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The Effects of Monetary Policy in the Czech Republic: An Empirical Study

Magdalena Morgese Borys and Roman Horváth *

Abstract

In this paper, we examine the effects of Czech monetary policy on the economy within the VAR, structural VAR, and factor-augmented VAR frameworks. We document a well-functioning transmission mechanism similar to the euro area countries, especially in terms of persistence of monetary policy shocks. Subject to various sensitivity tests, we find that a contractionary monetary policy shock has a negative effect on the degree of economic activity and the price level, both with a peak response after one year or so. Regarding prices at the sectoral level, tradables adjust faster than non-tradables, which is in line with microeconomic evidence on price stickiness. There is no price puzzle, as our data come from a single monetary policy regime. There is a rationale in using the real-time output gap instead of current GDP growth, as using the former results in much more precise estimates. The results indicate a rather persistent appreciation of the domestic currency after a monetary tightening, with a gradual depreciation afterwards.

JEL Codes: E31, E52, E58.
Keywords: Monetary policy transmission, real-time data, sectoral prices, VAR.

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Nontechnical Summary

In this paper, we examine the effects of monetary policy within various econometric frameworks (vector autoregression (VAR), structural VAR (SVAR), and factor-augmented VAR (FAVAR)) during the inflation targeting period in the Czech Republic. More specifically, we focus on assessing the persistence and magnitude of monetary policy effects on output, prices (at both the aggregate and sectoral level) and the exchange rate.

In general, monetary transmission in the Czech Republic seems to be similar, in terms of persistence of the responses of economic variables to monetary shocks, to that in more developed countries, including the euro area.

All in all, subject to various sensitivity tests, we find that prices and output decline after a monetary tightening, with the bottom response occurring after about one year. This finding corresponds with the actual targeting horizon of the Czech National Bank. In addition, we document that the reaction of tradable prices is faster than that of non-tradable prices. While the maximum effect of a monetary shock on tradables can be seen after a year or so, it is at least a year and a half for non-tradable prices. This result broadly confirms the microeconomic evidence on the effect of competition on price rigidity.

Our results support the notion that the price puzzle (i.e. an increase in prices after a monetary tightening) is associated with model misspecification rather than with the actual behavior of the economy. This is supported by other empirical VAR studies on monetary transmission in the Czech Republic, as all studies estimating the effects of monetary policy across different monetary policy regimes (i.e., the fixed exchange rate regime and inflation targeting regime mixed together) exhibit the price puzzle.

Next, we find that there is a rationale for using the real-time output gap estimate instead of current GDP growth, as using the former results in much more precise estimates of monetary policy effects. The impulse responses of GDP to an unexpected change of interest rates are less precisely estimated, and thus our findings point to the importance of real-time data in monetary policy analysis. Finally, our results also indicate a persistent appreciation of the domestic currency after a monetary tightening ("delayed overshooting"), although the confidence intervals are in this case rather wide, with a gradual depreciation afterwards.

1. Introduction

Understanding the transmission of monetary policy to inflation and other real economic variables is of key importance if central bankers are to conduct monetary policy effectively. Not surprisingly, there is extensive theoretical as well as empirical literature studying the effects of monetary policy shocks on real economy aggregates and prices. For a small open economy such as the Czech Republic, it is vital to analyze monetary policy transmission for several reasons. First, there is somewhat mixed evidence regarding monetary policy transmission, as many studies estimate standard vector autoregression (VAR) models mixing data from two distinct policy regimes, i.e., from the fixed exchange rate regime under which the Czech National Bank conducted its policy until May 1997, and from the inflation targeting regime that was adopted in January 1998.[1] Not surprisingly, the identification of monetary policy shocks then becomes somewhat cumbersome and *all* these studies exhibit the price puzzle (see our Table 1 in the results section).

Therefore, it is worthwhile to update previous results reflecting the monetary policy regime changes, to utilize a wider range of econometric techniques and, on top of that, to incorporate real-time and forward-looking variables into the VAR analysis. To our knowledge, real-time data has not been applied to study monetary transmission in the Czech Republic. This is in a sense paradoxical, as an important feature of monetary policy conduct is that it is based on the information set available at the time of policy-making. This implies that using *ex-post* revised data (note that these are typically more precise, but are not available at the time of monetary policy action) may contaminate the estimated effects of monetary policy (Croushore and Evans, 2006). The revisions are typical for output data.[2]

There is also no empirical evidence about monetary policy effects on sectoral prices. This is striking, because tradable prices in a small open economy may be driven to a large extent by international factors that domestic monetary policy is unlikely to affect. Our prior assumption is that as non-tradable prices are typically less exposed to international competition and more labor-intensive, the reaction of non-tradable prices is likely to be more persistent (see e.g. Barro, 1972, and Martin, 1993, for models relating the degree of competition to price rigidity).[3]

In this paper, we examine the effects of monetary policy within the vector autoregression (VAR), structural VAR (SVAR), and factor-augmented VAR (FAVAR) frameworks during the inflation targeting period in the Czech Republic. More specifically, we focus on assessing the persistence and magnitude of monetary policy shocks on output (including the real-time output gap), prices

[1] See Coats, Laxton, and Rose (2003) and Kotlán and Navrátil (2003) for an overview of Czech monetary policy.

[2] We therefore utilize the real-time estimates of the output gap available from the Czech National Bank (CNB). Using the central bank output gap is advantageous for monetary policy shock identification, as the central bank conducts its policy based on *its* estimate of the degree of economic activity, not the estimates of other institutions or individuals. Note that price indices are not revised *ex post* by the Czech Statistical Office. An additional rationale for using the output gap is that in an environment of changing potential growth of the economy, as is the case in our sample, actual GDP growth does not necessarily give an accurate picture about the degree of economic activity.

[3] The negative link between the degree of competition and price rigidity is also documented empirically using microeconomic data at the price-setter level by Alvarez and Hernando (2006) for the euro area and Coricelli and Horvath (2006) for Slovakia.

(at both the aggregate and sectoral level) and the exchange rate, controlling for a standard set of factors.

The paper is organized as follows. Section 2 discusses the related literature. The data are presented in section 3. Section 4 is focused on identification issues. Section 5 contains our results on the effects of monetary policy. We present our conclusions in section 6, and an appendix follows.

