The role of house prices in the monetary policy transmission mechanism

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Abstract
We analyse the role of house prices in the monetary policy transmission mechanism in Norway, Sweden, UK and USA using structural VARs. A solution is proposed to the simultaneity problem of identifying shocks to monetary policy and house prices by using a combination of short-run and long-run (neutrality) restrictions. By allowing the interest rate and housing to react simultaneously to news, we find the role of house prices in the monetary transmission mechanism to increase considerably. In particular, house prices fall immediately by 1-2 percent due to a monetary policy shock that raises the interest rate by one percentage point. Furthermore, the fall in house prices enhances the negative response in output and consumer price inflation that has traditionally been found in the conventional literature. Finally, we find that following an innovation that increases house prices with one percent, monetary policy will (eventually) respond by increasing the interest rate with 10-40 basis points.

Keywords: VAR, monetary policy, house prices, identification.
JEL-codes: C32, E52, F31, F41

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1 Introduction

The widespread liberalisation of financial markets in the 1980s has increased the interest in asset price developments, in particular among central banks. This is primarily due to the fact that asset prices, such as housing and stock prices, have a central collateral role in the lending sector, making them an important source of macroeconomic fluctuations that an inflation targeting central bank may want to respond to, see e.g. Bernanke et al. (2000) and Bernanke and Gertler (1989).

However, asset prices are not only considered as sources of shocks. Due to their role as stores of wealth, they may also be important transmitters of shocks since asset prices react quickly to news (incl. monetary policy announcements), as emphasised in Zettelmeyer (2004), Rigobon and Sack (2004) and Bernanke and Kuttner (2005) among others. Hence, with their timely response to economic shocks, asset prices may be important indicators of the stance of monetary policy. Understanding the role of asset prices in the transmission mechanism of monetary policy may therefore be imperative for the implementation of an efficient monetary policy strategy.

In this paper, we analyse the role of house prices in the monetary transmission mechanism in four different (open and closed) economies; Norway, Sweden, UK and the US, using a structural vector autoregressive (VAR) model. We focus on housing as it is the most significant 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 shock to house prices may therefore have the potential of influencing growth and ultimately consumer price inflation. In particular, a higher house price will increase the wealth of homeowners, who may want to extract some of the gain to consumption or investment. Moreover, when the value of collateral rises, this will increase the availability of credit for borrowing-constrained agents. Finally, due to the Tobin’s q effect, increased house prices may have a stimulating effect on housing construction. Hence, a shock to house prices may therefore eventually affect real growth and consumer prices, making house prices an important forward looking variable that convey useful information relevant to the monetary policymaker.

The common procedure for analysing the effect of monetary policy on economic variables has usually been the structural VAR approach, first initiated by Sims (1980). Based on this approach, there is by now a substantial literature providing a consensus regarding the effects of monetary policy on macroeconomic variables in the closed economy, (see e.g. Christiano et al., 1999) and in the open economy (see e.g. Eichenbaum and Evans, 1995). However, so far the role of housing in the monetary policy transmission mechanism has largely been ignored; with the recent exceptions of Goodhart and Hofmann (2001), Iacoviello (2005) and Giuliodori (2005).

A major challenge when incorporating house prices into the VAR model, though, is how to identify the various shocks, as both the interest rate and house prices may respond simultaneously (within the quarter) to news. Most of the VAR studies that incorporate

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1 More precise, while there is a consensus with regard to the effect on variables such as output and inflation, the results are more ambiguous with respect to the exchange rate (see Bjørnland, 2006).
housing, including those cited above, largely ignore this simultaneity by placing recursive, contemporaneous restrictions on the interaction between monetary policy and house prices. In particular, they either assume 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, 2005). Yet, both restrictions are potentially wrong, the first as theory predicts that house prices will respond quickly to a monetary policy shock (see the structural model presented by Iacoviello, 2005) and the second because it restricts the policy maker from using all the current information when designing monetary policy. By not allowing for potential simultaneity effects in the identification of a monetary policy shock, these studies may therefore have produced a numerically important bias in the estimate of the degree of interdependence between monetary policy and house prices.

Another issue to be considered is to what extent one should allow for other asset prices when analysing the role of house prices in the monetary transmission mechanism. For the open economy, the exchange rate may be a relevant candidate. It plays a significant part in the formulation of monetary policy (being an important influence on the overall level of prices), and is itself also influenced by monetary policy. Hence, monetary policy and exchange rate interactions may be substantial, each reacting to news in the other, as emphasized recently by Faust and Rogers (2003), Bjørnland (2006) and Bjørnland and Halvorsen (2007).

For a country like the US, the open economy aspect is less important. Instead, it may be more relevant to include a measure of share prices, as they have been found to play a notable role in the US monetary policy transmission mechanism (see Rigobon and Sack, 2003, and Bjørnland and Leitemo, 2006).

