form:

$$y = (I_n \otimes X)\alpha + \epsilon \tag{4}$$

where n is the number of endogenous variables in the VAR and $\alpha = vec(A)$. The natural conjugate prior has the following form:

$$\alpha|\Sigma \sim \mathcal{N}(\underline{\alpha}, \Sigma \otimes \underline{V}) \tag{5}$$

and

$$\Sigma^{-1} \sim \mathcal{W}(\underline{S}^{-1}, \underline{\nu}) \tag{6}$$

where $\underline{\alpha}$, $\underline{V}$, $\underline{\nu}$ and $\underline{S}$ are hyperparameters. Noninformativeness is then achieved by setting $\underline{\nu} = \underline{S} = \underline{V}^{-1} = cI$ and letting $c \to 0$. With this prior the posterior becomes:

$$\alpha|\Sigma, y \sim \mathcal{N}(\overline{\alpha}, \Sigma \otimes \overline{V}) \tag{7}$$

and

$$(\Sigma^{-1}|y) \sim \mathcal{W}(\overline{S}^{-1}, \overline{\nu}) \tag{8}$$

where

$$\overline{V} = (\underline{V}^{-1} + X'X)^{-1}, \tag{9}$$

$$\overline{A} = \overline{V}(\underline{V}^{-1}\underline{A} + X'X\hat{A}), \tag{10}$$

$$\overline{\alpha} = vec(\overline{A}), \tag{11}$$

$$\overline{S} = S + \underline{S} + \hat{A}'X'X\hat{A} + \underline{A}'\underline{V}^{-1}\underline{A} - \overline{A}'(\underline{V}^{-1} + X'X)\overline{A} \tag{12}$$

and

$$\overline{\nu} = T + \underline{\nu} \tag{13}$$

Where T is the number of observations and $\hat{A} = (X'X)^{-1}X'Y$ is the OLS estimate of A.

Appendix C: Robustness

In order to arrive at the best alternative reduced form specifications, I estimate a large number of candidate VARs and compare their out-of-sample forecasting performance. The number of variables in each VAR is 6 or 7 [17] with a lag order of two or three. A general requirement is that every individual VAR includes the main variables of interest, namely the nominal interest rate, real house price growth and real household credit growth. The candidate reduced form VARs are then generated by adding all possible three or four-variable subsets from a larger set of potentially relevant variables. The list of "relevant" variables includes: GDP growth (mainland Norway), output gap, change in output gap, change in hours worked, consumption growth, core inflation, domestic inflation, residential investment growth, change in the real exchange rate, foreign interest rates and real foreign interest rates. This amounts to approximately 400 reduced form models.

All the reduced form models are estimated from 1994 Q1 to 2003 Q4 and than recursively estimated from 2004 Q1 to 2013 Q4.[18] In the recursive estimation period the out-of-sample point-forecast error is stored. The average mean root squared forecast error (MRSE) for interest rate, house prices and household credit 1 to 8 quarters ahead is then calculated. The MRSE is adjusted for the standard deviation of the variables when the MRSEs for the three variables of interest are weighted together. The ten models with the lowest MRSE are reported in Table 3.[19]

Table 3: Alternative models

Rating	Variables	LAGS
1	Core inflation, Residential investment growth and Consumption growth	2
2	Domestic inflation, Residential investment growth and Consumption growth	2
3	Core inflation, Real foreign interest rates and Consumption growth	2
4	Domestic inflation, Change real exchange rate and Consumption growth	2
5	Domestic inflation, Residential investment growth and GDP growth (mainland Norway)	2
6	Core inflation, Residential investment growth, real foreign interest rates and Consumption growth	2
7	Domestic inflation, Change real exchange rate and GDP growth (mainland Norway)	2
8	Core inflation, Residential investment growth and Real foreign interest rates	2
9	Core inflation, Residential investment growth and GDP growth (mainland Norway)	2
10	Domestic inflation, Residential investment growth and Real foreign interest rates	2

Note: These are the ten models with the lowest MRSE in the out-of-sample forecasting exercise. Nominal interest rate, real house price growth and real household credit growth are included in all the models