2. Related VAR Literature

Vector autoregressions (VARs), as introduced by Sims (1980), are considered to be benchmarks in econometric modeling of monetary policy transmission. It has been argued that this class of models provides a certain mix between a mere "data-driven" approach and an approach coherently based on economic theory (see Fry and Pagan, 2005, on the applications of VARs for macroeconomic research). In terms of monetary policy analysis, the VAR methodology has been further developed among others by Gerlach and Smets (1995); Leeper, Sims, and Zha (1998); and Christiano, Eichenbaum, and Evans (1999). The last-mentioned study provides a detailed review of the literature on this topic in the United States. Similarly, there has been extensive research undertaken in Europe to study various aspects of monetary transmission in the euro area countries (see Angeloni, Kashyap, and Mojon, 2003). The research on monetary transmission in the euro area either focuses on euro area-wide analysis (Peersman and Smets, 2001) or studies specific countries in detail (Mojon and Peersman, 2001).

The economic theory suggests that output and prices should temporarily fall after a monetary contraction. Nevertheless, as regards prices, a number of papers document that, on the contrary, prices rise after a monetary contraction. This effect has been labeled as the "price puzzle." The literature typically argues that the price puzzle is a consequence of some model misspecification (Brissimis and Magginas, 2006, and Giordani, 2004). Meanwhile, Barth and Ramey (2001) suggest that a fall in both prices and output would indicate that monetary policy affects the economy mainly through the demand channel. On the other hand, falling output and rising price levels would point to the prevalence of the supply or cost channel.[4]

In addition, the literature examines the effect of monetary policy on exchange rate behavior. Generally, an immediate exchange rate appreciation after a monetary tightening and then a gradual depreciation of the domestic currency is expected according to uncovered interest rate parity. However, the empirical evidence is again somewhat mixed. Some authors find a rather persistent appreciation of the domestic currency ("delayed overshooting", Eichenbaum and Evans, 1995), while others report that the exchange rate actually depreciates with a monetary contraction and provide explanations for the so-called exchange rate puzzle (Kim and Roubini, 2000).

A number of approaches to dealing with model misspecification related to monetary policy shock identification have been stressed in the literature. For example, Brissimis and Magginas (2006) show that by adding forward-looking variables such as federal funds futures to a standard VAR

[4] If a firm has to borrow to finance its production, interest rates enter its cost function. Consequently, a monetary policy tightening increases the firm's costs, to which the firm may react by increasing the price of the products it sells. In consequence, this argument suggests that the price puzzle does not have to be caused by model misspecification. In general, see Coricelli *et al.* (2006) for more specific explanations of the price puzzle.

specification, one is able to obtain responses to monetary policy that are consistent with the theory. The rationale for including federal funds futures is that they contain market expectations about future monetary policy action (this expectation element may also be found in commodity prices or money, to a certain extent).

In addition, Croushore and Evans (2006) emphasize the role of data revisions for monetary policy shock identification. Monetary policy makers react to the information set available at the time they make their decision, and it is often the case that GDP data are revised afterwards. As a result, using ex-post GDP data series may contaminate the estimated monetary policy effects. Also, monetary policy makers often tend to react to the output gap rather than GDP growth. In addition, Giordani (2004) shows that using the output gap instead of GDP growth alleviates the price puzzle. These concerns are especially appealing in our case. First, the CNB's main forecasting model (the so-called Quarterly Projection Model) indeed contains an output gap in its reaction function (Coats *et al.*, 2003). Second, GDP growth may still be useful as the measure of the degree of economic activity if potential output growth is not changing much. However, in the case of the Czech economy, it is estimated that potential output growth sharply increased from some 2% in 1998 to around 5.5% in 2005 (Dybczak, Flek, Hájková, and Hurník, 2006).

Next, there has been a lot of research focusing on the sensitivity of the responses of aggregate variables such as aggregate inflation and output to monetary policy within the VAR framework. However, much less is known about the responses to monetary policy at the more disaggregated level. Erceg and Levin (2006) find that the durable goods sector is more sensitive to interest rate changes than the non-durable goods sector in the U.S. Based on this empirical finding, they investigate the impact of monetary policy on these two industries and find, as expected, that monetary policy effects are much stronger in the durable goods industry. Dedola and Lippi (2005) study the responses to monetary policy of various industrial sectors for a number of OECD countries. They find that the responses vary between sectors in terms of their magnitude and persistence. This result is confirmed by Peersman and Smets (2005), who find a number of significant differences between various industries in the euro area in terms of both the magnitude of the output response as well as the asymmetry of the responses over the business cycle.

Bouakez *et al.* (2005) is one of the few studies that examine the impact of monetary policy on disaggregate prices. Their results suggest that monetary transmission affects household consumption in the construction and durable manufacturing sectors the most, but the impact of a monetary policy shock vanishes relatively quickly. They also find significant differences between the sectors' inflation in terms of variance decomposition, volatility, and persistence. Bouakez *et al.* (2005) find that the response of services inflation to monetary policy shocks is relatively pronounced and also the most persistent. Boivin *et al.* (2007) study the effect of macroeconomic fluctuations on disaggregate prices within the factor-augmented VAR framework. Among other things, their results indicate that the degree of market power explains the diversity of the responses of disaggregate prices to monetary policy shocks.

Several papers study the monetary policy effects for the Czech Republic within the VAR framework.[5] Using the sample period after the adoption of inflation targeting (1998–2004), Hurník and Arnoštová (2005) find that prices respond with a peak around 5–6 quarters after a

[5] See Coricelli, Égert, and MacDonald (2006) for a survey of current findings on monetary policy transmission in Central and Eastern Europe, including those undertaken within the VAR framework.

shock, although there is some evidence for a price puzzle in the first two quarters after the shock. Output falls after a monetary contraction, with a peak after one year or so. There is a delayed overshooting of the exchange rate, as it depreciates only some 4 to 5 quarters after the monetary policy innovation. Extending the sample back to 1994, when the fixed exchange rate regime was in use, yields less satisfactory results, as it is obviously more difficult to identify monetary policy shocks across two monetary policy regimes. In our paper, we use a similar, slightly extended time horizon (after the adoption of inflation targeting), but we opt for monthly rather than quarterly data. In addition, in our paper we include the real-time output gap in the benchmark specification, as opposed to the ex-post revised GDP used by Hurník and Arnoštová (2005). The effects of a monetary policy contraction estimated in our paper are largely in line with the responses observed in more developed economies and countries in the Eurozone, in particular. Contrary to Hurník and Arnoštová (2005), we do not find evidence for a price puzzle in the Czech Republic.