In this study, we analyse the effects of monetary policy shocks on house prices, paying attention also to other asset prices. For the three open economies (Norway, Sweden and the UK), we include the exchange rate into the model, while for the US, a share price index is included. By incorporating additional asset prices, the role of housing will be set in a wider context. However, including additional asset prices also comes at a cost, as the problem of simultaneity will now also relate to the new variables. Previous studies analysing the role of house prices, have therefore either ignored additional asset prices (Iacoviello, 2005), assumed the exchange rate to be exogenous (Giuliodori, 2005) or assumed a recursive order among the asset prices, so that all asset prices respond with a lag to monetary policy shocks (Goodhart and Hofmann, 2001).

In contrast, we will allow for full simultaneity between the asset prices and monetary policy. To identify all shocks, we will use an identification that restricts the long run multipliers of shocks, but leaves the contemporaneous relationship between the interest rate and asset prices intact. For the three open economies, identification is achieved by assuming that monetary policy shocks can have no long run effect on the level of the real exchange rate or on real gross domestic output (GDP). These are standard neutrality assumptions that hold for large classes of models in the monetary policy literature (see Obstfeld, 1985, Blanchard and Quah, 1989, and Clarida and Gali, 1994). Similar restrictions have also recently been
found to be highly successful in alleviating the exchange rate puzzle in several small open economies, see Bjørnland (2006, 2008). For the US, where we include real stock prices in the VAR, we assume that monetary policy shocks can have no long run effect on the level of the real stock price or on real GDP. This maintains the high degree of interdependence found between monetary policy and stock prices in the US (see Bjørnland and Leitemo, 2006). Identified in this way, house prices and exchange rates/stock prices can now respond immediately to all shocks, while the monetary policymaker can consider news in all asset prices, when designing an optimal monetary policy response. Note, that we have not restricted the long run effects of monetary policy shocks on house prices, as we believe this to be much more of a controversial issue.

Once allowing for a contemporaneous relationship between the interest rate and asset prices, the remaining VAR can be identified using standard recursive zero restrictions on the impact matrix of shocks. That is, we build on the traditional closed economy VAR literature (Sims, 1980; Christiano et al., 1999, 2005, among many others), in that a standard recursive structure is identified between macroeconomic variables and monetary policy, so variables such as output and inflation do not react contemporaneously to monetary shocks, whereas the monetary policymaker might respond immediately to macroeconomic news. That monetary policy affects domestic variables with a lag, is consistent with the transmission mechanism of monetary policy emphasised in the theoretical set up in Svensson (1997). These restrictions are therefore less controversial and studies identifying monetary policy without these restrictions have found qualitatively similar results, see for example Faust et al. (2004). Furthermore, by using a combination of restrictions, we will allow for a contemporaneous interaction between monetary policy and asset price dynamics, without having to resort to methods that deviate extensively from the established view of how one identifies monetary policy shocks in the literature (Christiano et al. 1999, 2005).

Our findings suggest that, following a contractionary monetary policy shock, house prices fall immediately. Yet, we find the impact of monetary policy shocks on housing to be small in comparison to the magnitude of fluctuations in this asset. Furthermore, we find the interest rate to respond systematically to a changing house prices. However, the strength and timing of the response varies from one country to another, indicating that housing may play a different role in the monetary policy setting.

The paper is organised as follows. In Section 2, the VAR methodology is explained, whereas in Section 3 we discuss the empirical results for the baseline model. Section 4 discusses robustness of results and Section 5 concludes.

2 The identified VAR model
The choice of variables in the VAR reflects the theoretical set up of a New-Keynesian small open economy model, such as that described in Svensson (2000) and Clarida et al. (2001). In particular, for the three open economies, the VAR model comprises the annual changes of the log of the domestic consumer price index (πt) – referred to hereafter as inflation, log of real GDP (yt), the three month domestic interest rate (it), the (trade weighted) foreign interest rate (it*), the log of the real exchange rate against a basket of trading partners (et) and the log of
real house prices \((ph_t)\). With respect to the US, we include real share prices \((s_t)\) in the VAR model and leave out the real exchange rate and foreign interest rate, consistent with treating the US as a closed economy (see Christiano et al., 1999).

In all cases, the nominal interest rate is chosen to capture monetary policy shocks; consistent with the fact that the central bank uses interest rate instruments in the monetary policy setting. This is in line with Rotemberg and Woodford (1997), which find central bank behaviour to be well modelled by a policy rule that sets the interest rate as a function of variables such as output and inflation.

2.1 Identification in the open economy (Norway, Sweden, UK)

We first define \(Z_t\) as the \((6\times1)\) vector of the macroeconomic variables discussed above, where \(y_t, e_t\) and \(ph_t\) are non-stationary and differenced to stationary\(^2\): \(Z_t = [i_t, Δy_t, π_t, Δph_t, Δe_t, i_t]′\).