[17] I do not allow for more variables due to the curse of dimensionality problem. The number of parameters in a VAR increases exponentially with the number of variables

[18] OLS estimates of the parameters are used in this exercise

[19] In a Diebold-Mariano test 250 of the 400 reduced form models have a significantly higher MRSE than the "best" model(at a five percent level). The main reduced form model presented in this paper has the 23rd lowest MRSE, not significantly higher than the best model

A monetary policy shock is identified for all the models in Table 3 using sign restrictions as described in Section 2. I impose the restriction that all economic activity[20] and inflation[21] measures do not on impact increase after a contractionary policy shock and that the real exchange rate appreciates. I place no restrictions on the response of foreign interest rates. Figure 10 shows the median response of real house prices and real household credit to a monetary policy shock for all the models in Table 3. This robustness exercise supports the claim that the effect of a monetary policy shock is relatively large for house prices and small for household credit.

[20] GDP growth, residential investment growth and consumption growth

[21] Core inflation and domestic inflation

Appendix D: Figures

Figure 1: Core inflation Norway

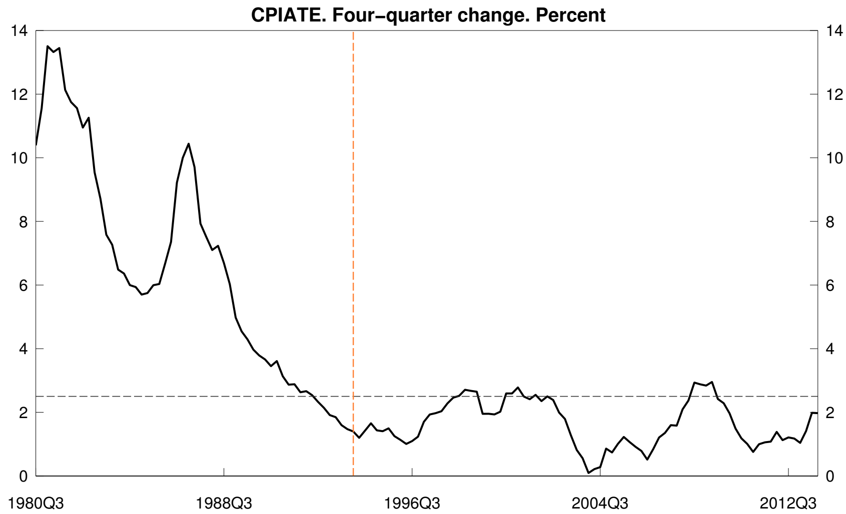


Figure 2: Credit and house prices

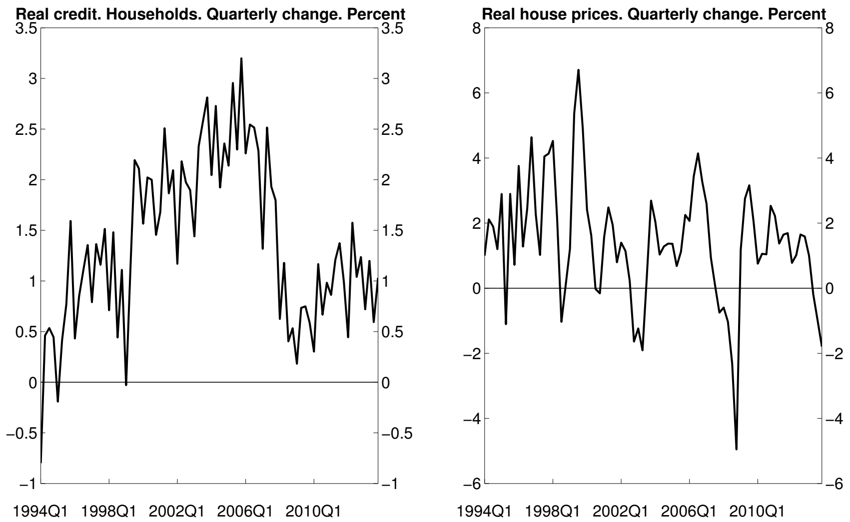
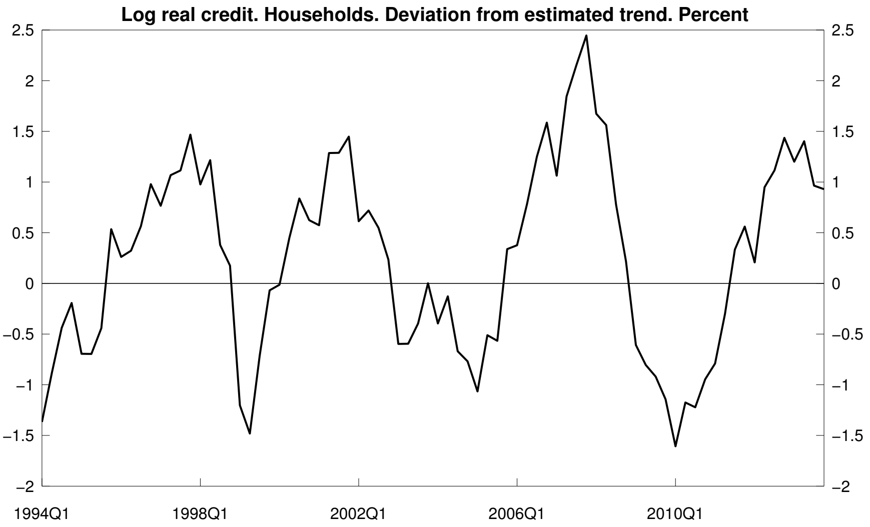
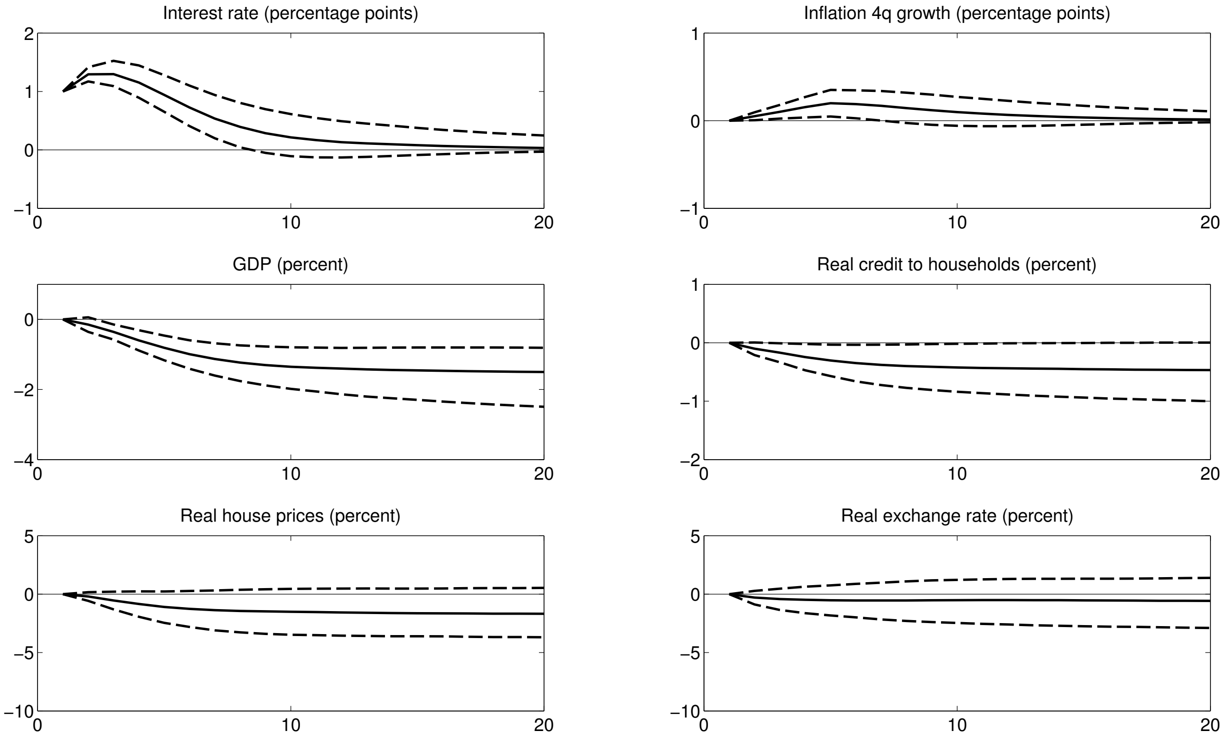


