

# Risk premium shocks, monetary policy and exchange rate pass-through in the Czech Republic, Hungary and Poland

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## Abstract

This paper investigates the role of monetary policy in a small open economy, where exchange rate shocks are important. VAR models are estimated for the Czech Republic, Hungary and Poland. Contemporaneous and sign restrictions are imposed in order to identify the effect of monetary policy and risk premium shocks. Estimates from the same model for Canada, Sweden and the UK are used as benchmark for developed economies with low inflation. The results suggest that the typical size of a risk premium shock renders it almost impossible for the interest rate policy to smooth the exchange rate with the aim of minimising inflationary consequences. On the other hand, low inflation may decrease the exchange rate pass-through, which helps the monetary policy ignore exchange rate shocks.

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## 1. Introduction

After the collapse of the communist regimes in Central and Eastern Europe (CEE henceforth), several ex-communist countries were looking for a proper monetary regime. In the beginning, they faced high inflation as a consequence of price liberalisation, as well as slow growth, due to the process of restructuring the economy. Since these economies were small and open ones, stabilisation of the exchange rate seemed to be the most straightforward way to contain inflationary pressures.

After the first, more or less successful years of tight exchange rate management, the limits, or in some cases the pitfalls of these regimes became obvious. The Czech central bank widened the intervention band of the koruna in 1996 from  $\pm 0.5$  percent to  $\pm 7.5$  percent. After the attack against and the depreciation of the currency in 1997, the intervention band was abandoned. Since the beginning of 1998, the Czech central bank operates an inflation targeting regime. In 1995, the Hungarian government and the central bank decided to introduce a crawling band regime, with a bandwidth of  $\pm 2.25$  percent. In 2001 the band was widened to  $\pm 15$  percent and the central bank announced targets for the inflation. The intervention band was fully eliminated only in 2008. Poland replaced its crawling peg by a crawling band regime in 1995. The band was widened in several steps from  $\pm 2$  to  $\pm 15$  percent. They switched to free float and inflation targeting in 2000.

Even though all these CEE countries under investigation have floating exchange rate and inflation target, the question still remains open: how flexible the monetary policy should be towards exchange rate movements? Opponents of free floating regimes argue that in these countries the exchange rate channel dominates the interest rate channel, thus interest rate policy should aim at managing the exchange rate. They advise marked policy rate response to exchange rate shocks. On the other hand, tight exchange rate management, even if conducted by interest rate policy instead of intervention in the foreign exchange market, may bring about speculation and instability of the exchange rate. Moreover, higher volatility of exchange rate may also reduce the pass-through of exchange rate movements. According to this view, letting the exchange rate to absorb shocks, even those originating from financial markets, has no harmful consequence in the long run, as economic agents learn to hedge themselves. This attitude has the major benefit of relieving the interest rate policy of pursuing short-term exchange rate targets.

Although the inflationary effect is only one aspect of exchange rate volatility, in this paper I ignore all the trade-enhancing and other long-run welfare aspects of exchange rate regimes. I try to focus instead purely on the role monetary policy plays in the pass-through of exogenous exchange rate shocks to consumer prices. In particular, I address the following questions: what are the effects of risk premium shocks? How should monetary policy react to these shocks? How successful were these countries in preventing exchange rate disturbances to spread to overall consumer prices?

I adopt a VAR approach. I identify monetary policy and exchange rate risk premium shocks by imposing both contemporaneous and sign restrictions on impulse responses. I investigate the reaction of interest rate policy to the latter shock and evaluate its performance in terms of price stability. In order to avoid methodological bias and to capture specific features of exchange rate pass-through in transition

economies, I estimate the same model for three developed countries as well: to Canada, Sweden and the UK.

The structure of the paper is the following: first, the econometric framework is introduced. Section 3 presents the estimated effect of monetary policy and risk premium shocks on the key variables. In section 4, the issue of exchange rate pass-through is discussed. Section 5 concludes.

## 2. The empirical model

This section describes the econometric modelling framework for estimating the effect of monetary policy and risk premium shocks.

### *Data and specification of the VAR model*

As endogenous variables of the VAR, one should include some measure of real activity, a price index, and because of the focus of the paper, the exchange rate and the policy instrument. This can be regarded as the minimum set. On the other hand, the short time span does not allow including too many endogenous variables without increasing the risk of overfitting.

As a measure of real activity I used the industrial production. I used it instead of GDP or other more general statistics because of the huge measurement error of the latter in these countries. Another aspect was to use monthly series, as the identification of the shocks is more reliable using higher frequency data, as discussed later.

The appearance of overall consumer price index in the VAR can be justified by the fact that all three countries under investigation are targeting this measure of prices. It should be noted, however, that in the Czech Republic the target variable was the so-called net inflation up until 2004. Nevertheless, the difference between the headline and the targeted inflation was mainly the effect of the government's tax and regulated price policy, so from the aspect of exchange rate pass-through this potential misspecification may be of limited relevance.

For measuring the policy stance, I used 3-month T-bill rates in the case of Hungary and Poland, 3-month money market rates for the Czech Republic. Albeit these are all market rates and have longer maturity than that of the policy instrument, they correlate with the latter strongly, and due to the longer maturity, can capture market expectation for the near future action of the central bank. Finally, I used nominal effective exchange rate series for all countries. More detailed description of the data sources can be found in the appendix.

An intercept was included in the VARs. I also experimented with foreign exogenous variables. I used contemporaneous and lagged German industrial production, consumer prices, short interest rate and nominal effective exchange rate to control for external effects. Since the main results did not altered significantly when I omitted these controls, only the results without exogenous variables are presented in the paper.

The industrial production and consumer price series are seasonally adjusted. I used variables in levels. When making statistical inference, I adopt a Bayesian approach, hence I need not address the issue of unit roots<sup>2</sup>.

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<sup>2</sup> See Sims and Uhlig (1991).

Since the transition process, and particularly, the change in monetary policy regimes may have caused structural breaks in the data generating process, the selection of the sample may be crucial for the results we obtain. Here we are facing a trade-off again: shorter periods are more likely to be free of structural breaks but contain fewer observations. For the Czech Republic I started the sample in 1998:M1, when the central bank switched to inflation targeting. The Polish sample starts in 1997:M1, earlier than the introduction of the free floating and inflation targeting regime, but that time the intervention band was already wide enough to let the exchange rate absorb shocks. Since in Hungary the inflation targeting regime started in 2001, I used a longer sample that contains the crawling narrow band regime as well. The Hungarian sample, therefore, starts in 1995. In order to ensure comparability, I used almost the same sample period for Canada, Sweden and the U.K.

As a lag selection criterion, I aimed at eliminating the autocorrelation in the residuals. Usually 3 to 8 lags were enough. It more or less coincided with what the popular model selection criteria suggested.

### *Identification*

There is a huge literature on how to identify monetary policy shocks.<sup>3</sup> One of the most widely used assumptions is that monetary policy affects the economy only with some delay. In our case it means that the contemporaneous effect on production and prices is zero. Of course, financial variables, like the exchange rate, can react immediately to monetary policy. The intuition behind contemporaneous zero restrictions is that it takes time until shocks originated in financial markets or monetary policy spread onto the real economy.

In small open economies contemporaneous zero restrictions on quarterly data can be criticised. For example, an unexpected rate hike by the central bank may appreciate the currency. In the presence of producer currency pricing, this may lead to quick drop in import prices and even in overall consumer prices. Since I use monthly data, this problem might be less relevant.

The aim of this paper is to identify two sources of economic disturbances: monetary policy and risk premium shocks. The argument of delayed transmission applies to both, therefore I imposed contemporaneous zero restrictions on industrial production and consumer prices<sup>4</sup> for each shock. Unfortunately, this is not sufficient to disentangle them from each other. Additional assumptions are needed.

Authors using VAR for estimating the exchange rate pass-through usually adopt a recursive identification scheme.<sup>5</sup> This approach rests on the assumption that there exists an ordering of the variables so that shock to one variable affects the others ordered before only with lag. These authors sometimes do robustness check with respect to the ordering. Hahn (2003) reports no change of her estimated pass-through for the euro area after using alternative identification schemes. Ca'Zorzi et al (2007) obtain similar estimates using various ordering for almost all transition countries with the exception of Hungary. Faruquee (2006) found his results for the euro area and the U.S. robust to the ordering.

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<sup>3</sup> For a review, see Christiano et al (1998)

<sup>4</sup> I also experimented with identification without imposing zero restrictions on prices. The impulse responses in some cases were implausible as consumer prices jumped immediately with the risk premium shocks to an extent that was counterintuitive.

<sup>5</sup> See McCarthy (2006), Ca'Zorzi et al (2007), Hahn (2003), Faruquee (2006).

If both the interest rate and the exchange rate are included in the VAR, recursive identification can be justified as long as either the monetary or the risk premium shock has no impact on one of these variables within one period. We have, however, obvious reasons to believe that our shocks may have contemporaneous effect on both financial variables, at least in the case of Hungary. Based on the methodology of Rigobon and Sack (2004), Rezessy (2005) showed that unexpected interest rate changes made by the Hungarian central bank have impact on the exchange rate even within the same day. On the other hand, minutes of the Monetary Council meetings and press releases reveal that change in perceived risk premium did play an important role in rate setting.

In order to distinguish between monetary policy and risk premium disturbances, I exploit the usual interest parity approach. The most standard assumption when characterising exchange rate dynamics in theoretical macro models is that expected returns are equal among various currencies. In other words, interest rate differentials reflect only the expected change in the exchange rate. This law is called the uncovered interest parity (UIP). Partly because of the failures of empirical UIP tests, the equation is often augmented by a residual term, which can be thought of as an excess compensation for investing in assets denominated in a risky currency:

$$i_t = i_t^* + E_t s_{t+1} - s_t + \rho_t$$

where  $i$  and  $i^*$  denote domestic and foreign one-period interest rate, respectively;  $s$  stands for the home currency price of one unit of foreign currency, thus increasing values indicate the depreciation of the domestic currency. The residual term  $\rho$  is the risk premium.

Within this framework, monetary policy and risk premium shocks can be represented in unexpected change in  $i$  and  $\rho$ , respectively. Assuming constant foreign interest rate and exchange rate expectations,<sup>6</sup> higher domestic interest rate is associated with stronger exchange rate. An increase in the risk premium may increase the domestic interest rate and depreciate the currency. Note that a shock to the foreign interest rate is equivalent to a risk premium shock.