Assuming \(Z_t\) to be invertible, it can be written in terms of its moving average (ignoring any deterministic terms)

\[
Z_t = B(L)v_t, \quad (1)
\]

where \(v_t\) is a \((6\times1)\) vector of reduced form residuals assumed to be identically and independently distributed, \(v_t \sim iid(0,Ω)\), with positive definite covariance matrix \(Ω\). \(B(L)\) is the \((6\times6)\) convergent matrix polynomial in the lag operator \(L\), \(B(L) = ∑_{j=0}^{∞} B_j L^j\). Following the literature, the innovations, \((v_t)\), are assumed to be written as linear combinations of the underlying orthogonal structural disturbances \((ε_t)\), i.e., \(v_t = Sε_t\). The VAR can then be written in terms of the structural shocks as

\[
Z_t = C(L)ε_t, \quad (2)
\]

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. To identify \(S\), the \(ε_t\)’s are normalised so they all have unit variance. The normalisation of \(\text{cov}(ε_t)\) implies that \(SS′ = Ω\). With a six variable system, this imposes 21 restrictions on the elements in \(S\). However, as the \(S\) matrix contains 36 elements, to orthogonalise the different innovations, we need fifteen additional restrictions.

With a six variables VAR, we can identify six structural shocks. The three shocks that are of primary interest here are the shocks to monetary policy \((ε_t^{MP})\), shocks to house prices \((ε_t^{PH})\) and exchange rate shocks \((ε_t^{ER})\). We follow standard practice in the VAR literature and only loosely identify the last three shocks as inflation (or cost push) shocks (moving prices

\(^2\) Section 3 discusses the time series properties further.
before output \((\epsilon_t^{CP})\), output shocks \((\epsilon_t^Y)\) and foreign interest rate shocks \((\epsilon_t^{i*})\). We then order the vector of structural shocks as 

\[
\begin{bmatrix}
\epsilon_t^{i*} \\
\epsilon_t^Y \\
\epsilon_t^{CP} \\
\epsilon_t^{PH} \\
\epsilon_t^{ER} \\
\epsilon_t^{MP}
\end{bmatrix}
\]

Regarding the order of the variables, the foreign interest rate is placed on the top of the ordering, assuming it will only be affected by exogenous foreign monetary policy contemporaneously; a plausible small country assumption. Furthermore, the standard restrictions in the closed economy (namely that macroeconomic variables do not simultaneously react to policy variables, while the simultaneous reaction from the macroeconomic environment to policy variables is allowed for), is taken care of by placing output and inflation above the interest rate in the ordering, and by assuming zero restrictions on the relevant coefficients in the S matrix as described in (3). We also assume that house prices do not react simultaneously to an exchange rate shock.

This provides us with thirteen contemporaneous restrictions directly on the S matrix. The matrix is, however, still two restrictions short of identification. Since we do not want to restrict monetary policy from responding contemporaneously to shocks in house prices and the exchange rate (i.e. \(S_{64} = S_{65} \neq 0\)), or house prices and exchange rates from responding contemporaneously to monetary policy shocks (i.e. \(S_{46} = S_{56} \neq 0\)), we therefore suggest imposing the restrictions that i) a monetary policy shock can have no long-run effects on the level of the real exchange rate ii) a monetary policy shock can have no long-run effects on the level of the real output, which as discussed above, are plausible neutrality assumptions. The restrictions can be found by setting the values of the infinite number of relevant lag coefficients in (2), \(\sum_{j=0}^{\infty} C_{26,j}\) and \(\sum_{j=0}^{\infty} C_{56,j}\), equal to zero, (see Blanchard and Quah, 1989). There are now enough restrictions to identify and orthogonalise all shocks. Writing 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 (6x6) long-run matrix of \(B(L)\) and \(C(L)\) respectively. The long-run restrictions \(C_{26}(1) = 0\) and \(C_{56}(1) = 0\) implies respectively

\[
\begin{align*}
B_{21}(1)S_{16} + B_{22}(1)S_{26} + B_{23}(1)S_{36} + B_{24}(1)S_{46} + B_{25}(1)S_{56} + B_{26}(1)S_{66} &= 0 \\
B_{31}(1)S_{16} + B_{32}(1)S_{26} + B_{33}(1)S_{36} + B_{34}(1)S_{46} + B_{35}(1)S_{56} + B_{36}(1)S_{66} &= 0.
\end{align*}
\]
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 restriction (4), where \( B(1) \) is calculated from the reduced form estimation of the reduced form of (1). Note that (4) reduces to:

\[
B_{24}(1)S_{46} + B_{25}(1)S_{56} + B_{26}(1)S_{66} = 0 \quad \text{and} \quad B_{54}(1)S_{46} + B_{55}(1)S_{56} + B_{56}(1)S_{66} = 0,
\]

given the zero contemporaneous restrictions.\(^3\)

2.2 Identification in the closed economy (US)

With regard to the US, we follow standard practice and treat the US as a closed economy, thereby eliminating foreign interest rates and the exchange rate from the set of variables. Instead, we include the real stock price into the VAR, as it has the potential of being important in the monetary policy transmission mechanism (see Bjørnland and Leitemo, 2006).