Figure 3: Band-pass filtered credit gap



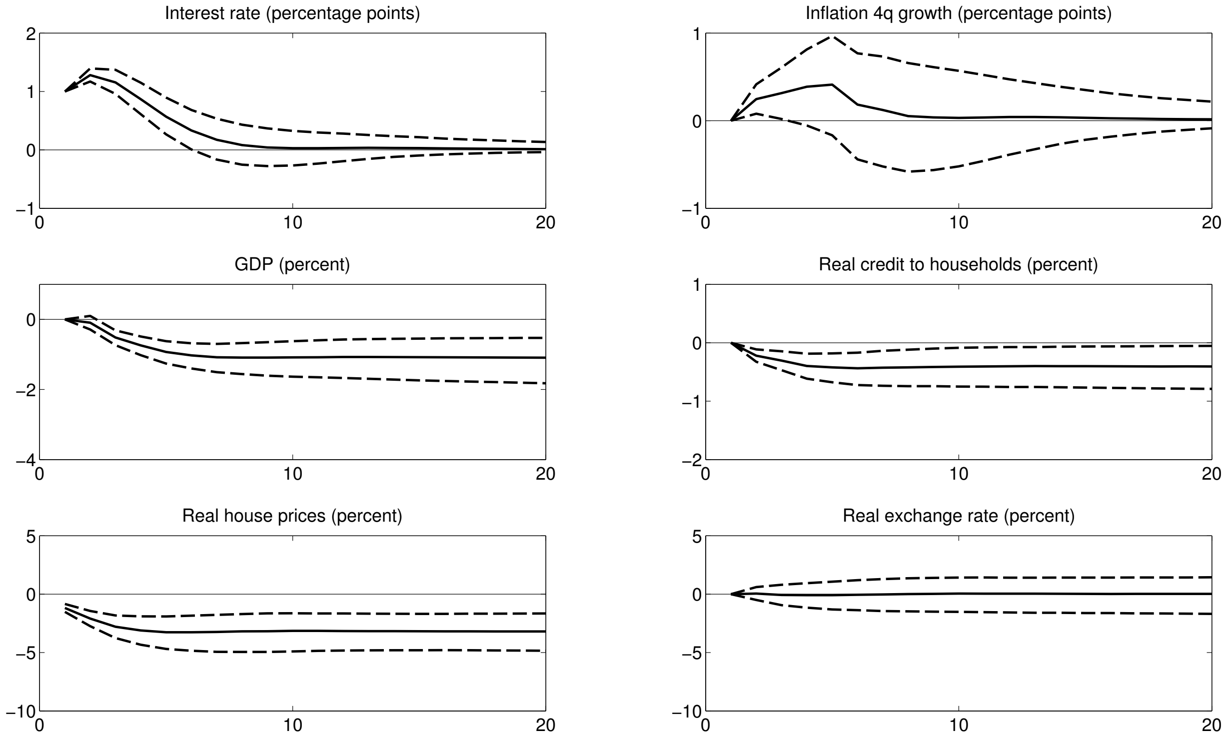
Log of Band-pass filtered credit series. The band-pass filter applied removes growth cycles longer than 8 years. The first difference of this series is used in the models