I derived the remaining identifying restrictions from this partial exchange rate model. I assumed that after an unexpected monetary tightening the domestic interest rate increases and the exchange rate appreciates. Regarding the risk premium shocks, an increase in the expected excess return leads to higher interest rate and depreciates the currency. So it is the sign of correlation between the exchange rate and interest rate that makes the distinction between the two sources of financial market disturbances.<sup>7</sup> I imposed the sign restrictions on the first 12 months of the impulse responses.

In Vonnák (2005) I demonstrated that this identification scheme provides similar results to a completely different approach in the case of Hungary. Jarociński (2006) uses very similar identification of monetary policy shocks in CEE countries. Sánchez (2007) relies entirely on sign restrictions when identifying technology, preference, monetary policy and risk premium shocks for emerging countries.

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<sup>6</sup> Obviously, the latter assumption is too strong. For modelling the expected exchange rate, a full model would be needed. However, reasonable rational expectation models would not generate considerably different cross-correlations.

<sup>7</sup> Among the first and most influential applications of sign restrictions were Faust (1998), Canova and de Nicolò (2002) and early versions of Uhlig (2005).

The case of Hungary is worth some further discussion. During the crawling band exchange rate regime, which covers roughly the half of the observations, the logic of monetary policy may have been different. The pre-announced devaluation rate of the currency served as an anchor for the exchange rate expectations, meaning that monetary tightening appeared in the form of the slow-down of the devaluation rate. When the exchange rate could not react to this change of the policy stance because of the strong edge of the band, the interest rate should have been lowered according to the interest parity. Later the exchange rate becomes more appreciated, due to the slower pace of devaluation. Hence, in these cases, the change in the path of exchange rate and interest rate will be similar to my assumptions used to characterise risk premium shocks. Nonetheless, the similarity of the impulse responses across CEE countries suggests that the identifying restrictions seem to fit even Hungary quite well.

The numerical implementation followed the algorithm of Uhlig (2005). To obtain posterior distribution of impulse response functions and other derived statistics, I draw jointly from the posterior of VAR coefficients, variance-covariance matrix and the subspace of potential candidates for shock vectors. The VAR prior is a Normal-Wishart distribution parameterised by the OLS estimates. The posterior distribution is constituted by draws that fulfilled the sign restrictions. For more detailed description see the referred paper.

### **3. The effect of monetary policy and risk premium shocks**

The following section summarises what we can learn by investigating impulse responses<sup>8</sup> (IRFs) to the structural shocks. During the discussion I rely on median estimates and confidence bands obtained by connecting the corresponding percentile values of the posterior distribution for each period. Since there are some arguments that these statistics might not be the best way to present the results, in the second part of the appendix I use other reporting techniques as well. I conclude there that the main findings of the paper are not affected significantly by these critics.

The first general observation is that in most cases the effect on industrial output and consumer prices was not significantly different from zero.<sup>9</sup> It means that the middle 95% of the IRF posterior distribution contains the x-axis in most cases. There may be several explanations for that. First, the effects may be indeed small. Second, our data may contain a considerable amount of noise. Third, there may be important structural breaks in the data generating processes. And finally, our identification may be too loose to capture the structural shocks precisely, so the IRFs may show the mixed effect of several different shocks.

Another important observation is that the point estimates for the three CEE countries are fairly similar. Since results for the control group differ significantly, this may not be an artifact of the estimation method, but rather an evidence for common features of the transition economies.

Another important feature of our results is that the exchange rate responses to monetary policy shocks do not suffer from the so-called delayed overshooting

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<sup>8</sup> See **Figures 7-12** in the appendix.

<sup>9</sup> The significance of interest rate and exchange rate responses are not as informative as in the case of the other two variables. The Bayesian approach and the identifying restrictions together imply that these posterior distributions do not contain the zero during the first 12 months, but this is an assumption, not a result.

phenomenon that much. In the literature a typical finding is that monetary contraction leads to a prolonged appreciation of the currency. This contradicts to the prediction of the model proposed by Dornbusch (1976), in which the appreciation takes place immediately, followed by gradual depreciation to the new equilibrium level. Delayed overshooting violates the UIP condition, as for several periods there is a predictable excess return<sup>10</sup> in the home currency. Although there exist theoretical models explaining the delayed response of exchange rate,<sup>11</sup> this remains an unpleasant feature of empirical estimates. Our impulse responses, however, exhibit only a temporary deviation from the UIP, as the maximum exchange rate response is reached within 6 months in each country. This may be an indication that our identifying restrictions are more capable to capture the characteristics of monetary policy shocks than those typically used in the literature. Scholl and Uhlig (2005) also find that proper identification may mitigate the delayed overshooting puzzle.

The responses to monetary policy shocks are intuitive. After a surprise interest rate increase, which is typically 30-40 basispoint in Hungary and Poland, 15-20 in the Czech Republic, output seems to fall, especially in the former two countries. Consumer prices decrease, too, with the trough being within the second year by -0.1 percent lower than the initial level. Since the shock is associated with an almost 1 percent appreciation, the IRFs suggest rather similar exchange rate pass-through dynamics.

The IRFs for the developed countries I used for control group show much more diverse picture. While the responses in the UK to the monetary policy shocks are intuitive and comparable to those in CEE countries, in the case of Canada and Sweden I encountered the phenomenon called price puzzle, that is rising prices after monetary contraction. As this may indicate the failure of identification of monetary policy shocks, I will use results for these two countries only with respect to risk premium shocks.

The effect of risk premium shocks on the price level looks alike as well in CEE countries: the immediate depreciation is followed by a relatively quick rise in prices. Rough comparison of exchange rate and CPI responses suggests again comparable exchange rate pass-through dynamics. The reaction of the industrial output, however, is ambiguous, which is in line with the findings of other authors.<sup>12</sup>

The reaction of the monetary policy to the risk premium shocks shows significant differences in the CEE countries. While in the Czech Republic and Poland interest rate responds slowly, with the peak being around 6 months after the shock, in Hungary the central bank reacts by a quick interest rate step. After a negative risk premium shock causing similar depreciation of the currency, the MNB typically increased its policy rate within two months by 6-8 times more than the other two banks. This can be understood easily by taking into account the monetary policy regimes. Contrary to the Czech Republic and Poland, Hungary operated an intervention band for its currency during the first half of the sample period. Even in the beginning of the inflation targeting regime introduced in 2001, some exchange

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<sup>10</sup> Predictable excess return is the interest rate spread plus the expected appreciation over the corresponding period.

<sup>11</sup> For instance, Bacchetta and Wincoop (2005) explain it with costs associated with processing information.

<sup>12</sup> Sánchez (2007), based on his calibrated theoretical model, could not impose *a priori* sign restriction on real output response to risk premium shocks. His empirical results confirmed this indeterminacy.

rate preferences were regularly announced. In light of this, the IRF of the exchange rate does not seem to justify the Hungarian practice: although in the other two countries the interest rate policy seems to be less concerned about risk premium changes, the correction of the initial exchange rate shock has the same pace as in Hungary.

The reason for the failure of the MNB to offset the effect of risk premium on the exchange rate is that the size of the shocks are on average much larger than the interest rate steps. To see this, I calculated the predictable excess return a foreign investor would realize in her currency after a risk premium shock. By calling it predictable, we assume that our investor knows exactly the dynamic effect of a risk premium shock.

The advantage of calculating this measure is that it can be considered as the evolution of the excess yield a typical investor requires as a compensation for either the higher perceived risk or the lower propensity to take the same risk as earlier. Predictable excess return may, therefore, properly characterise the exogenous risk premium shock, as long as a representative investor is only interested in her total return, not in whether she gained it from her foreign exchange or interest rate position. In this framework monetary policy can have influence only on the relative responses of interest rates and exchange rate, not on the total return.

According to Figure 1, the excess return on a 3-month maturity T-bill after a negative risk premium shock is typically around 3% in CEE countries. The typical interest rate hike after the shock is between 0.1 and 0.4%. Hence, the bulk of the excess return is provided by the exchange rate after the immediate depreciation, even in Hungary, where the response is significantly larger and faster than in the other two countries. For an effective exchange rate smoothing, much bigger steps, like several percentage points would be needed.

Probably due to the comparable exchange rate responses, the medium run volatilities of the consumer prices are roughly the same in the CEE countries. In the next section we will see that the exchange rate changes pass through to consumer prices indeed with almost the same dynamics in these economies.

#### **4. The exchange rate pass-through**

In this section I use the impulse response estimates in order to investigate how exchange rate changes pass through to consumer prices. In particular, I will focus on the role of monetary policy. Two dimensions of our estimation will be useful in the aspect: comparing pass-through estimates for different shocks and comparing pass-through estimates across countries with different monetary policies.

One of the main challenges of estimating exchange rate pass-through is the simultaneity problem. Some movements in the exchange rate may be endogenous reactions to underlying shock that may affect consumer prices as well, independently of the exchange rate. In this case the causal interpretation may be misleading. Another major problem is that the co-movement between the exchange rate and the consumer prices may depend on the nature of the shock. These difficulties are related to each other. Identified VARs are solutions to these problems as the identification of shocks eliminates simultaneity and provides shock-dependent estimates.

The derivation of the exchange rate pass-through dynamics are described in details in the appendix. For each country and each shock, the reaction of the consumer prices

to a permanent one percent depreciation of the currency is meant by exchange rate pass-through. Based on these estimates,<sup>13</sup> the following observations can be made:

Firstly, the pass-through estimates are quite close to each other across countries and shocks for the Czech Republic, Hungary and Poland (Figure 17). One percent permanent depreciation of the currency due to consecutive risk premium shocks typically increases consumer prices by 0.2 and 0.3 percent by the end of the first and second year after the shock, respectively. In the case of monetary policy shocks, the corresponding values are 0.1 and 0.2. This means that risk premium shocks have relatively large effect on the annual inflation rate in the first year, but it halves during the second, and virtually disappears later. By contrast, monetary policy has smaller, but prolonged effect on the year-on-year consumer price index. Nevertheless, the differences between pass-through dynamics conditioned on different shocks are insignificant at usual significance levels.

The cross-country similarity of exchange rate pass-through, on the one hand, is in line with our earlier findings with respect to the impulse response functions. Later we will see that in countries used for control group, exchange rate pass-through is different, so the dynamics we obtained for CEE countries is indeed their special feature.