In the following, we therefore define \( Z_t \) as the \((5x1)\) vector \( \Delta y_t, \Delta \pi_t, \Delta ph_t, \Delta s_t, i_t \)\(^\prime\).

With a five variables VAR, we can identify five structural shocks. The three shocks that are of primary interest are the shocks to monetary policy (\( \epsilon_t^{MP} \)), shocks to house prices (\( \epsilon_t^{PH} \)) and shocks to stock prices (\( \epsilon_t^{SP} \)). Ordering the structural shocks as follows: \( \epsilon_t = [\epsilon_t^Y, \epsilon_t^{CP}, \epsilon_t^{PH}, \epsilon_t^S, \epsilon_t^{MP}] \), implies the following restrictions on the S matrix:

\[
\begin{bmatrix}
\Delta y \\
\pi \\
\Delta ph \\
\Delta s \\
i
\end{bmatrix}
= B(L)
\begin{bmatrix}
S_{11} & 0 & 0 & 0 & 0 \\
S_{21} & S_{22} & 0 & 0 & 0 \\
S_{31} & S_{32} & S_{33} & 0 & S_{35} \\
S_{41} & S_{42} & S_{43} & S_{44} & S_{45} \\
S_{51} & S_{52} & S_{53} & S_{54} & S_{55}
\end{bmatrix}
\begin{bmatrix}
\epsilon_t^Y \\
\epsilon_t^{CP} \\
\epsilon_t^{PH} \\
\epsilon_t^S \\
\epsilon_t^{MP}
\end{bmatrix}
\]

The recursive order provides 8 contemporaneous restrictions directly on the S matrix. In addition, we impose the restriction that a monetary policy shock has no long-run effects on real output, which as discussed above, is a plausible neutrality assumption. Finally, we build on Bjørnland and Leitemo (2006) and assume that monetary policy shocks have no long-run effects on the real stock price, which is a plausible restriction when stock prices are measured in real terms. 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. The long-run restrictions imply respectively:

\[
B_{11}(1)S_{15} + B_{12}(1)S_{25} + B_{13}(1)S_{35} + B_{14}(1)S_{45} + B_{15}(1)S_{55} = 0
\]

\[
B_{41}(1)S_{15} + B_{42}(1)S_{25} + B_{43}(1)S_{35} + B_{44}(1)S_{45} + B_{45}(1)S_{55} = 0.
\]

\(^3\) The joint use of short-run and long-run constraints could also be sufficient to side-step some of the criticism of Faust and Leeper (1997), who argue that for a long-run identifying restriction to be robust it has to be tied to a restriction of finite horizon dynamics.
These restrictions will be reduced to: 
\[ B_{13}(1)S_{35} + B_{14}(1)S_{45} + B_{15}(1)S_{55} = 0 \]
\[ B_{43}(1)S_{35} + B_{44}(1)S_{45} + B_{45}(1)S_{55} = 0, \]
given the zero contemporaneous restrictions.

3 Empirical results

The model is estimated for Norway, Sweden, UK and the United States, using quarterly data from 1983Q1 to 2006Q4. Using an earlier starting period will make it hard to identify a stable monetary policy regime, as monetary policy prior to 1983 has experienced important structural changes and unusual operating procedures (see Bagliano and Favero, 1998, and Clarida et al., 2000). Data and sources are described in appendix A.

All variables in the VAR are either stationary or differenced to be stationary. Hence for Norway, Sweden and the UK, the VAR comprises the domestic and foreign interest rates, inflation, and quarterly growth rates of GDP, real house prices and real exchange rates. For the US, which is treated as a closed economy, we exclude the foreign interest rate and the real exchange rate from the VAR, but include the quarterly growth rates of the real share price. Inflation is measured as the annual growth rate of CPI for all countries. Alternatively, we could have included the quarterly growth rate of CPI in the VAR. However, annual inflation is a more direct measure of the target rate of importance to the policymakers. Moreover, using quarterly inflation may produce misleading results about the dynamic effects of monetary policy, if there are time-varying seasonal variations in the inflation rate (Lindé, 2003).

For all countries, the VAR is now invertible. Yet, for some countries, in particular the UK, some of the variables may be in the borderline of being (trend) stationary and non-stationary. This could be due to the low power of the tests in distinguishing between a unit root and a (trend) stationary variable. For UK, where the problem may be most pronounced, we therefore also include a trend in the VAR. However, as will be seen in the end, the results do not hinge on these assumptions.