Next, there are a number of papers analyzing and comparing the effects of monetary policy in groups of Central and Eastern European countries vis-à-vis other, more advanced economies (Creel and Levasseur, 2005; Darvas, 2006; EFN[6], 2004; Héricourt, 2005). Many studies find evidence of price and/or exchange rate puzzles for the Czech Republic. As argued by Coricelli *et al.* (2006), the price puzzle is generally avoided in studies that allow for changes in coefficients and in papers employing more sophisticated identification schemes. As we argue below, the price puzzle in these studies often arises because monetary policy regime changes are ignored. In our paper we consider only the period after the change of monetary policy regime, characterized by stable coefficients (as assessed by the estimation of recursive coefficients).

Among the studies that do not find evidence of a price puzzle, Jarocinski (2006) provides a Bayesian VAR analysis of monetary policy effects in Western and Central Europe. Interestingly, Jarocinski finds that monetary policy is more potent in Central Europe, despite a lower level of financial development and smaller indebtedness. Regarding the Czech Republic, he uncovers that there is a relatively strong appreciation of exchange rates as well as a larger price decline after a monetary policy innovation, as compared to other Central European countries. Elbourne and Haan (2006) study the interactions between the financial system and monetary transmission within the structural VAR framework for a group of ten Central and Eastern European countries. For the Czech Republic, they find a hump-shaped response of prices, an exchange rate appreciation, and a fall in industrial production after a monetary policy innovation. Next, financial structure is found to be of little importance for monetary transmission.

3. Data

This section contains a description of our dataset. We restrict our sample to the data from 1998 onwards, i.e., since the inflation targeting framework was adopted by the Czech National Bank (previously – until May 1997 – it had operated a fixed exchange rate regime). Our sample thus spans from 1998:1 to 2006:5 at monthly frequency. While studies in this stream of literature often employ quarterly data, given the length of our sample we decided to work at monthly frequency. As a result, we have 101 observations. The source of our data is the CNB's public database ARAD (except for the output gap, which is only available internally within the CNB). The plots of all the series are available in Appendix 1.

[6] European Forecasting Network (2004).

We use GDP, *lgdp*$_t$, and the real-time output gap estimate, *outputgapreal*$_t$, as measures of economic activity.[7] GDP is traditionally used for this kind of exercise, but Giordani (2004) suggests using the output gap. In addition, by using the real-time output gap estimate we avoid the risk resulting from the use of *ex-post* data, which are not available to central bankers at the time of monetary policy formulation (Croushore and Evans, 2005). As GDP and the output gap are only available at quarterly frequency, we interpolate these two using the quadratic-match average procedure.[8] Note that all the other variables we use are not revised afterwards.

Next, we employ the net price index, *lnet*$_t$, (the net price index is the consumer price index excluding regulated prices). For our disaggregate analysis, we employ the tradable price index, *tradable*$_t$, and the non-tradable price index, *nontradable*$_t$. Note that the individual components underlying the consumer price indices are grouped into tradables and non-tradables categories in line with the internal CNB classification.

Further, the nominal CZK/EUR exchange rate, *lexrate*$_t$, and the three-month interbank interest rate (3M PRIBOR[9]), *pribor*$_t$, are used. To capture external developments, the 1-year EURIBOR, *euribor*$_t$, and the commodity price index, *lcommodity*$_t$, are utilized. The forward rate agreement rate (9*12 FRA rate), *fra*$_t$, is used to bring in an additional forward-looking element. Given that there are no futures or forwards in the Czech Republic that are directly linked to the monetary policy rate (2W repo) as is the case in the U.S., we decided to use forwards on interbank rates, which are very closely related to the policy rate. Finally, all data are in logs except interest rates and the real-time output gap.

4. Identification

In this section, we discuss the VAR framework we adopt. The choice of variables for our VAR model is largely motivated by an open economy New Keynesian model (see, for example, Gali and Monacelli, 2005). The main equations of this class of models are aggregate demand, the Phillips curve, the monetary policy rule, and uncovered interest rate parity.

We estimate two benchmark models and then undertake a sensitivity analysis. The difference between these two benchmark models is that the first includes only the aggregate price index, while the second distinguishes between the tradable and non-tradable price indices. The specification of the first baseline model is the following:

$$Y_t = A(L)Y_{t-p} + B(L)X_t + u_t \qquad (1)$$

[7] See Coats *et al.* (2003, chapter 5) on the construction of the output gap used by the CNB. The output gap is the difference between actual and potential output, where the latter is estimated by a multivariate filter, more specifically by the Kalman filter procedure, where the system of equations is in the state-space representation.

[8] We admit that interpolation introduces information not available at the time of policy making.

[9] The actual monetary policy instrument of the CNB is the 2W repo rate. Since the repo rate is not changed continuously and is censored, we opt for the 3M PRIBOR, which is very closely linked to the 2W repo rate; its correlation stands at 0.998 in our sample. In addition, the 3M PRIBOR may capture central bank communication. See Horvath (2008) for a discussion related to the use of the monetary policy rate vs. the interbank market rate in the Czech Republic.

where Y_t and X_t represent endogenous and exogenous variables[10], respectively. The data vectors are: $Y_t = \{outputgapreal_t, lnet_t, pribor_t, lexrate_t\}$ and $X_t = \{euribor_t, lcommodity_t, fra_t\}$. For our second benchmark specification: $Y_t = \{outputgapreal_t, lnontradable_t, tradable_t, pribor_t, lexrate_t\}$ and X_t remains the same.