On the other hand, the similarity of exchange rate pass-through across CEE countries supports our earlier finding that the bigger weight Hungarian monetary policy gave to exchange rate stability did not fostered the price stability. Although the interest rate steps of the Magyar Nemzeti Bank to the same risk premium shocks were larger, the exchange rate and the consumer prices reacted like in the other two countries. The interest rate change was not enough to influence significantly the exchange rate; hence the exchange rate pass-through should not differ from those of the other countries, other things being equal.

Comparison of pass-through dynamics conditioned on different type of shocks may give an impression about how price-setting works. As we noted in the previous section and according to the estimates, monetary policy has more gradual, but also more protracted effect on the exchange rate than risk premium shocks have. If price-setters were rational and forward-looking, one would expect lower pass-through in the latter case, as changing prices may be costly, and the more temporary the exchange rate shock is, the less the benefit re-pricing has. On the contrary, monetary policy generates more permanent revaluation of the currency, so it may pay-off more to re-optimize prices in such cases.

The results do not reveal shock-dependent pass-through, at least not in CEE countries. Although there is some difference in the short-run pass-through dynamics, it is not significant enough, and even has a counterintuitive direction. Based on the reaction of the exchange rate to these shocks, we would expect faster reaction of consumer prices to exchange rate movements generated by monetary policy. However, the estimates show slightly faster pass-through in the case of risk premium shocks.

The second major observation is that monetary policy has the same exchange rate pass-through in both CEE region and in the UK during the first year, but later it seems to slow down in the UK, while continuing further in the transition economies (Figure 18, left hand panel).

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<sup>13</sup> See Figures 17-18 in the appendix.

Thirdly, the pass-through of exchange rate movements to consumer prices caused by risk premium shocks is much higher in transition economies. Although the interpretation of the finding is not the same, together with the previous observation we can conclude that the role of the exchange rate in price setting is lower in Canada, Sweden and the UK. This result reinforces again that our findings for the CEE countries are not pure artifact of the methodology; these countries do share some common features regarding the exchange rate pass-through.

The reason for the different pass-through may be the credibility of monetary policy and the inflationary environment. While the central banks in the CEE countries during the sample period had the main objective of bringing down the inflation to the level corresponding to price stability, in Canada, Sweden and the UK the low inflation was already a fact. This is the main argument of Taylor (2000).

Gagnon and Ihrig (2004) estimate long-run pass-through coefficients for several developed countries controlling also for the change in the level of inflation. They found that low inflation brought about lower rate of exchange rate pass-through in these countries. For Canada, Sweden and the UK using a sample period almost like ours as the 'low inflation era', they estimated virtually no long-run effect. Their results are in general in line with ours.

## 5. Conclusion

In this paper I investigated the effect of monetary policy, investors' risk assessment and risk preference on the exchange rate, interest rate, industrial production and consumer prices in the Czech Republic, Hungary and Poland. The main focus was on the role monetary policy plays in the pass-through of exchange rate changes due to external shocks.

A VAR model was used to capture the dynamic interaction among our variables. I identified monetary policy and risk premium shocks by imposing restrictions on the impulse responses. For identification I assumed that neither of these shocks has impact on industrial production and consumer prices within one month. I also assumed that while an interest rate increase caused by an unexpected monetary tightening is coupled with an appreciation of the currency, in the case of the risk premium higher interest rate comes with weaker exchange rate for one year. I estimated the same model to Canada, Sweden and the UK in order to identify features that are specific to the CEE region. Roughly ten years of data was used, starting in the middle of the nineties.

I found that the transmission of monetary policy is fairly similar in CEE countries. After a monetary contraction, consumer prices and industrial production fall in line with intuition.

Concerning risk premium shocks, the case of Hungary is a bit special. Among the three transition countries, Hungarian monetary policy has been less tolerant towards exchange rate movements caused by financial markets. Its policy assigned a larger weight to exchange rate stability than in the other two countries. To achieve this stability, interest rate responded faster and sharper to risk premium shocks. However, the results did not confirm that this policy resulted in higher price stability. The reason is that the interest rate responses proved to be still too small compared to the shock, and therefore could not dampen significantly the exchange rate response.

Based on the impulse responses to the identified shocks, I calculated the dynamic response of consumer prices to a permanent, one percent depreciation of the

currency. I derived this measure with respect to both shocks and called it exchange rate pass-through. The implied pass-through rates were almost identical in the CEE countries independently of the nature of the shock. They were, however, higher than in the countries of the control group of developed countries. I explained the difference by the credibility of the monetary policy and the average inflation rate. While in Hungary, Poland and to a lesser extent in Czech Republic, the sample period could be characterised by 'converging to the price stability', in Canada, Sweden and the UK it was the era of low and stable inflation. In the latter countries the anchored inflation expectations may have contributed to the low exchange rate pass-through.

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## Appendix

### a. Calculation of the exchange rate pass-through

Comparing exchange rate pass-through dynamics across countries and different shocks is not straightforward. The problem is that the exchange rate itself is also an endogenous variable having its own specific response to each shock. Exchange rate pass-through means the dynamic response of some price variables to the change in exchange rate. How can one compare these responses if the exchange rate responds differently to different shocks?

The way other authors using VAR calculated exchange rate pass-through is not always clearly presented. Faruquee (2006) reports the price response divided by the exchange rate IRF. Others, like Hahn (2003), McCarthy (2006), Ca'Zorzi et al (2007) normalise CPI impulse response by the size of the immediate exchange rate response. Darvas (2001), in a slightly different, but also simultaneous modelling framework, reports long-run price responses in a similar way. However, the comparison of these statistics is still questionable, as they may differ if the exchange rate IRFs have different shape.

My approach was to create a sequence of the same type of shocks, but of different size in order to achieve a permanent one percent depreciation of the exchange rate. I then calculated the accumulated response of consumer prices to these series of shocks. I could then compare the modified IRFs of CPI with respect to both shocks. The comparison now makes sense, as these responses correspond to exactly the same exchange rate movement.

Probably the main objection to this approach could be a conceptual one. While this calculation is technically feasible, it may contradict to the logic of VAR models and impulse response analysis. Impulse responses are the reactions of certain variables to a certain unexpected event, which could not have been forecasted from the lags of the variables in the VAR. Impulse responses are valid as long as the shock is really unexpected. If, for example, the monetary policy tries to surprise the economic agents in a way that it generates a permanent 1 percent depreciation of the currency, agents may realise this 'new' policy rule. If they learn the modified behaviour of the central bank, they can forecast it, and their reaction to the interest rate shocks will change. Our experiment, however, assumes that for several periods private agents are again and again surprised by the fact that the interest rate is still not there where it should be if the monetary policy followed her rule. Since in the long run this may be - but not necessarily is - an unrealistic assumption, we restrict ourselves to formulate firm statements only for the short run pass-through.

Even though the method looks straightforward to implement, I had some problems in calculating pass-through conditioned on monetary policy shock, especially in the case of Czech Republic. The posterior distributions became extremely wide, compared to those of the original IRFs. Moreover, even the median response exhibited a disturbing oscillation.

The reason for it is the delayed overshooting, that is it takes some months for the exchange rate to reach its maximum deviation after the shock. The standardisation was based on achieving an immediate and permanent one percent shift in the exchange rate by giving a series of the same shock to the system. Therefore a large initial monetary policy shock is needed to generate the required appreciation or depreciation. But this initial shock has an even bigger impact on the exchange rate

during the next few periods. Since it would cause too much appreciation or depreciation, the monetary policy has to surprise the markets again with a shock, but now to the opposite direction. After all, the earlier steps have a cumulative effect on the exchange rate, which is too large, thus bigger and bigger shocks with opposite signs are needed to stabilise the exchange rate. This results in exploding oscillation in the path of other variables, like prices, which is of distinguished interest here. The policy implication of this seemingly technical finding is that in the presence of delayed overshooting, tight exchange rate targeting may be difficult to implement if it is not the announced rule known by the public.

Since the delayed overshooting, and therefore the oscillation is most pronounced in the Czech impulse responses, I omitted them when discussing exchange rate pass-through related to monetary policy shocks. Similar oscillation in pass-through dynamics in the Hungarian and Polish case is also present, but its magnitude is not so disturbing. Fortunately, in the case of risk premium shocks, exchange rate jumps immediately, so the modified responses of prices can be derived and compared without any difficulties. As a control group I use first of all estimates for the UK. Since the identification of monetary policy shocks was not convincing for Canada and Sweden, they are considered as a benchmark for CEE countries only in the case of risk premium shocks.

#### **b. Alternative methods for selecting the mean responses**

Fry and Pagan (2007) criticized the practice reporting posterior distribution of impulse responses by connecting median estimates for each period. Their main argument was that this pointwise median response typically does not belong to any plausible shock; its points usually lie on different impulse responses. Hence, deriving conclusions about the shape of the response may be misleading. The second problem arises when one identifies more than one shock simultaneously. In this case median responses usually belong to shocks that are not orthogonal, which renders their comparison and the use of forecast error variance decomposition invalid.

They proposed an algorithm to choose impulse responses by minimizing their squared deviation from the first period median. Using Peersman's (2005) model and data set, they demonstrated that the difference between their proposed median and the pointwise median can be substantial, even affecting the main conclusions.

Liu (2007) generalized Fry and Pagan's median selection rule by minimizing the squared deviation of the responses from the pointwise median over several period. Obviously, this approach tends to select median response which is closer to the pointwise median than that of Fry and Pagan's, since the latter uses information of only the first period posterior distribution.

There are however some arguments against using Fry and Pagan's or Liu's statistics for reporting posterior distributions. First, their methods can pick only the mean, and it cannot be extended to provide confidence bands or percentiles. Second, especially with VARs with several lags, impulse responses may oscillate excessively, which is obviously the result of imprecise estimation. While pointwise medians sometimes tend to smooth out these counterintuitive oscillating, the Fry-Pagan or Liu median usually inherits this unappealing feature. Third, there is some inconsistency between opposing the use pointwise median on one hand, and penalizing the deviation from it when choosing the mean response, on the other. Finally, choosing 'median shocks' based on the distribution of the impulse responses of the VAR's variables may produce outlier results when one considers other statistics that are not linear or even

not monotonous function of the original IRFs. Later I will demonstrate that the derived pass-through dynamics are such statistics.