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 for all countries. With a relatively short sample, we use four lags in the estimation and check for robustness using alternative lag lengths. With four lags, the hypothesis of autocorrelation and heteroscedasticity is rejected at the five-percent level for all countries. Some non-normality remained in the system, but essentially due to non-normality in the foreign interest rate equation. Some impulse dummies (that take the value 1 in one quarter and 0 otherwise) were also included in the models, to take account of extreme outliers (see appendix A).4

3.1 Impulse responses and variance decomposition

Figures 1-4 plot the response in the interest rate, GDP and inflation in Norway, Sweden, UK and the US respectively to a contractionary monetary policy shock, whereas figures 5-8 plot

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4 For all countries, the main results are robust to the exclusion of these dummies, with a few exceptions that will be discussed below.
the responses in the real house price and the real exchange rate (real share price for the US) to the same shock in the four respective countries. In all cases, the monetary policy shock is normalized to increase the interest rate with one percentage point the first quarter. In appendix B, we report the impulse responses to all shocks with standard error bands. These are generated from 2500 draws by Monte Carlo integrations following Sims and Zha (1999). The draws are made directly from the posterior distribution of the VAR coefficients, as suggested in Doan (2004).

Figure 1-4 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). In particular, interest-rate inertia is known to let the policymaker smooth out the effects of policy over time by affecting private-sector expectations. Moreover, the reversal of the interest rate stance is consistent with the
policymaker trying to offset the adverse effects of the initial policy deviation from the systematic part of policy.

Regarding the other variables, output falls by 0.5-1.5 percentages for close to two years, before the effects essentially dies out. The effect on inflation is also eventually negative as expected. However, with the exception of Sweden, there is some evidence that consumer prices increase initially, also referred to as price puzzle (see Sims, 1992). The puzzle may 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 et al., 2006). Eventually, though, prices start to fall, until after 3-4 years, inflation has fallen by 0.5-1 percentages. The effect thereafter dies out.

We now turn to asset prices, and in particular house prices. Figure 5-8 suggest that, following a contractionary monetary policy shock, house prices fall immediately in all four economies, although the effect on UK house prices is small and insignificant. For the other countries, the simultaneous effect is significant (see appendix B) and ranges from approximately 1 to 2½

\[\text{Figure 5} \quad \text{Response to a monetary policy shock.} \quad \text{Norway}\]

\[\text{Figure 6} \quad \text{Response to a monetary policy shock.} \quad \text{Sweden}\]

\[\text{Figure 7} \quad \text{Response to a monetary policy shock.} \quad \text{UK}\]

\[\text{Figure 8} \quad \text{Response to a monetary policy shock.} \quad \text{USA}\]
percentages. Hence, the initial effect is non-trivial. Following the initial effect, house prices fall even further, until after 1.5-3 years, real house prices have fallen with 3 to 5 percentages.

Thus, monetary policy has a strong and prolonged effect on house prices, emphasising the role of house prices in the monetary policy transmission mechanism. The results are consistent with the fact that a contractionary monetary policy shock also lowers output and will accordingly have an expected negative effect on employment and wages. In addition, higher interest rates will raise household’s interest payments. Thus, household’s debt servicing capacity will decline when interest payments increase and income is curbed. This can explain the strong effect of monetary policy shocks on house prices.

These results are different from those that were found in for instance Goodhart and Hofmann (2001) and Giuliodori, (2005) analysing several European countries. However, in both of these studies, housing is restricted from responding immediately to monetary policy shocks. But even after a year, monetary policy has a much smaller impact on house prices than we find here. Similar findings are also found for the US in Iacoviello (2005), although there the impact effect is larger initially (as they allow for an instantaneous response in housing to monetary policy shocks, but restrict instead monetary policy from reacting contemporaneously to shocks in house prices). In contrast, Del Negro and Otrok (2007) find in a recent study for the US, results that are more in line with what we find here (or even stronger). To obtain these results, they refrain from the Cholesky recursive decomposition. Instead they use sign restrictions, where they search among all possible reasonable identification procedures and VAR specifications, for the one that deliver the largest impact on house prices (that is, the upper bound).

Regarding the other asset prices, Figures 5-7 also show that the monetary policy shock has an immediate and negative effect on the exchange rates. For UK, the immediate effect is delayed one quarter, whereas for Norway, the maximal impact is delayed 3-5 quarters, possibly reflecting the fixed exchange rate regime during part of the estimation period. For Sweden, the immediate, negative effect on the exchange rate from the monetary policy shock is rather strong, and the exchange rate thereafter gradually depreciates back to baseline consistent with the Dornbusch overshooting hypothesis (Dornbusch, 1976). These findings are consistent with the results found in Bjørnland (2006).

For the U.S., where we have included the real stock price instead of the exchange rate in the structural VAR, Figure 8 shows that the effect on real stock prices is also strong and negative as expected. This is consistent with results found in Bjørnland and Leitemo (2006).

What is the contribution of the various shocks to the forecast variance in real house prices on impact (the first quarter)? Table 1 answer this question by giving the forecast error decomposition. Clearly, and as seen in the figures above, monetary policy explain a large part of the variance in house prices in Sweden and the USA the first quarter (36 and 12 percent respectively), whereas the effect in Norway and the UK is more delayed. Hence, although the

\[6\text{ For Norway, the delayed overshooting for the exchange rate depends somewhat on the choice of dummies and sample period. By excluding all dummies or focusing on the post 1993 sample, the overshooting is less delayed, consistent with the results in Bjørnland (2007) and Bjørnland and Halvorsen (2007).}\]
impact effect of monetary policy shocks on house prices are large, monetary policy still explain a relatively small share of the variance of house prices, (except possibly Sweden).