The VAR specification in (1) represents a so-called reduced-form equation. In order to identify the original shocks we can apply the recursiveness assumption by imposing restrictions on a matrix linking the structural shocks to the reduced-form disturbances. The variables are ordered in a specific way so as to represent the assumption that the monetary authorities choose the interest rate taking into account the current level of prices and output (as in Mojon and Peersman, 2001). In addition, the output gap and prices are assumed not to react immediately to the monetary policy shock, but rather with a one-period lag. Mojon and Peersman (2001) follow a recursive specification to analyze the impact of a monetary policy shock in some of the euro area countries.

We analyze the sensitivity of our benchmark models first by using GDP instead of the output gap, second by estimating a very parsimonious model without exogenous variables, and third by estimating the baseline models by structural VAR instead of recursive VAR.

As regards the first sensitivity check, actual GDP data are used instead of the output gap. The rationale for this exercise is that the output gap, as opposed to GDP, is unobservable. Our second sensitivity check is motivated by degrees-of-freedom considerations. Here, we assume that external shocks influence the Czech economy only via the exchange rate (i.e., *B(L)*=0). Admittedly, this is a simplistic specification, but its main advantage is its limited number of variables and thus its greater degree of freedom in comparison to our other models. As the third robustness check, the two baseline models are estimated by structural VAR (SVAR). SVAR represents an alternative identification scheme in order to recover the original residuals from the reduced-form VAR. For structural VAR, we apply here the AB-model of Amisano and Giannini (1997), which is defined as follows in a reduced form:

$$Y_t = A^*(L)Y_{t-p} + B^*(L)X_t + u_t \qquad (2)$$

$u_t = A^{-1}Be_t, e_t \sim (0, I_K)$, where I is the identity matrix and K is the number of variables. A and B are $k \times k$ matrices to be estimated. In the case of our first benchmark model, they are specified as follows.

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 \\ a_{31} & 0 & 1 & a_{34} \\ a_{41} & a_{42} & a_{43} & 1 \end{bmatrix} \qquad B = \begin{bmatrix} b_{11} & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 \\ 0 & 0 & b_{33} & 0 \\ 0 & 0 & 0 & b_{44} \end{bmatrix}$$

It follows from matrix A that a forward-looking monetary authority does not consider contemporaneous prices while deciding on monetary policy (i.e., $a_{32}=0$). However, monetary authorities are likely to react to contemporaneous output (a_{31}, as output can be regarded as an excess demand pressure indicator) and exchange rate shocks (a_{34}), which is a reasonable

[10] The inclusion of foreign variables that are considered exogenous is motivated by the need to control for foreign shocks and thus not to confuse domestic monetary shocks with the central bank's responses to external developments (Jarocinski, 2006).

assumption for small open economies according to Kim and Roubini (2000). More specifically, exchange rate fluctuations influence the inflation forecast if they are deemed not to be transitory.

For our second benchmark model, in which we consider disaggregate prices (hence five variables), matrices A and B look as follows:

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 & 0 \\ a_{41} & 0 & 0 & 1 & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & 1 \end{bmatrix} \qquad B = \begin{bmatrix} b_{11} & 0 & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 & 0 \\ 0 & 0 & b_{33} & 0 & 0 \\ 0 & 0 & 0 & b_{44} & 0 \\ 0 & 0 & 0 & 0 & b_{55} \end{bmatrix}$$

Following each VAR estimation, we perform stability checks in order to ensure the robustness of our results (the results of these tests are available upon request). It is important to note that the variables used in the VAR analysis do not need to be stationary. Sims (1980), among others, argues against differencing even if the series contain a unit root. The main goal of the VAR analysis is to analyze the co-movements in the data. What matters for the robustness of the VAR results is the overall stationarity of the system (see Lütkepohl, 2006, for details).

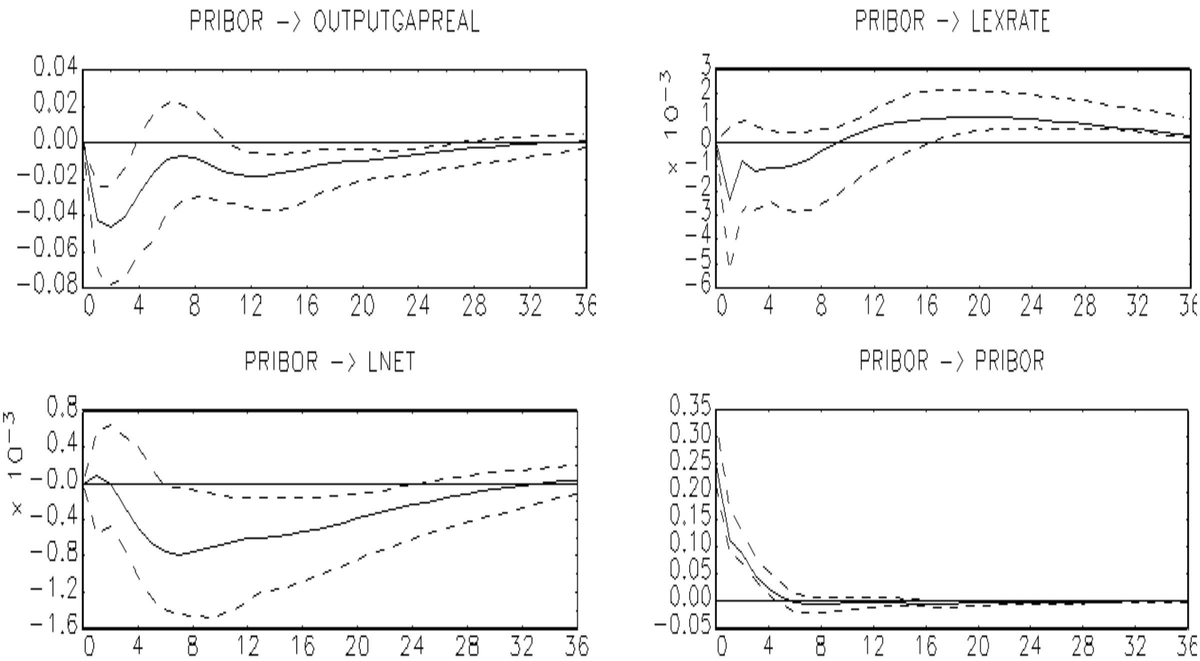
A description of the FAVAR model is presented in Appendix 3.