In order to assess whether my results depend on relying on the usual pointwise percentiles, I calculate alternative mean responses as well. The first candidate was Liu's approach. I used it instead of the Fry-Pagan mean because it uses more information than the other. Practically, I chose the pair of orthogonal monetary policy and risk premium shocks that produced impulse responses as close to the pointwise medians as possible for 60 periods, ore more formally:

$$\min_i \sum_{t=1}^{60} \left( y_t^{m(i)} - y_t^{m,med} \right)^2 + \left( p_t^{m(i)} - p_t^{m,med} \right)^2 + \left( i_t^{m(i)} - i_t^{m,med} \right)^2 + \left( s_t^{m(i)} - s_t^{m,med} \right)^2 + \left( y_t^{r(i)} - y_t^{r,med} \right)^2 + \left( p_t^{r(i)} - p_t^{r,med} \right)^2 + \left( i_t^{r(i)} - i_t^{r,med} \right)^2 + \left( s_t^{r(i)} - s_t^{r,med} \right)^2$$

where  $i$  counts the succesfull draws,  $m(i)$  and  $r(i)$  denotes the response of output, price level, interest rate and exchange rate to the  $i$ th monetary policy and risk premium shock. Superscript *med* stands for the pointwise median.

I also propose another mean, which does not use the pointwise median as a benchmark. I define a distance between two draws similarly to the sum in the previous expression by replacing the median impulse responses with the IRFs of the second draw. In other words, I calculate the unweighted<sup>14</sup> sum of squared differences of impulse responses for each variable to each shock over 60 periods, that is five years. Then I choose the draw that has the minimum sum of distance from the rest. This algorithm minimizes the expected deviation when all draws are equally likely and the distance measure is the squared difference – analogously what the arithmetic mean does in the one dimensional case. Formally:

$$\min_i \sum_j \sum_{t=1}^{60} \left( y_t^{m(i)} - y_t^{m(j)} \right)^2 + \left( p_t^{m(i)} - p_t^{m(j)} \right)^2 + \left( i_t^{m(i)} - i_t^{m(j)} \right)^2 + \left( s_t^{m(i)} - s_t^{m(j)} \right)^2 + \left( y_t^{r(i)} - y_t^{r(j)} \right)^2 + \left( p_t^{r(i)} - p_t^{r(j)} \right)^2 + \left( i_t^{r(i)} - i_t^{r(j)} \right)^2 + \left( s_t^{r(i)} - s_t^{r(j)} \right)^2$$

I will call this mean Euclidean referring to the sum of squares distance definition.

In most cases these alternative means were within the middle 68% of the posterior distributions, so at first glance the results seem to be robust to the way of reporting the posterior. However, when I calculated the exchange rate pass-through, in the case of some countries the response of prices to the exchange rate after a monetary policy shock seemed to be immediate and complete, contradicting to our earlier finding. The reason for this may be similar to the strongly oscillating median pass-through mentioned in the paper. Deriving the standardized pass-through dynamics involves dividing by close-to-zero numbers several times making the result extremely sensitive to even very small changes in the underlying impulse response functions. Hence, even if the alternative means lied nearly in the middle of the posterior distribution of price and exchange rate responses, the derived exchange rate pass-through dynamics provided an outlier observation.

An alternative way to check the robustness of our results is to calculate directly statistics that capture those features we consider relevant to our conclusions. One important finding in the paper was that the Hungarian monetary policy reacts faster

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<sup>14</sup> Should we have a preference regarding the most relevant shocks, variables or horizons, a proper weight vector can be used.

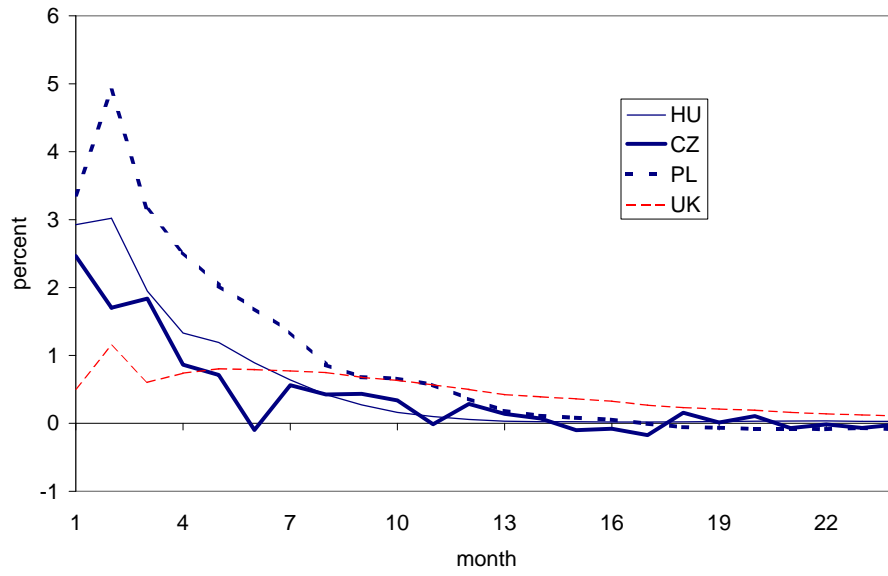
and stronger to risk premium shocks than in other countries. In order to quantify this, I calculated the timing and the size of the maximum interest rate response after the shocks. Then I compared the posterior distributions of these statistics. The comparison confirmed our earlier findings.

Another important statement was that the pass-through of exchange rate changes due to risk premium shocks are lower in developed than in transition countries. I checked only the case of UK and monetary policy shock because it does not seem to be robust to the choice of the mean<sup>15</sup>. I calculated the posterior distribution of the pass-through after 12 and months. The distributions at both horizons were unimodal and symmetric around the median despite the fact that the Liu and Euclidean means appeared at the higher tail, suggesting that the pointwise median captures correctly the typical case. Based on these exercises, I conclude that the conclusions drawn by using the pointwise medians are indeed good characterization of the results.

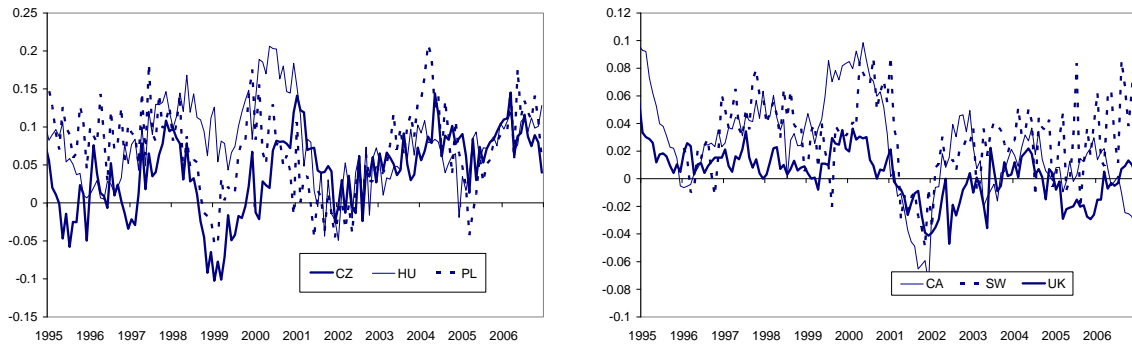
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<sup>15</sup> See Figures 14-16

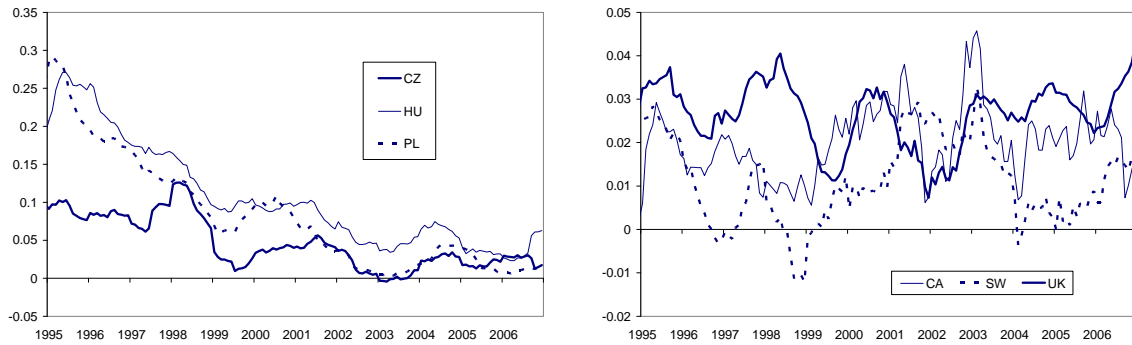
**Figure 1:** Annualised predictable excess returns on 3-month maturity after a one standard deviation risk premium shock (median estimates)



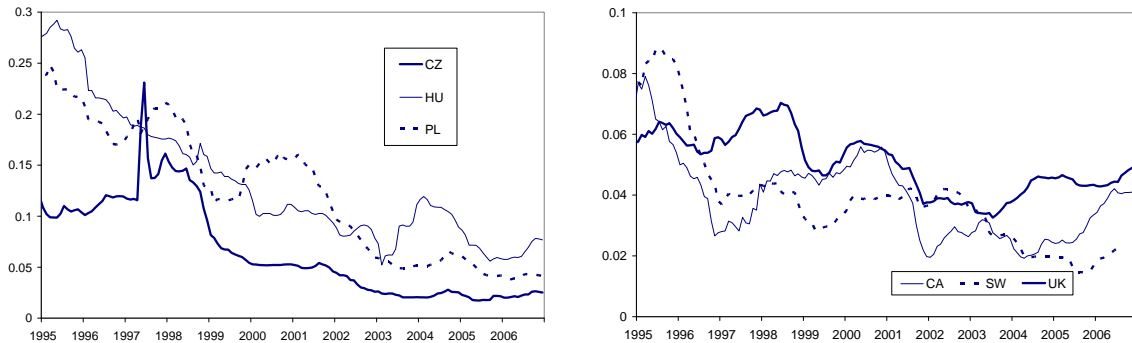
**Figure 2:** Year-on-year growth of industrial production (log-differences)