Table 1. Forecast error decomposition of house prices. Impact effect, percentage

<table>
<thead>
<tr>
<th></th>
<th>Monetary policy shock</th>
<th>House price Shock</th>
<th>Other shocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway</td>
<td>2</td>
<td>82</td>
<td>16</td>
</tr>
<tr>
<td>Sweden</td>
<td>36</td>
<td>60</td>
<td>4</td>
</tr>
<tr>
<td>UK</td>
<td>1</td>
<td>90</td>
<td>9</td>
</tr>
<tr>
<td>USA</td>
<td>12</td>
<td>73</td>
<td>15</td>
</tr>
</tbody>
</table>

Having examined the response in all variables to a monetary policy shock, we finally turn to investigate the reverse causation, namely the (systematic) response in monetary policy to a house price shock. Figure 9-12 plot the effect of a house price shock (normalized to increase house prices with one percent the first quarter) on both interest rates and inflation in Norway,
Sweden, UK, and the US respectively. We graph the response in inflation in the same frame as the response in interest rate, so as to investigate to what extent the response in interest rate also relates to that in inflation.

The figures emphasize that in all countries, but Norway, there is a simultaneous response in interest rates following the house price shock. In particular, following a one percent increase in house prices, interest rates increase with 10-20 basis points. For Norway, the increase is delayed by two quarters, but then increases with 10 basis points. The strength of the response thereafter varies from one country to another, temporarily declining in some countries, gradually increasing in others, indicating that housing may play a different role in the monetary policy setting. The maximum effect is found in the US, where the interest rate increases by 40 basis points after one and a half year. The response in interest rates also seems to be (indirectly) related to the effect of housing on inflation, with the latter increasing temporarily following the house price shock. Interestingly, the response in inflation following the house price shock is also largest in the US.

Hence, an unpredicted shock to house prices, influence the interest rate setting, at least within a year. Note however, that what we are measuring is the systematic response to unpredicted changes in house prices. Furthermore, the fact that innovations in house prices also increase inflation, imply that we can not exclude the possibility that the systematic monetary policy response to innovations in house prices could just reflect that house prices have an impact on less controversial objectives such as inflation. In the words of the Monetary Policy Committee at the Bank of England in May 2004:

“In presenting a decision to raise the repo rate, it would be important for the Committee to make clear that it was not targeting house prices inflation, or any other asset price. The significance of the unexpected acceleration in house prices was that it supported a stronger short-term outlook for consumption and output growth, and hence a steeper projected rise in inflation”

Sveriges Riksbank has also been fairly transparent as to how it takes into consideration developments in asset prices, including house prices. As Sveriges Riksbank (2007) puts it:

“…the paths of asset prices and indebtedness can at times be either difficult to rationalize or unsustainable in the long term. This means that there are risks of sharp corrections in the future which in turn affect the real economy and inflation. ... In practice, taking risks of this kind into consideration can mean that interest rate changes are made somewhat earlier or later, in relation to what would have been the most suitable according to the forecasts for inflation and the real economy.”

To sum up, we have documented that there is a great deal of simultaneity between monetary policy and asset prices. In particular, a contractionary monetary policy shock that increases the interest rate with 1 percentage point, reduces real house prices by 3-5 percent. Further, monetary policy responds by increasing interest rates by 10-40 basis points, following a shock that increases house prices by 1 percent. In the next section we test the robustness of these results to alternative model specifications.
4 Robustness

The robustness of the reported results have been analysed with respect to model specification, choice of lags, number of impulse dummies etc. The results are generally robust to these types of changes. The most pronounced differences were found when excluding all impulse dummies, as can be seen in figures C1-4 in appendix C. For two of the countries, Sweden and the UK, the initial response in house prices following a unit monetary policy shock turn out to be somewhat larger initially using the model that exclude all dummies, than in the baseline. For Norway and the US, the results are marginally smaller. However, following the initial response, the general pattern remains very much the same in all countries. In the remainder of this section we therefore instead focus on the implications of alternative identification schemes.

4.1 Alternative identification schemes

We first test robustness of the results to the ordering of the variables in the VAR model that are identified using recursive zero contemporaneous restrictions. That is, we analyse to what extent the effects of a monetary policy shock on house prices remain the same if inflation and output growth switch places in the VAR model, so that inflation is now ordered first. The results turn out to be exactly the same. In fact, rearranging the order of any of the three first variables (foreign interest rate, output growth and inflation) for the open economies (or output growth and inflation in the case of the US), the results are exactly the same. Hence, the responses to the monetary shock will be invariant to the ordering of these variables. This follows from a generalizing of the well known findings in Christiano et al., (1999; Proposition 4.1), stating that when the monetary policy variable (the interest rate) is ordered last in a Cholesky ordering, the responses to the monetary policy shock will be invariant to the ordering of the variables above the interest rate. Instead, the ordering of the variables becomes a computational convenience with no bite. The real bite here is the assumption that the foreign interest rate, output growth and inflation don't respond contemporaneously to a monetary policy shock.