5. Results

In this section, we discuss the estimated effects of Czech monetary policy within the aforementioned specifications. The number of lags has been chosen according to the Schwartz criterion and the parameter stability addressed by the CUSUM and CUSUM of squares tests and the recursive coefficient estimation (the results are available upon request).

Figure 1 present our results regarding the effects of a contractionary monetary policy shock on several economic variables of interest to a monetary authority. These figures contain the impulse responses and the associated 95% confidence interval, which was bootstrapped using 1,000 replications according to the percentile method by Hall (1988).

Figure 1: Contractionary Monetary Policy Shock, Impulse Responses



Note: This figure shows the impulse responses to a one standard deviation contractionary monetary policy shock.. Time (on the horizontal axis) is measured in months.

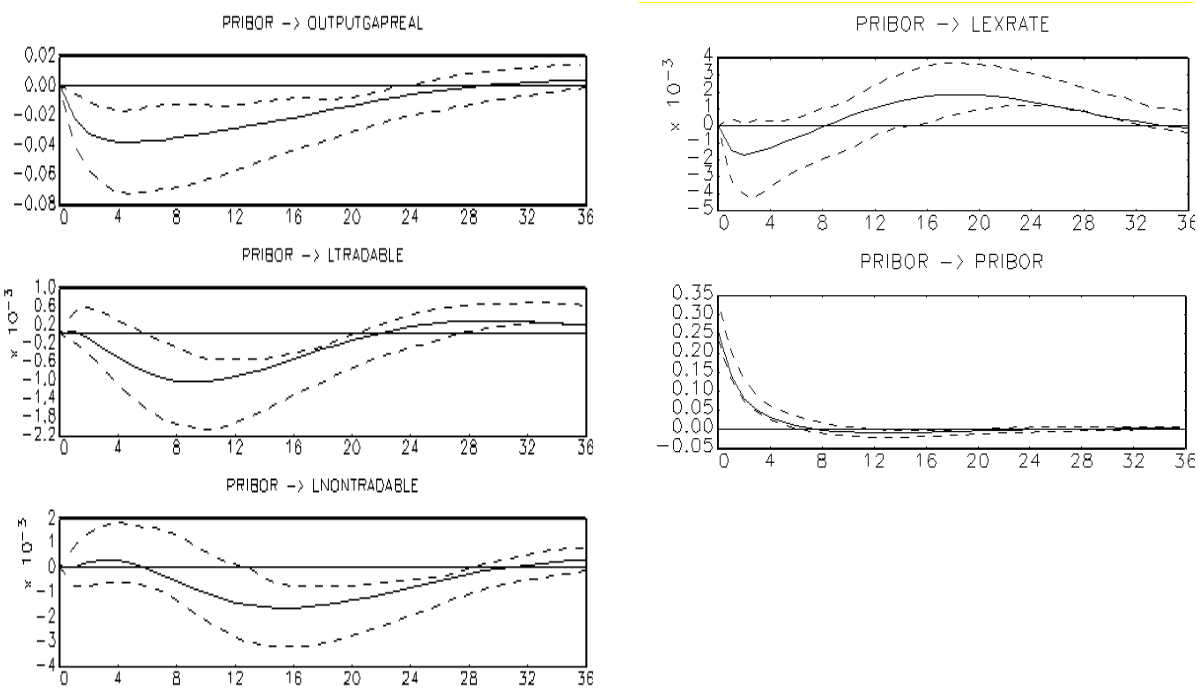
We find that prices fall after a monetary tightening and bottom out after one year or so. This is in line with the targeting horizon of the CNB, which is considered to be between 12 and 18 months. In terms of magnitude, our results show that a one Cholesky standard deviation of interest rates (a 30 basis point monetary policy shock) decreases the log of prices by about 0.1%.[11] Notably, there is essentially no evidence for a price puzzle.

The degree of economic activity, as measured by the output gap, falls after a contractionary monetary policy shock, bottoming out after about four months (this, however, is not confirmed in our sensitivity analysis, which identifies the bottom after about twelve months, which is more sensible). The results indicate that a monetary shock of 30 basis points decreases the output gap by about 5%. The responses of output and prices to a monetary shock show no support for the cost channel of monetary policy.

Next, our results show a delayed overshooting in exchange rate behavior, i.e., a rather persistent appreciation of the domestic currency after a monetary tightening (lasting typically about 6 months) and a gradual depreciation afterwards. However, it has to be pointed out that the estimated confidence intervals are relatively wide, which brings some margins of uncertainty into interpreting the results. Nevertheless, we can see that irrespective of specification and estimation technique, the exchange rate depreciates over the longer term, which conforms to the uncovered interest rate parity hypothesis (Kim and Roubini, 2000).

[11] Several authors have raised the question of the accuracy of monetary policy shocks within VARs. See Boivin and Giannoni (2002) for a related discussion.

Figure 2: Contractionary Monetary Policy Shock, Impulse Responses: Tradable vs. Non-tradable Prices



Note: This figure shows the impulse responses to a one standard deviation contractionary monetary policy shock.. Time (on the horizontal axis) is measured in months.

Figure 2 contains the estimates of the effect of monetary policy shocks on tradable and non-tradable prices. Generally, tradable prices react faster than non-tradable prices to a monetary contraction. While the bottom response of tradable prices is at one year or so (even 9–10 months), the bottom response of non-tradable prices occurs only after one and a half years. This result matches the findings based on micro-level data (Alvarez and Hernando, 2006; Coricelli and Horvath, 2006), which show that the frequency of non-tradable price changes is lower (and negatively affected by the degree of competition); hence, a slower response to the monetary policy shock is to be expected. On the other hand, the reaction of non-tradable prices is more pronounced. A monetary shock of about 0.3% decreases tradable and non-tradable prices by 0.1% and 0.2%, respectively. In addition, the results in Figure 2 largely confirm the results of the effect of monetary policy on output and the exchange rate from Figure 1.