Figure 4: Monetary policy shock: Choleski. Monetary policy ordered last



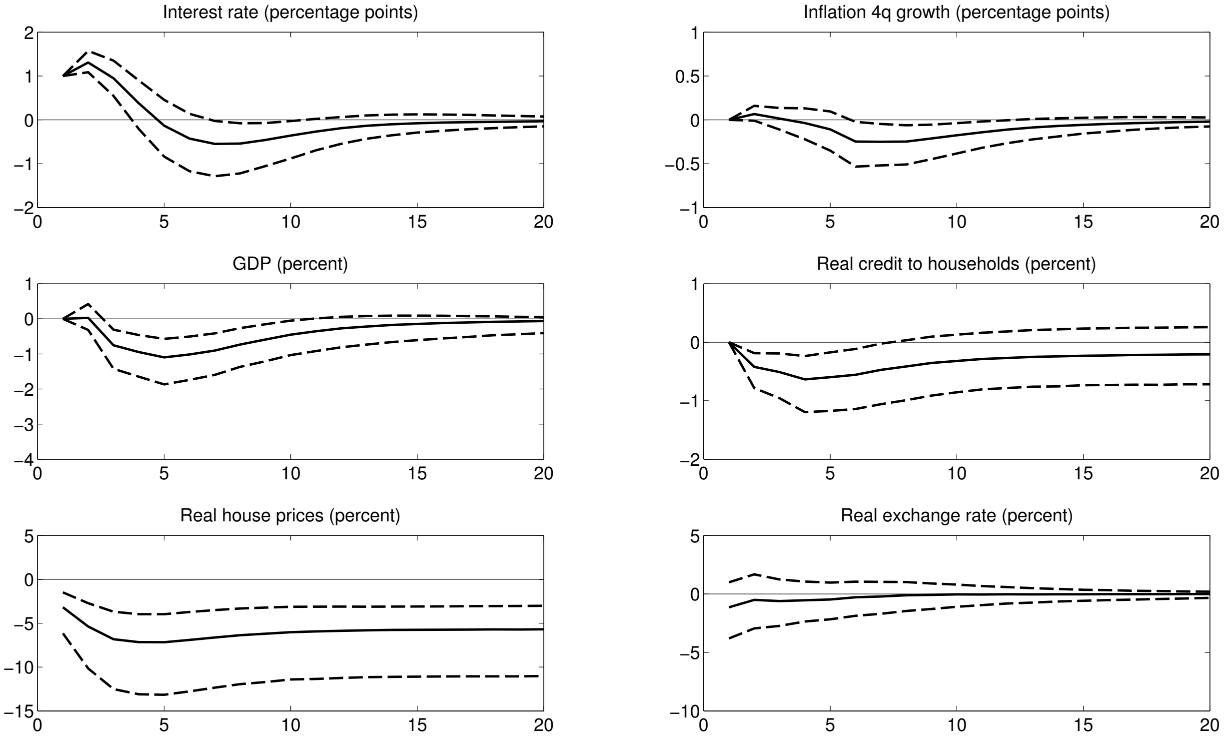
Impulse responses from a monetary policy shock. Identification is achieved through a Choleski factorisation of the variance-covariance matrix with interest rate ordered last. Solid lines are median estimates, while dotted lines are the 16th and 84th percentile probability bands