So far we have only investigated the robustness of the results to various orderings of the variables on ‘top’. 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 are ordered above the interest rate), such an decomposition will imply that house prices will be restricted from responding contemporaneously to monetary policy shocks.

In Figures 13-16 below, we compare our results with the findings from the Cholesky decomposition. The solid line is our baseline structural impulse response while the dotted line is the impulse response from the Cholesky decomposition. The results emphasize that in all countries but the UK, will the effects of monetary policy on housing be much smaller using the Cholesky decompositions than our suggested identification. In fact, for Sweden, the

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7 Results analysing robustness to choice of lags can be obtained at request
effects of a monetary policy shock are not only negligible, but also turn out with the wrong sign. Hence, accounting for interdependence between monetary policy and housing seems important. For the UK, where house prices respond very little the first quarter, the two decompositions provide approximately the same results.

Figures 17-20 investigate the implication for inflation by using the same Cholesky decomposition.\(^8\) In addition, we also perform an exercise where we throw out all the asset prices, and ask to what extent the responses in inflation will depend on the inclusion of financial variables. Hence, the figures compare our baseline results with two alternative models: (i) a closed economy VAR model with only three domestic variables, identified using the Cholesky decomposition with the ordering: output, inflation and the interest rate and (ii) our original VAR, but now identified using the Cholesky decomposition (where house prices respond with a lag to monetary policy shocks).

Using the closed economy VAR with the Cholesky decomposition, there is a substantial prize puzzle in all countries. Following a contractionary monetary policy shock,

\(^8\) Impulse responses for the other variables can be obtained at request.
the effect on inflation never turns negative. However, including all asset prices in the VAR, while maintaining Cholesky restrictions, seems to reduce the price puzzle in Norway and UK. However, for Sweden and the US, inflation is still always positive. Only when we use our structural identification scheme instead of the Cholesky decomposition, is the price puzzle clearly curbed also in Sweden and the US: In fact, for Sweden, the puzzle is completely eliminated.

Hence, we have shown that by adding just a few series of relevant financial variables and using an identification that allow for contemporaneous interaction between monetary policy and asset prices, will reduce the price puzzle (and in the case of Sweden, remove the puzzle). These results are in some sense consistent with the findings in Bernanke, Boivin and Eliasz (2005), who show that by using a data-rich factor augmented VAR, they are able to reduce the price puzzle substantially. Similar conclusion can also be drawn from Brissimis and Magginas (2006), who find that by incorporating forward-looking variables (leading indicators) into the VAR, they are able to reduce the price puzzle substantially.
5. Concluding remarks

Understanding the main features of the transmission mechanism of monetary policy is crucial for the implementation of an efficient monetary policy strategy. So far the implementation of inflation targeting seems to be successful, as it has brought consumer price inflation to a low and fairly stable level in an increasing number of countries. However, asset price fluctuations still appear to be substantial, and the US housing market stands as a recent example. Asset prices are affected by monetary policy shocks, and the volatility of asset prices may in turn have considerable effects on aggregate output and consumer price inflation. Hence, identifying the appropriate monetary policy and asset price interactions may be essential when analyzing monetary policy.

In this paper we analyze the role of house prices in the monetary transmission mechanism in four different economies; Norway, Sweden, UK and the US. The quantitative effects of monetary policy shocks are studied through structural VARs. A challenge in the VAR literature is how to properly address the potential simultaneity between monetary policy and asset prices. Most of the VAR studies that incorporate asset prices, place recursive, contemporaneous restrictions on the interaction between monetary policy and asset prices. This implies that asset prices will respond to a monetary policy shock with a lag or vice versa. Such restrictions are problematic since theory predicts that asset prices respond immediately following a monetary policy shock, and it seems unreasonable to restrict the policy maker from using all current information when designing monetary policy.

In this paper, identification is achieved by imposing a combination of short-run and long-run restrictions which allow interdependence between the monetary policy stance and asset price movements. By allowing for simultaneity between monetary policy and house prices, we find that there is interdependence. Unexpected changes in interest rates have an immediate effect on house prices in most countries, and house prices can contemporaneously convey important information for the conduct of monetary policy. We find that overall, house prices fall by 3-5 percent following a monetary policy shock that raises the interest rate by one percentage point. Interest rates also respond systematically to house price shocks, however, the strength and timing of the response varies across countries. This indicates that house prices play a different role in the monetary policy setting in the four economies. The systematic response of monetary policy to house prices could also reflect that shocks to house prices ultimately influence output and inflation.