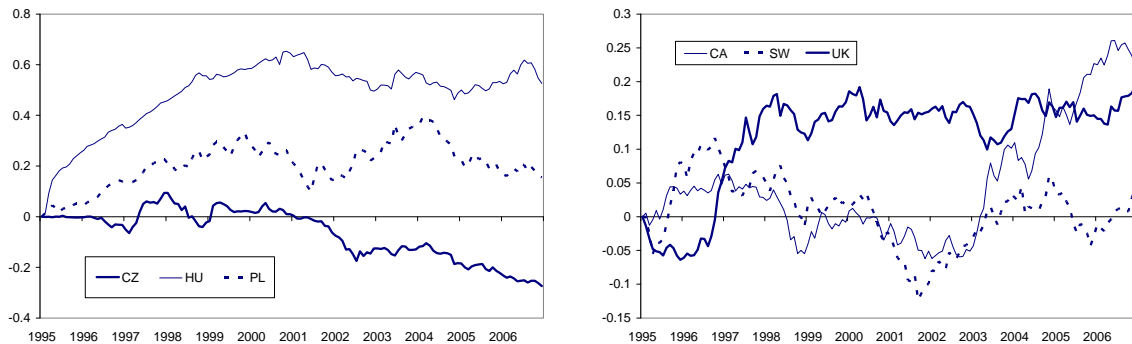
**Figure 3:** Year-on-year growth of consumer prices (log-differences)