Figure 5: Monetary policy shock: Choleski. House prices ordered last



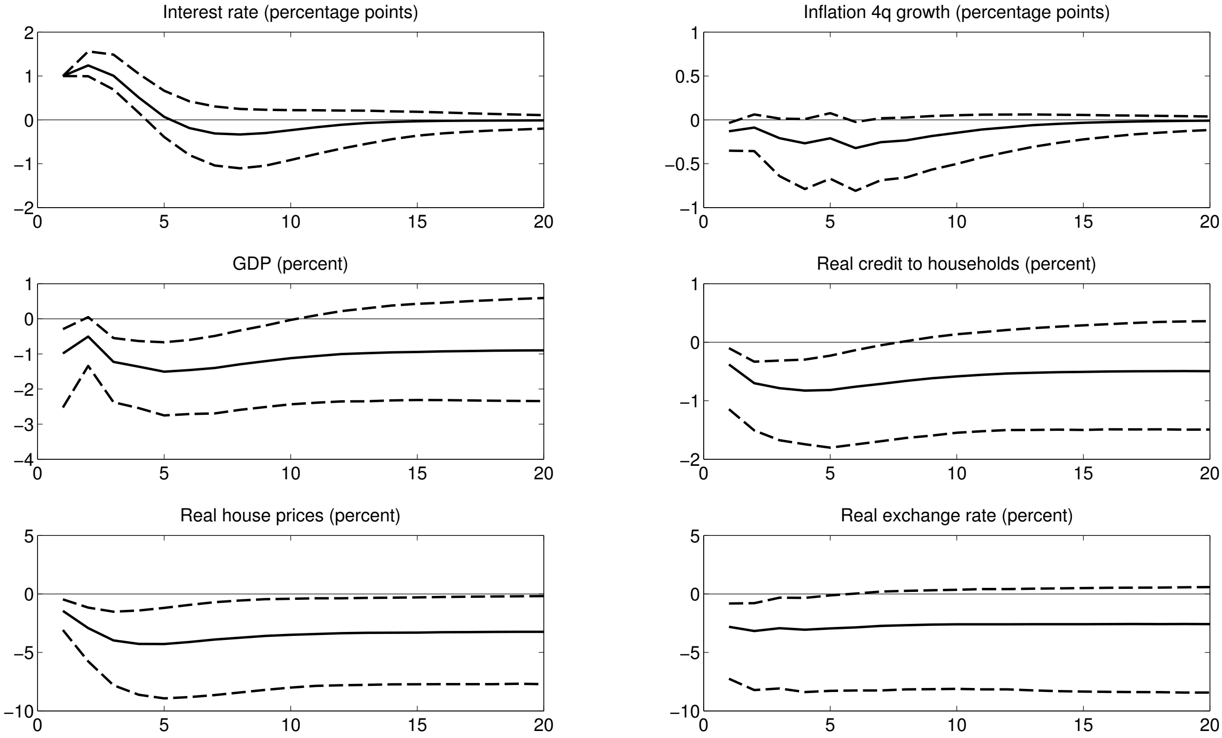
Impulse responses from a monetary policy shock. Identification is achieved through a Choleski factorisation of the variance-covariance matrix with house prices ordered last and interest rate ordered penultimate. Solid lines are median estimates, while dotted lines are the 16th and 84th percentile probability bands

Figure 6: Monetary policy shock: Long and short run restrictions



Impulse responses from a monetary policy shock. Identification is achieved through a combination of zero and long run restrictions. Solid lines are median estimates, while dotted lines are the 16th and 84th percentile probability bands

Figure 7: Monetary policy shock: Sign restrictions



Impulse responses from a monetary policy shock. Identification is achieved through sign restrictions on impact. Solid lines are median estimates, while dotted lines are the 16th and 84th percentile probability bands