Next, we analyze the sensitivity of our benchmark models, with all the results reported in Appendix 2. First, we investigate how our results change when we include ex-post revised data (GDP) instead of the real-time output gap in our data vector. Real-time variables are part of the information set available at the time of policy-making, so by using these variables in the VAR analysis we avoid the likely contamination of the results caused by data revisions.[12] There is no statistically significant reaction of GDP to the monetary shock and it seems that GDP does not capture adequately the degree of demand pressures in an environment of sharply changing potential output growth. Thus, our results stress the importance of using the real-time output gap in the VAR specification, as it improves the precision of the empirical analysis.

[12] In general, the output gap should be a better measure of demand pressures (especially when potential output growth is changing), but one should keep in mind that it is unobservable and thus subject to greater uncertainty.

Second, we estimate a very parsimonious model without exogenous variables, including the forward-looking component. The rationale behind this is merely degrees-of-freedom considerations. Interestingly, we find that a four-variable VAR is able to generate quite sensible and precisely estimated impulse responses.[13] This would suggest that economic agents during our sample period form their expectations in a rather backward-looking manner. This is somewhat surprising, but one has to consider the transition process of the Czech economy and the corresponding greater uncertainty in economic development, which could make agents rely more on current data than on forecasts.

Finally, we also estimate the benchmark models by structural VAR instead of recursive VAR, but SVAR seems to provide little value added and typically generates impulse responses close to those of VAR, but with much larger confidence intervals.

Table 1: Comparison to Other VAR Studies on Monetary Transmission in the Czech Republic

	Sample period	Single monetary policy regime	Estimation technique	Reaction of output to MP shock	Reaction of prices to MP shock	Bottom reaction of output and prices
EFN (2004)	1994–2003	No	VAR	(-), sig.	(+), sig.	6Q/---
Ganev et al. (2004)	1995–2000	No	VAR	(+), n.a.	(+), n.a.	----
Creel and Levasseur (2005)	1993–2004	No	SVAR	(+), sig.	(+), sig.	----
Darvas (2005)	1993–2004	No	TVC-SVAR	(-), n.a.	n.a.	4Q/n.a.
Héricourt (2005)	1995–2004	No	VAR	(-), sig.	(+), sig.	1Q/---
Hurník and Arnoštová (2005)	1994–2004	No	VAR	insig.	insig.	8Q/6Q
Elbourne and Haan (2006)	1998–2004	Yes	SVAR	(-), sig.	(-), sig.	4Q/4Q
Jarocinski (2006)	1997–2004	Yes	Bayesian VAR	(-), sig.	(-), sig.	4Q/4Q
Gavin and Kemme (2007)	1995–2006	No	SVAR	(-), sig.	(+), sig.	----
Anzuini and Levy (2007)	1993–2002	No	VAR, SVAR	(-), sig.	insig.	4Q/8Q
This paper	1998–2006	Yes	VAR, SVAR, FAVAR	(-), sig.	(-), sig.	3Q/4Q

***Note**:* (-) and (+) denote, respectively, a statistically significant decline and increase of the variable after a monetary policy shock. The column "Single monetary policy regime" indicates whether the sample period of the study comes from a single monetary regime or spans different regimes (the fixed exchange rate regime until May 1997 and the inflation targeting regime adopted in January 1998). Abbreviations: TVC-SVAR – time-varying coefficient SVAR, Sig. – the reaction of the variable to a monetary policy shock is statistically significant at the 5% level, and Q – quarters. If the reaction of the variable to a monetary shock does not have the correct sign, the bottom reaction of the variable is not reported (denoted as "----" in the table; n.a. indicates that the corresponding estimates were not available in the original study).

Next, we compare our results with other recent studies that analyze monetary policy shocks in the Czech Republic within the VAR approach. The comparison is summarized in Table 1. Most of the existing studies ignore the monetary policy regime change in the Czech Republic (the fixed exchange rate regime until May 1997 and the adoption of inflation targeting in January 1998). In consequence, it is not surprising that simple VAR methods have difficulty in identifying monetary

[13] The output gap and prices fall after a contractionary monetary policy shock, bottoming out after about twelve months. The exchange rate first appreciates, but later depreciates significantly, in line with uncovered interest rate parity (see also Eichenbaum and Evans, 1995). The results on the reaction of tradable and non-tradable prices largely comply with the benchmark case, except that non-tradable prices reach their bottom response a bit later (about two years).

policy shocks across these two regimes; i.e., they do not deliver plausible results and all exhibit the price puzzle (some of them even report a positive reaction of output to a monetary tightening).[14] This suggests that the price puzzle in these studies is associated with the monetary policy regime change. This is further confirmed by two papers that employ data from the inflation targeting period (Elbourne and Haan, 2006, and this paper), as their results do not exhibit the price puzzle. Finally, the results in Table 1 indicate that the bottom responses of output and prices seem to be at around 4 quarters, which is in line with our findings.

6. Concluding Remarks

In this paper, we analyze the transmission of monetary policy shocks in the Czech Republic within the VAR, SVAR, and FAVAR frameworks. In general, monetary transmission in the Czech Republic seems to be similar, in terms of persistence of the responses of economic variables to monetary shocks, to that in more developed countries, including the euro area (see e.g. Mojon and Peersman, 2001).

All in all, subject to various sensitivity tests, we find that prices and output decline after a monetary tightening, with the bottom response occurring after about one year. This finding corresponds with the actual targeting horizon of the Czech National Bank.[15] In addition, we document that the reaction of tradable prices is faster than that of non-tradable prices. While the maximum effect of a monetary shock on tradables can be seen after a year or so, it is at least a year and a half for non-tradable prices. This result broadly confirms the microeconomic evidence on the effect of competition on price rigidity (Alvarez and Hernando, 2006; Coricelli and Horvath, 2006). We avoid a price puzzle within the system. Thus, our results support the notion that the price puzzle is associated with model misspecification rather than with the actual behavior of the economy. This is also supported in other VAR studies on monetary transmission in the Czech Republic, as all studies estimating the effects of monetary policy across different monetary policy regimes (i.e., the fixed exchange rate regime and inflation targeting regime mixed together) exhibit the price puzzle.

Next, there is a rationale for using the real-time output gap estimate instead of current GDP growth, as using the former results in much more precise estimates. The impulse responses of GDP to an interest rate shock are less precisely estimated, and thus our findings point to the importance of real-time data in monetary policy analysis. Finally, our results also indicate a persistent appreciation of the domestic currency after a monetary tightening ("delayed overshooting", Eichenbaum and Evans, 1995), although the confidence intervals are in this case rather wide, with a gradual depreciation afterwards.