**Figure 4:** Short-term interest rates

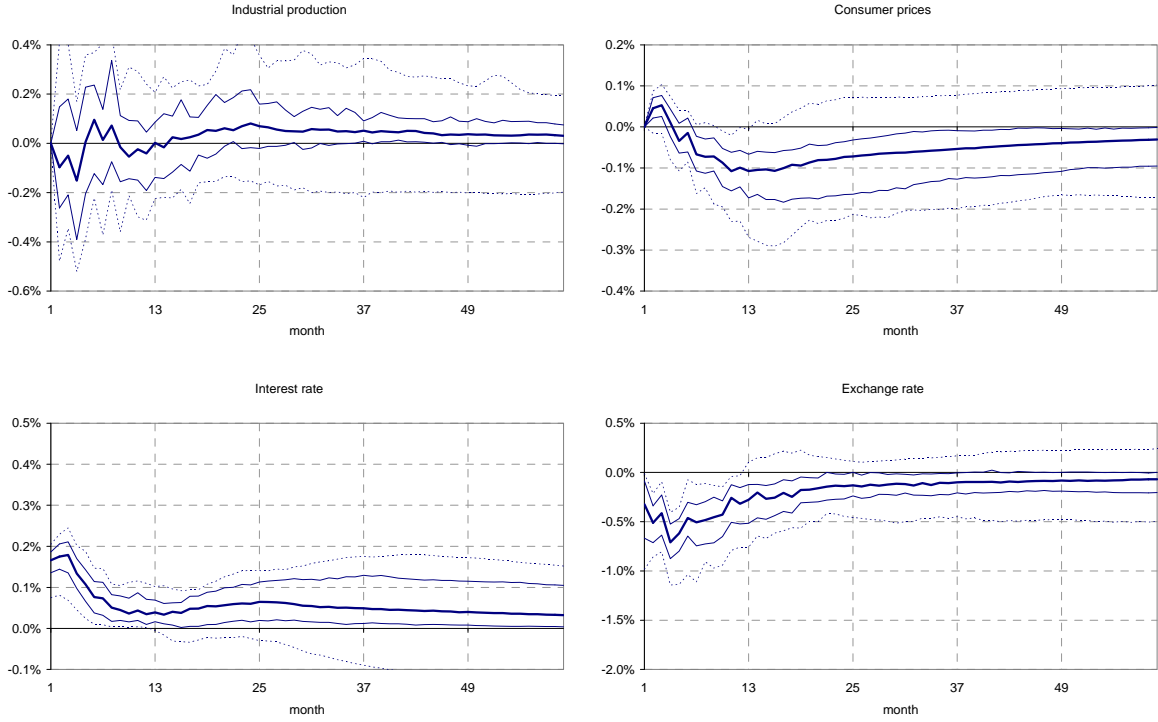


**Figure 5:** Nominal effective exchange rate (logarithmic deviation from the 1995:M1 level)

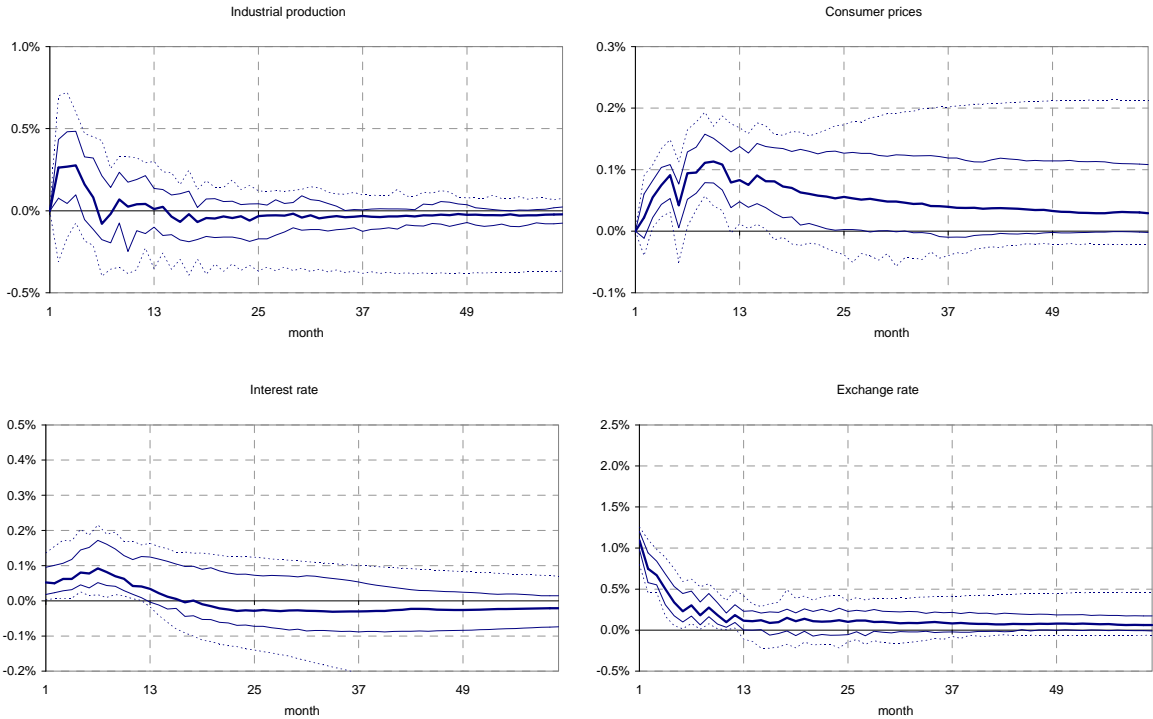


**Figure 6:** Impulse responses to a one standard deviation shock in the Czech Republic

*a) Monetary policy shock*



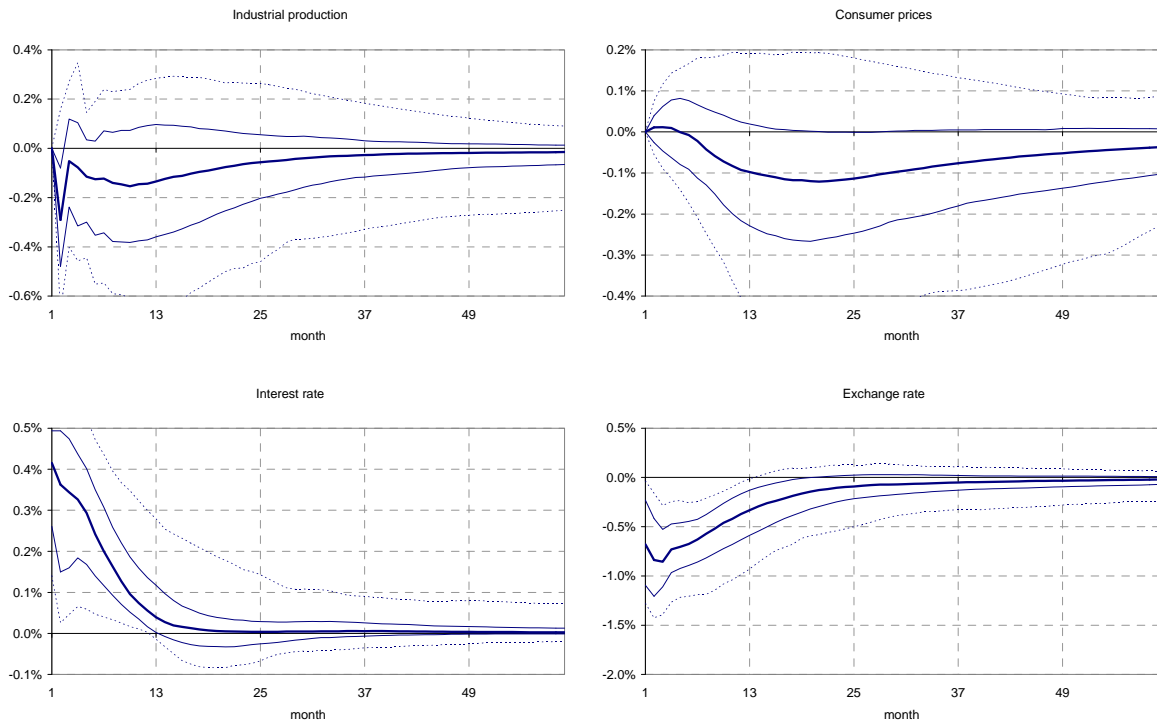
*b) Risk premium shock*



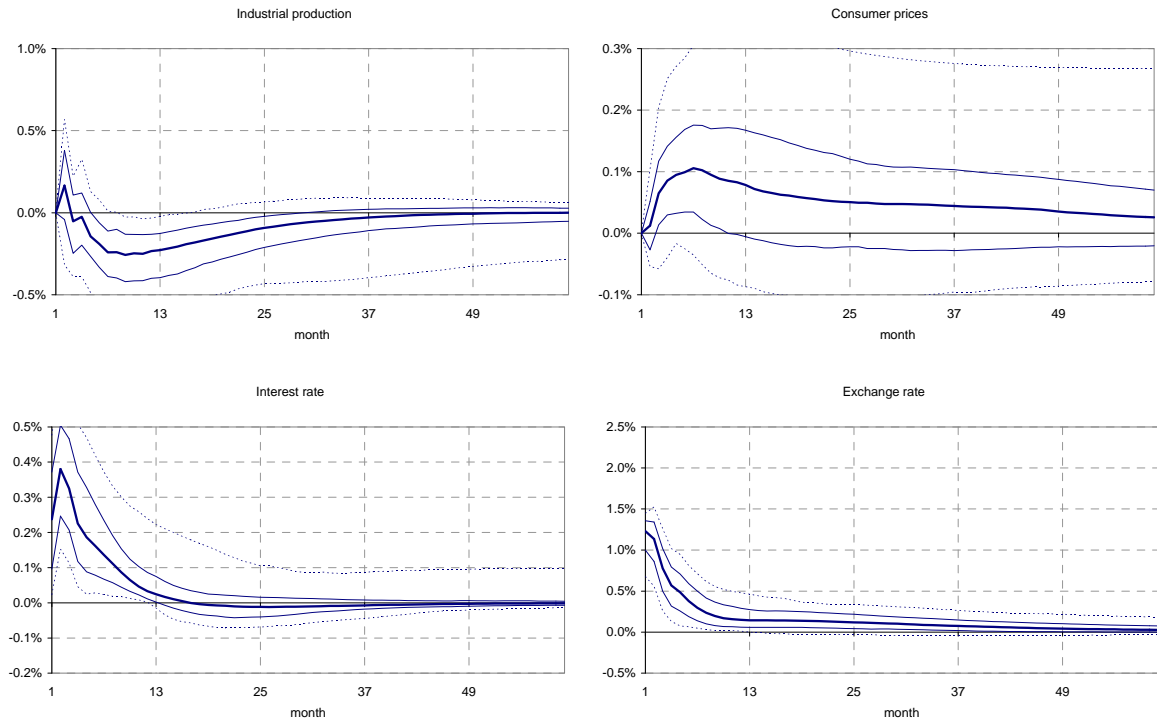
Median estimates (thick line), the middle 68 percent ( $\pm 1$  st. dev. for normal distribution; solid lines) and the middle 95.4 percent ( $\pm 2$  st. dev. for normal distribution; dotted lines) of the posterior distribution are reported.

**Figure 7: Impulse responses to a one standard deviation shock in Hungary**

*a) Monetary policy shock*



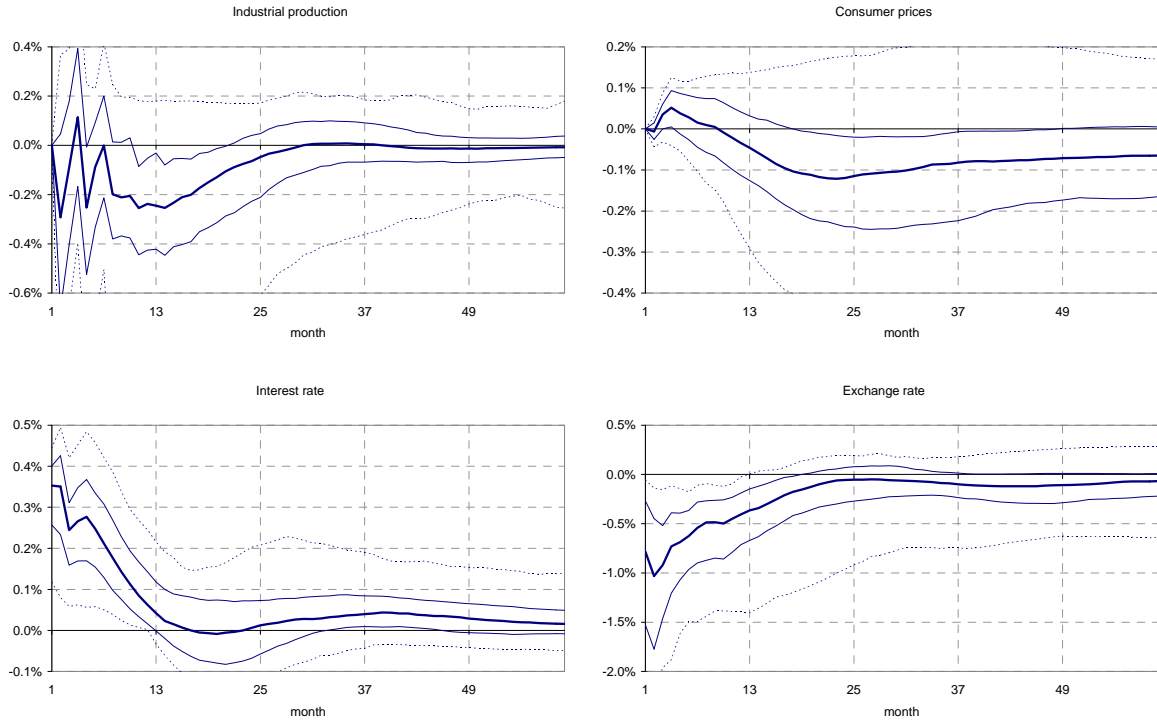
*b) Risk premium shock*



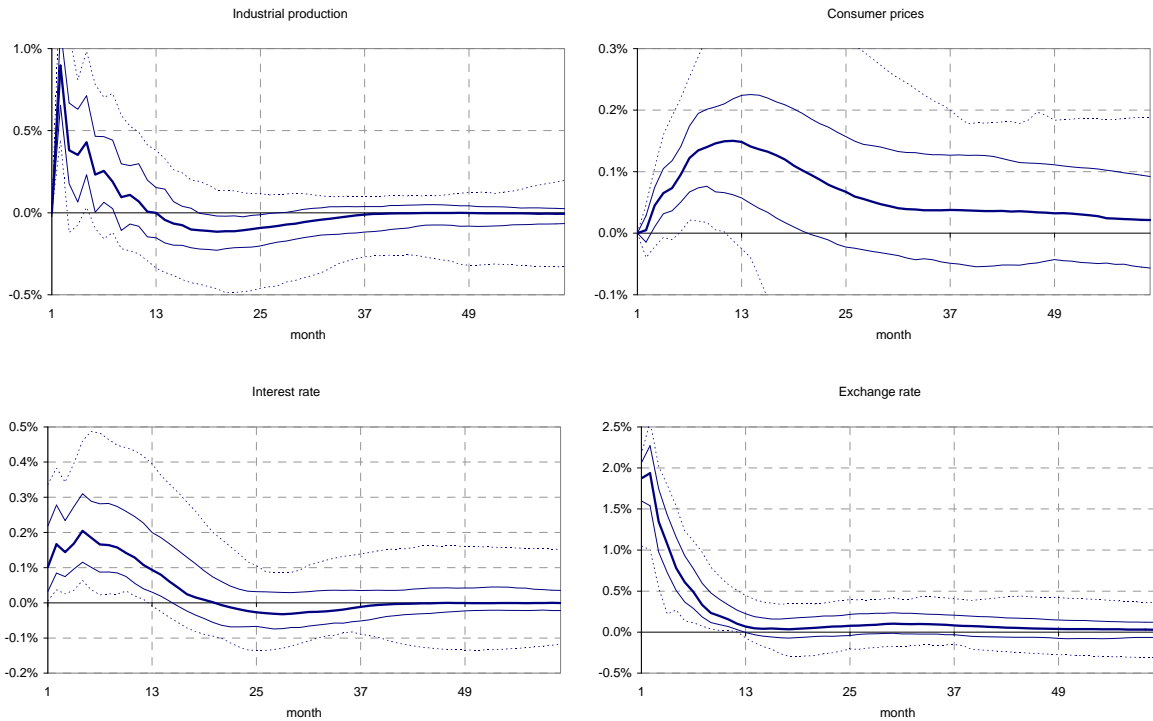
Median estimates (thick line), the middle 68 percent ( $\pm 1$  st. dev. for normal distribution; solid lines) and the middle 95.4 percent ( $\pm 2$  st. dev. for normal distribution; dotted lines) of the posterior distribution are reported.