Figure 8: Real house prices and real household credit per capita

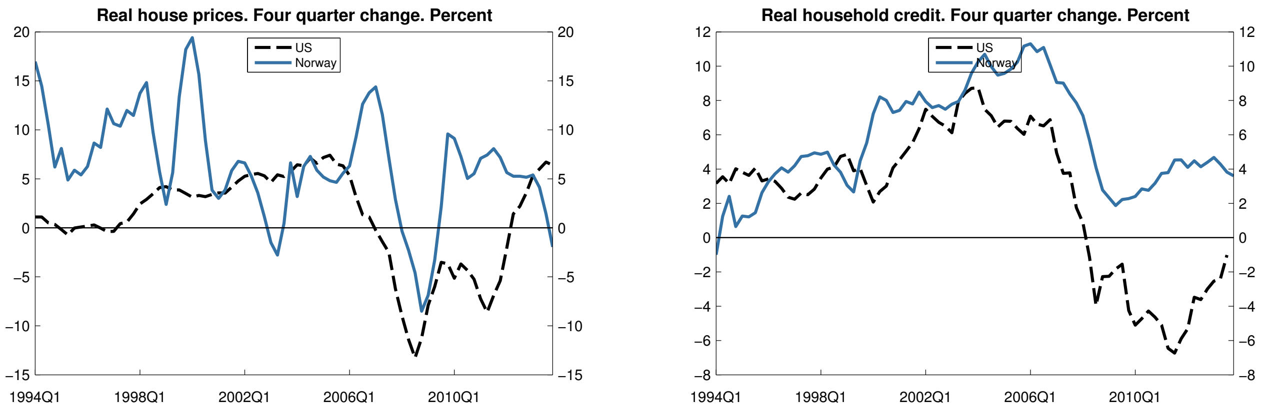
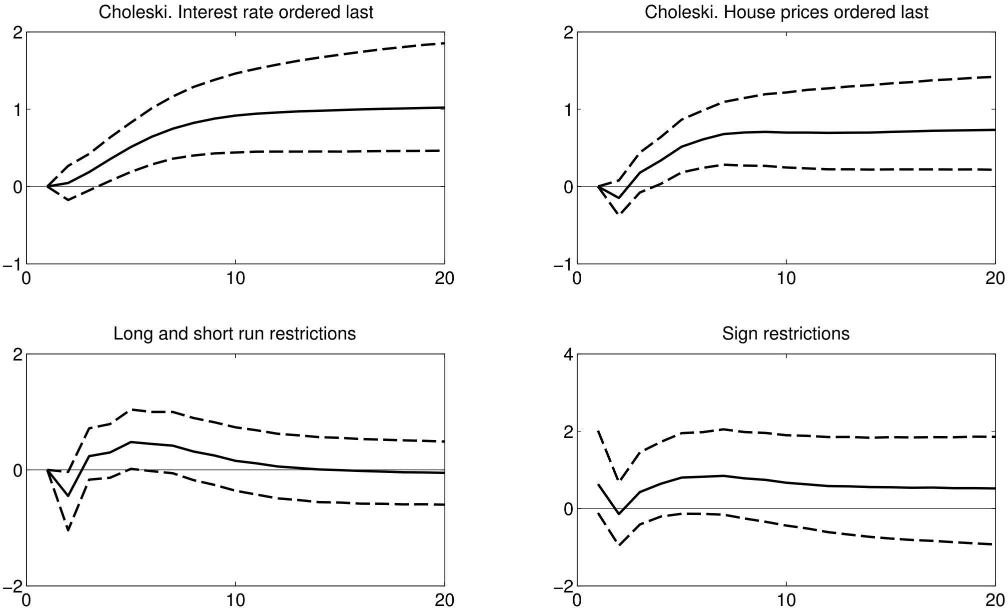
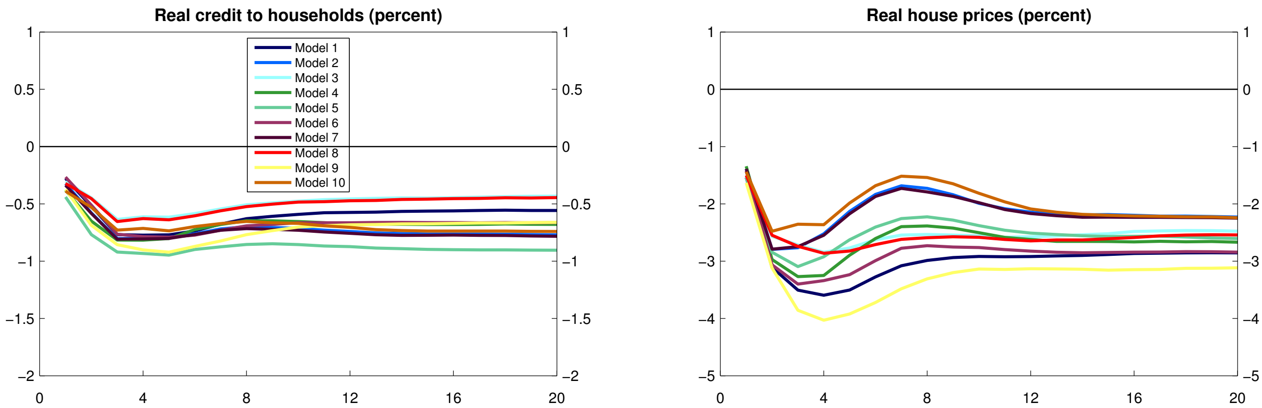


Figure 9: Monetary policy shock: Real credit over GDP



Impulse responses from a monetary policy shock on real household debt/GDP using the four identification schemes described above. Solid lines are median estimates, while dotted lines are the 16th and 84th percentile probability bands

Figure 10: Robustness: Monetary policy shock(sign restrictions)



Impulse responses from a monetary policy shock for all the models in Table 3. Identification is achieved through sign restrictions on impact. The lines are median estimates from the different models.