[14] The exemption is Jarocinski (2006). His sample starts in June 1997, which is before the adoption of inflation targeting, but after the exchange rate turbulence and the abandonment of the fixed exchange rate regime. As a result, we code his sample in Table 1 as coming from a single monetary policy regime. Another approach to dealing with monetary policy changes is presented by Darvas (2005), who estimates a time-varying coefficient VAR. Indeed, his results suggest that the values of the estimated parameters change rather abruptly around the year 1997 and remain relatively stable afterwards. (This is confirmed in this study by the recursive estimation of the parameters. The results are available upon request).

[15] However, note that the targeting horizon (i.e., the horizon minimizing the loss function of the monetary authority) and the horizon at which the monetary policy impact is the most profound are not identical concepts. See Strasky (2005) for details.

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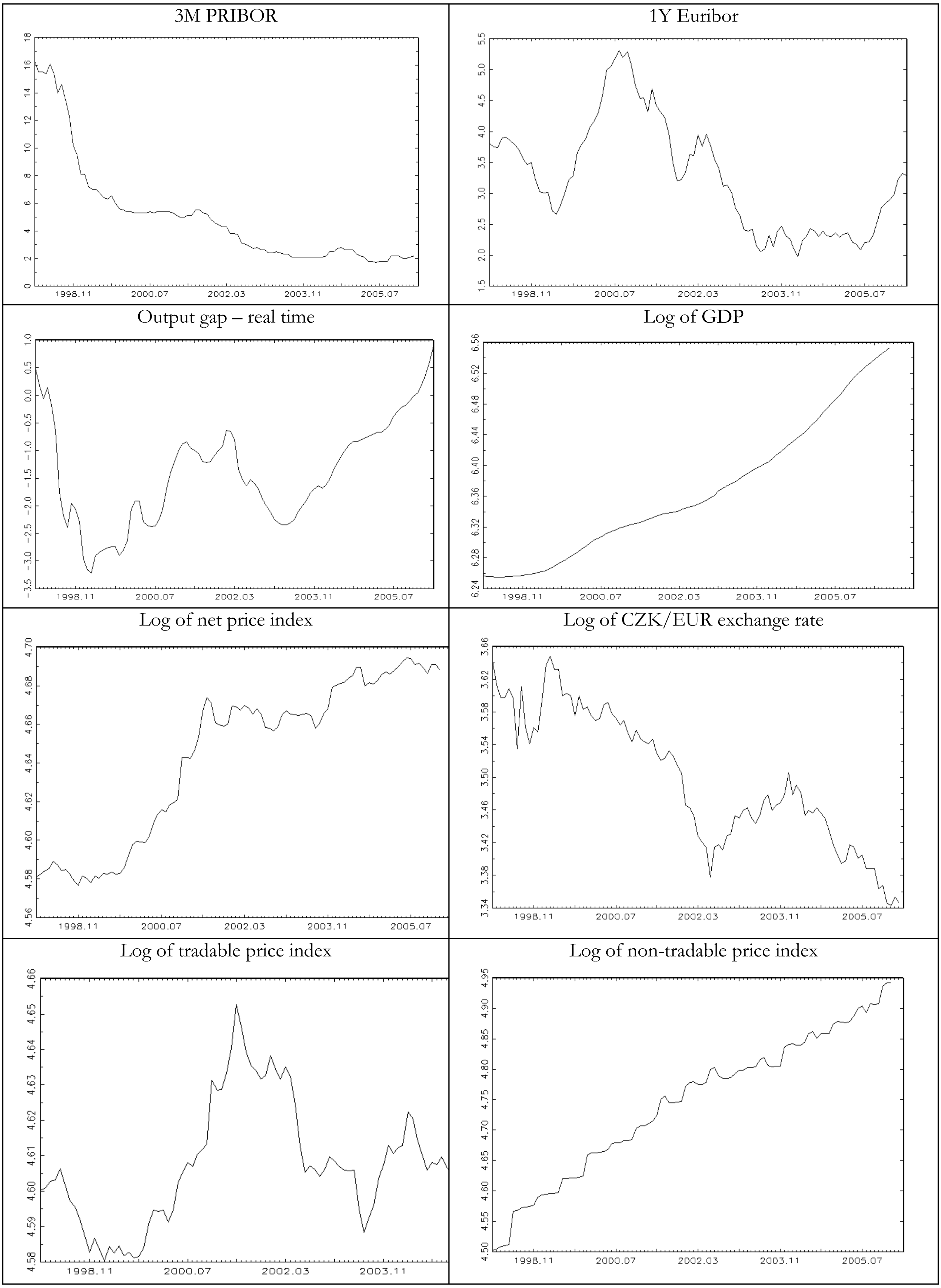
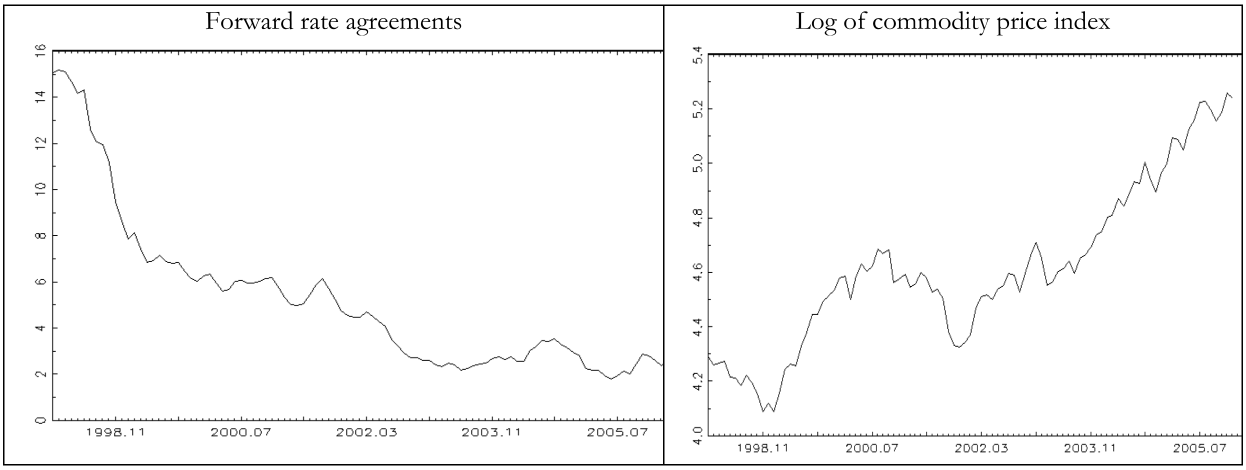
Appendix 1