**Figure 8: Impulse responses to a one standard deviation shock in Poland**

*a) Monetary policy shock*



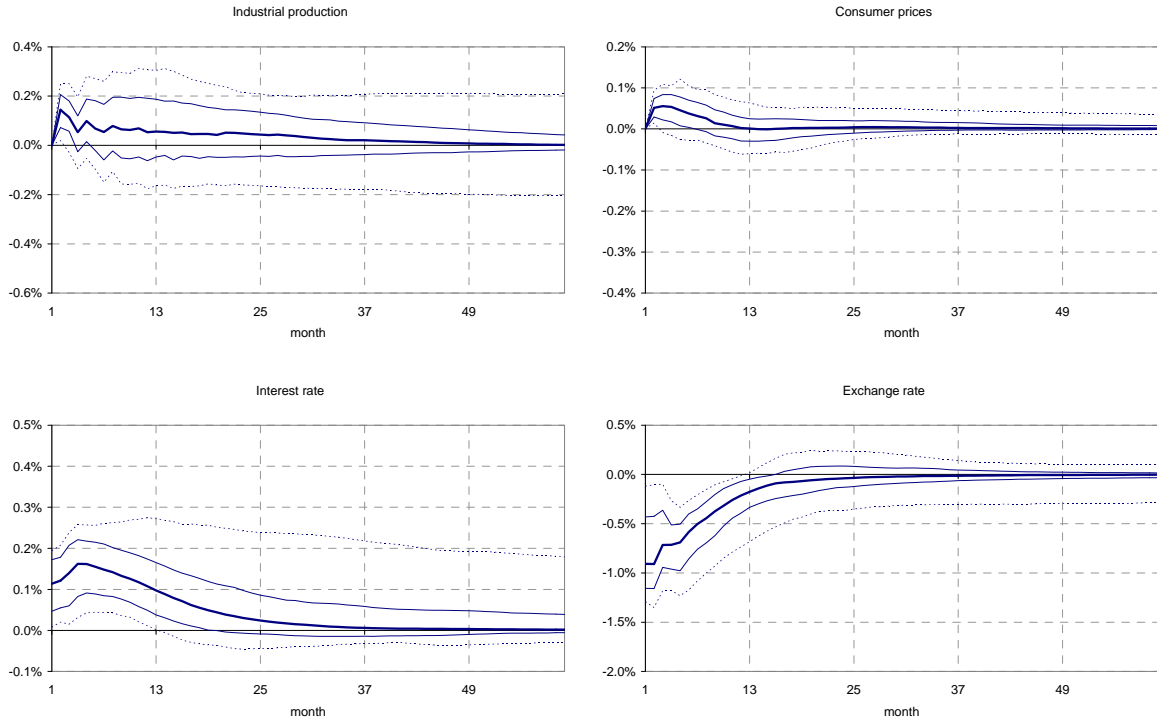
*b) Risk premium shock*



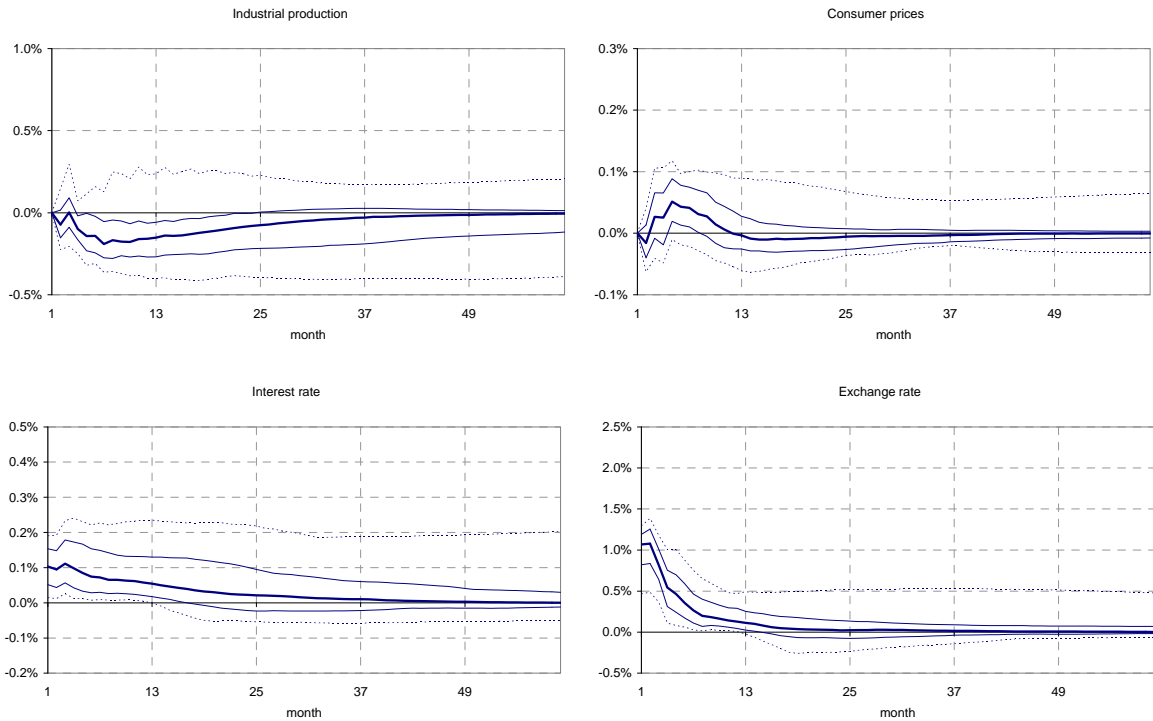
Median estimates (thick line), the middle 68 percent ( $\pm 1$  st. dev. for normal distribution; solid lines) and the middle 95.4 percent ( $\pm 2$  st. dev. for normal distribution; dotted lines) of the posterior distribution are reported.

**Figure 9: Impulse responses to a one standard deviation shock in Canada**

*a) Monetary policy shock*



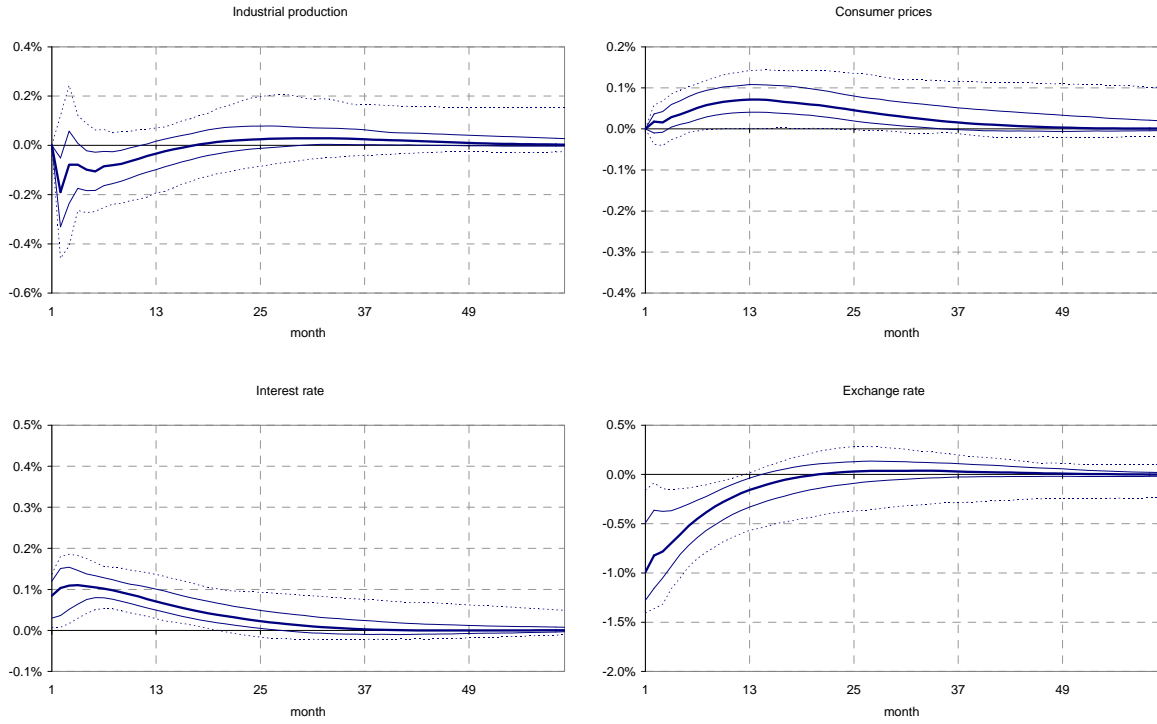
*b) Risk premium shock*



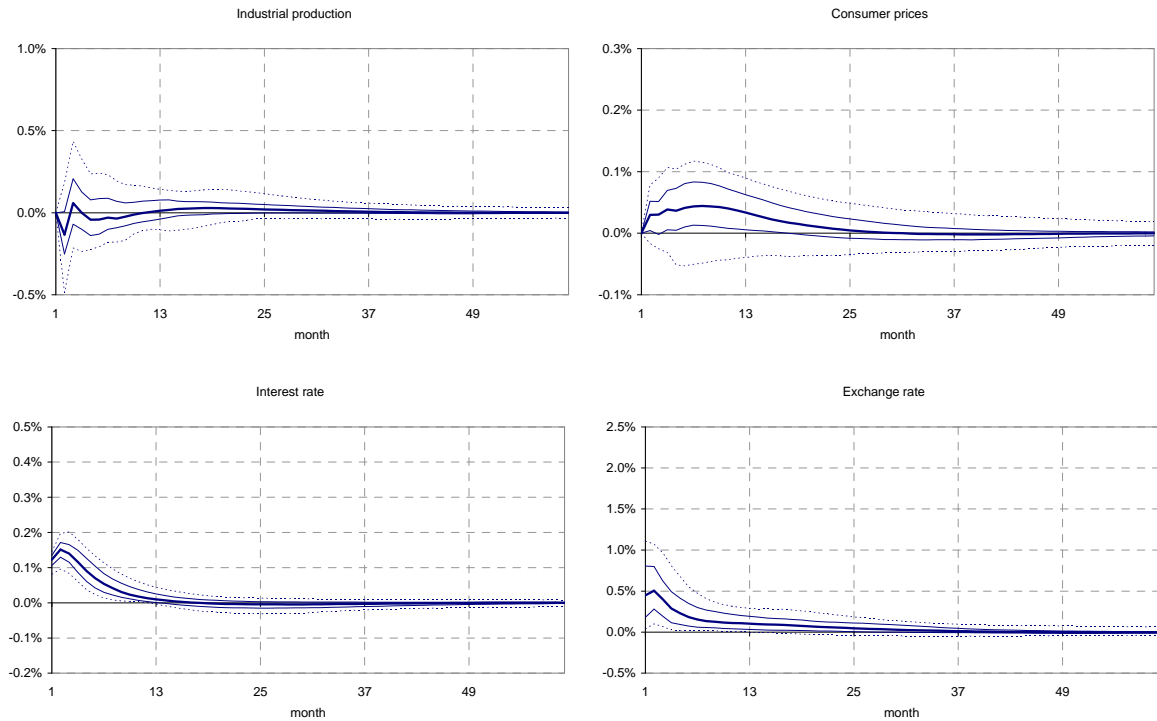
Median estimates (thick line), the middle 68 percent ( $\pm 1$  st. dev. for normal distribution; solid lines) and the middle 95.4 percent ( $\pm 2$  st. dev. for normal distribution; dotted lines) of the posterior distribution are reported.