Finally, the restrictions we impose preserve the qualitative impact on domestic variables of a monetary policy shock that has been found in the established VAR literature. A contractionary monetary policy shock raises interest rates, lowers output temporarily and has a sluggish and negative effect on consumer price inflation. Moreover, our results show that by including a few asset price series in the VAR, the “prize puzzle” that has been found in many studies is curbed. Further reductions are found when we allow for simultaneous responses using our structural decomposition instead of the Cholesky decomposition. As argued in the literature, evidence of a price puzzle could be due to VAR misspecification. Thus, by using more information in terms of asset prices in the VAR estimation, the risk of misspecification is considerably reduced.
References


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Appendix A. Data

The following data series are used:

($i^*$) Trade-weighted foreign money market rate (in the models for Norway, Sweden and UK). For the UK, the foreign interest rate is represented by the Federal Funds rate, as the US comprises more than 50 percent of the foreign trade weight. For Norway and Sweden, the foreign interest rate is a weighted average of the interest rate in the major trading partners. Sources: EcoWin, Norges Bank and Sveriges Riksbank

($y_t$) Log of real GDP, s.a. For Norway, GDP Mainland Norway is used. Sources: OECD and Statistics Norway

($\pi_t$) Inflation, measured as annual change in the log of the consumer price index (CPI). For UK, the harmonized CPI is used, and for Norway, the consumer price index is adjusted for taxes and energy prices. Sources: OECD and Statistics Norway

($p_{ht}$) Log of real house prices, s.a. Sources: EcoWin, Norwegian Association of Real Estate Agents, Association of Real Estate Agency Firms, FINN.no, ECON Pöyry and Norges Bank

($e_t$) Log of the real effective exchange rate, measured against a basket of trading partners (in the models for Norway, Sweden and UK). The exchange rate is specified so that an increase implies depreciation. Sources: OECD and Norges Bank

($s_t$) Log of a real share price index (in the US model). S&P 500 used as share price index. Source: EcoWin

($i_t$) Three months money market rate. Sources: OECD, EcoWin and Norges Bank

Dummies

For Sweden, three dummies were included; 1992Q3, 1993Q1 and 1995Q4. The first captures an exceptionally high interest rate that reflects defense of the Swedish exchange rate, the second captures the subsequent floating of the Swedish krona and the third reflects additional turbulence in the exchange rate.

For UK, two dummies were included; 1991Q2 and 1992Q2. A spike in the consumer price series in 1991Q2 necessitates two dummies as the fourth-difference of the consumer prices series is incorporated in the model.
Three dummies were included in the model for the US; 1984Q4, 1986Q2 and 2006Q4. The first represent a very high interest rate and the second and third captures large residuals in the equation for consumer price inflation.

For Norway, we had to include more dummies in order to identify a fairly stable monetary policy regime, as various, and partly idiosyncratic circumstances characterize Norwegian monetary policy in this period. Seven impulse dummies were included; 1986Q2, 1986Q3, 1992Q3, 1992Q4, 1993Q1, 1998Q3 and 2002Q4. The dummy for 1986Q2 reflects a devaluation of the Norwegian krone by 9 per cent, and the 1986Q3-dummy accounts for a subsequent sharp rise in inflation. The dummies for 1992Q3, 1992Q4 and 1993Q1, all adjust for the interest rate and exchange rate turbulence that resulted in the breakdown of the fixed exchange rate regime in December 1992. The dummy for 1998Q3 captures a very high interest rate in order to defend the Norwegian krone, and the 2002Q4-dummy reflects a severe appreciation of the Norwegian krone in excess of its fundamentals, see Bjørnland (2008). Olsen et al. (2002) compute interest rates in accordance to Taylor rules using Norwegian data for the period 1995 till 2002, and argue that with the exception of the brief period 1996/7-1998, monetary policy can be described as following close to some kind of Taylor rule in this period. Sveen (2000) shows similar comparisons of Taylor-interest rates and actual short term interest rates for the period 1981 to 1998. The analysis confirms the deviation from the Taylor rule in the brief period 1996/7-1998, and also identifies a more prolonged Taylor rule deviation from around 1989 till about 1994. We therefore include two dummies that take the value 1 in the respective period 1989Q2-1994Q1 and 1996Q4-1998Q2, and 0 otherwise. Their coefficients have the expected sign, and imply that the interest rate should have been kept lower from 1989 to 1994 and higher from 1996 to 1998, had the Taylor rule been followed.
Appendix B. Standard error band [To be completed]
Appendix C. Model without impulse dummies

Figure C1  Response to a monetary policy shock. Check of robustness w.r.t. dummy variables. Norway

Figure C2  Response to a monetary policy shock. Check of robustness w.r.t. dummy variables. Sweden

Figure C3  Response to a monetary policy shock. Check of robustness w.r.t. dummy variables. UK

Figure C4  Response to a monetary policy shock. Check of robustness w.r.t. dummy variables. USA