**Figure 10:** Impulse responses to a one standard deviation shock in Sweden

*a) Monetary policy shock*



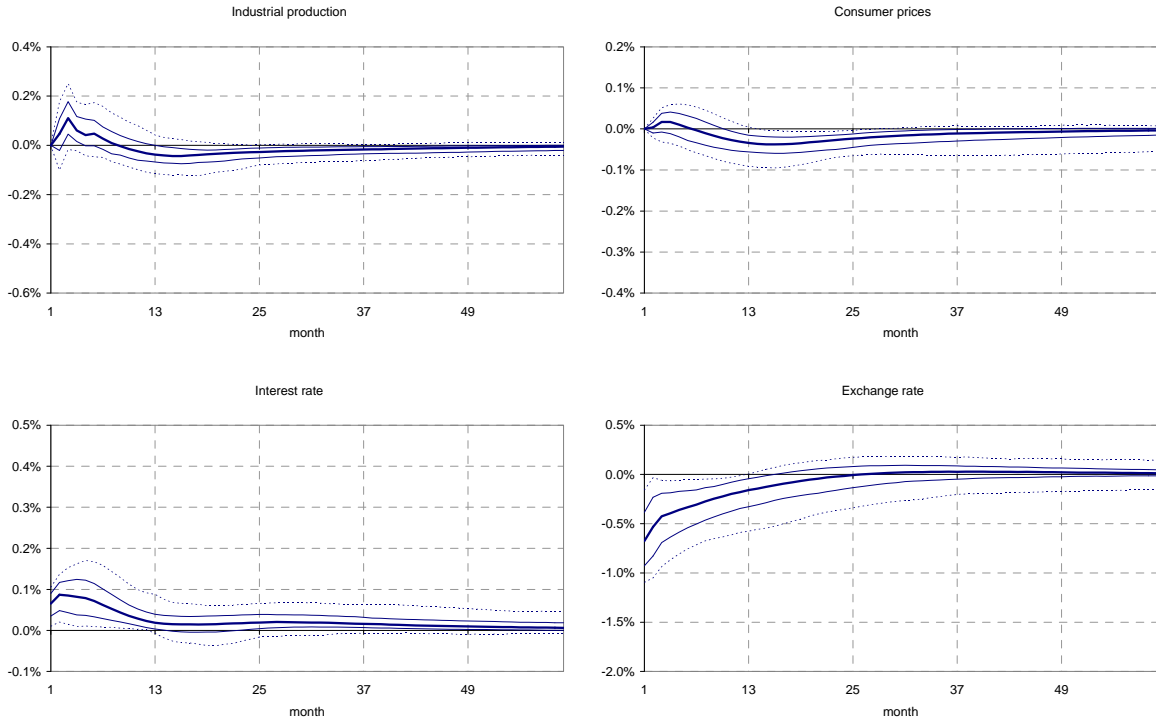
*b) Risk premium shock*



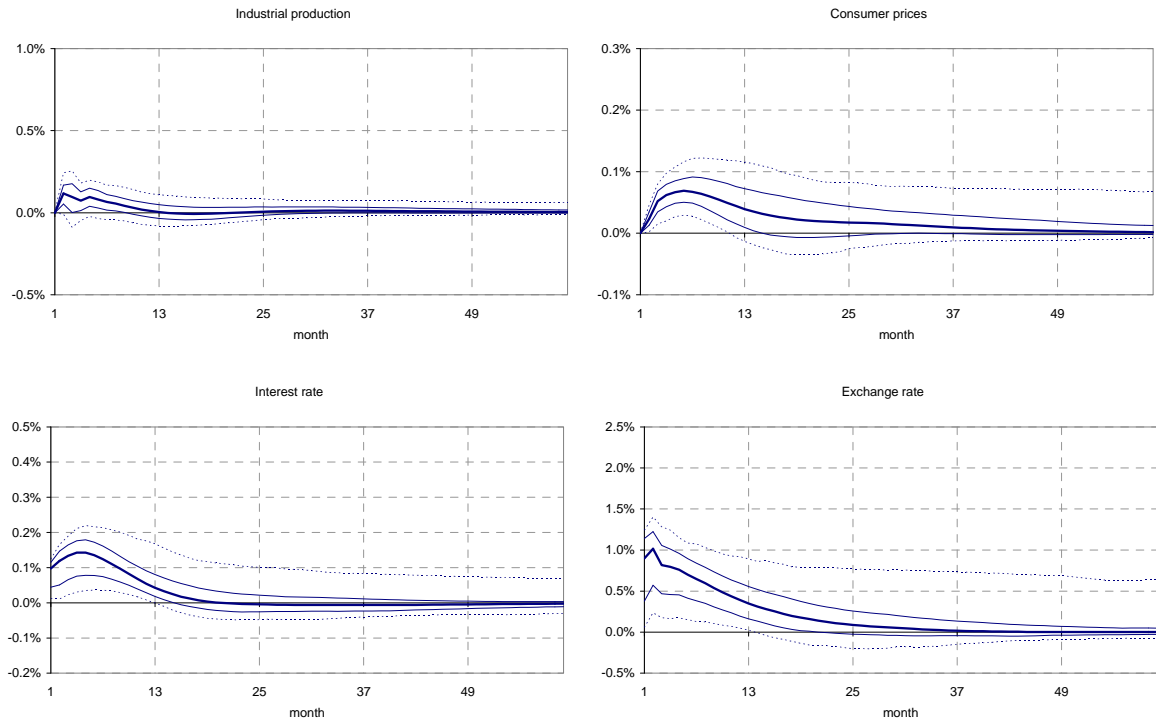
Median estimates (thick line), the middle 68 percent ( $\pm 1$  st. dev. for normal distribution; solid lines) and the middle 95.4 percent ( $\pm 2$  st. dev. for normal distribution; dotted lines) of the posterior distribution are reported.

**Figure 11: Impulse responses to a one standard deviation shock in the UK**

*a) Monetary policy shock*

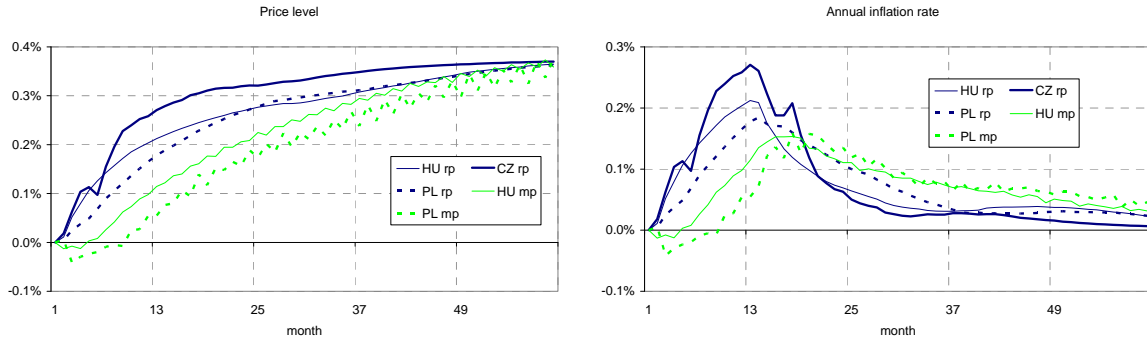


*b) Risk premium shock*

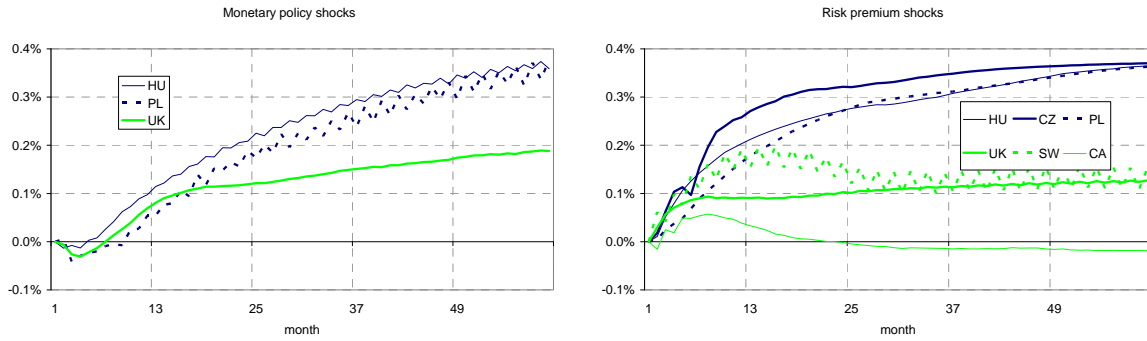


Median estimates (thick line), the middle 68 percent ( $\pm 1$  st. dev. for normal distribution; solid lines) and the middle 95.4 percent ( $\pm 2$  st. dev. for normal distribution; dotted lines) of the posterior distribution are reported.

**Figure 12:** The pass-through of one percent nominal exchange rate depreciation to the consumer prices in the CEE countries, conditioned on monetary policy (mp) and risk premium (rp) shocks

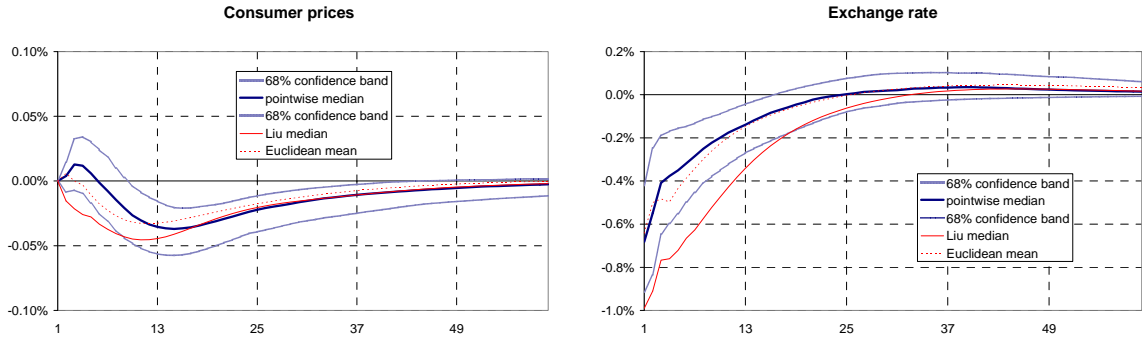


**Figure 13:** The pass-through of one percent nominal exchange rate depreciation to the consumer prices conditioned on monetary policy and risk premium shocks in CEE and developed countries

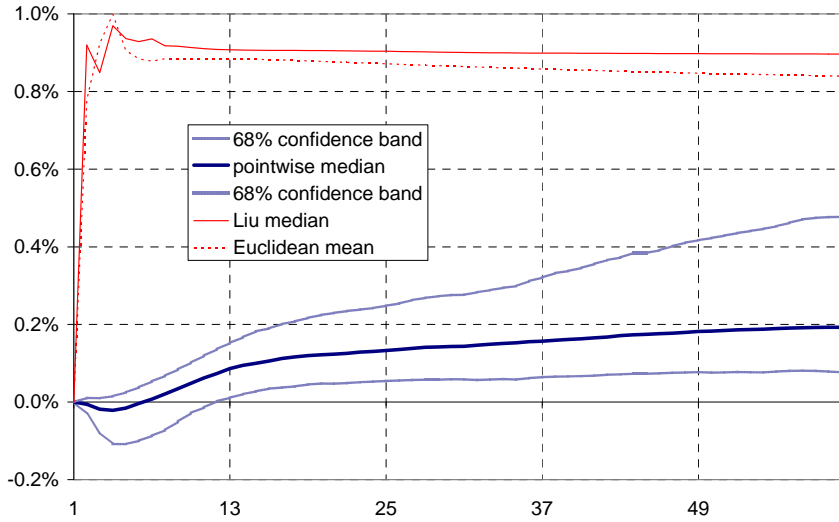


Median estimates.

**Figure 14:** Price and exchange rate impulse responses to a one standard deviation monetary policy shock in the UK. Comparison of alternative means



**Figure 15:** The pass-through of one percent nominal exchange rate depreciation to the consumer prices in the UK, conditioned on monetary policy shocks. Comparison of alternative means



**Figure 16:** The posterior distribution of the price response to a permanent one percent nominal exchange rate depreciation in the UK