Figure 3: Time Series




Forward rate agreements
16
14
12
10
8
6
4
2
0
1998.11
2000.07
2002.03
2003.11
2005.07
Log of commodity price index
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
1998.11
2000.07
2002.03
2003.11
2005.07

Appendix 2: Additional Results: Impulse Responses to a Monetary Shock

Figure 4: GDP instead of Output Gap

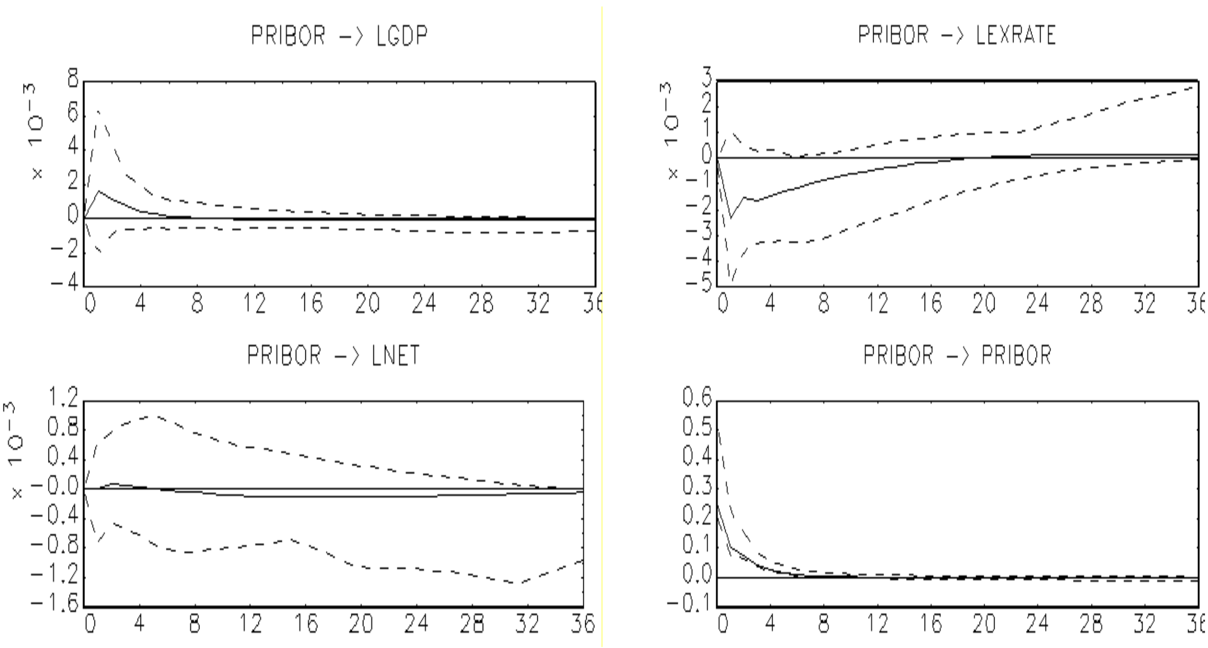


Figure 5: GDP instead of Ooutput Gap, Sectoral Prices

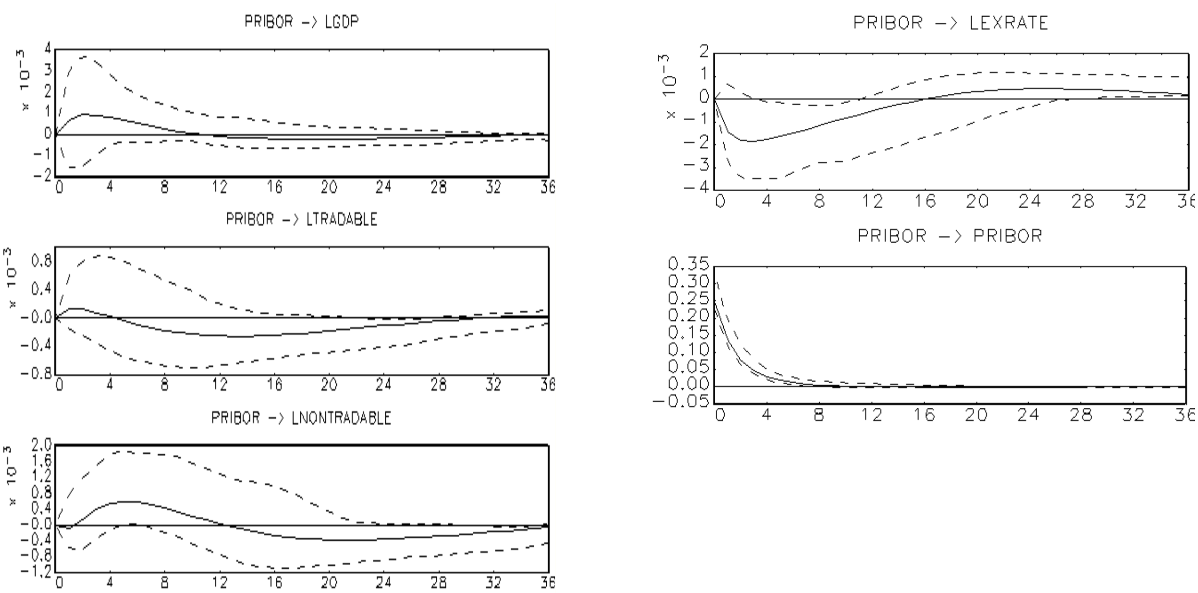


Figure 6: No Exogenous Variables

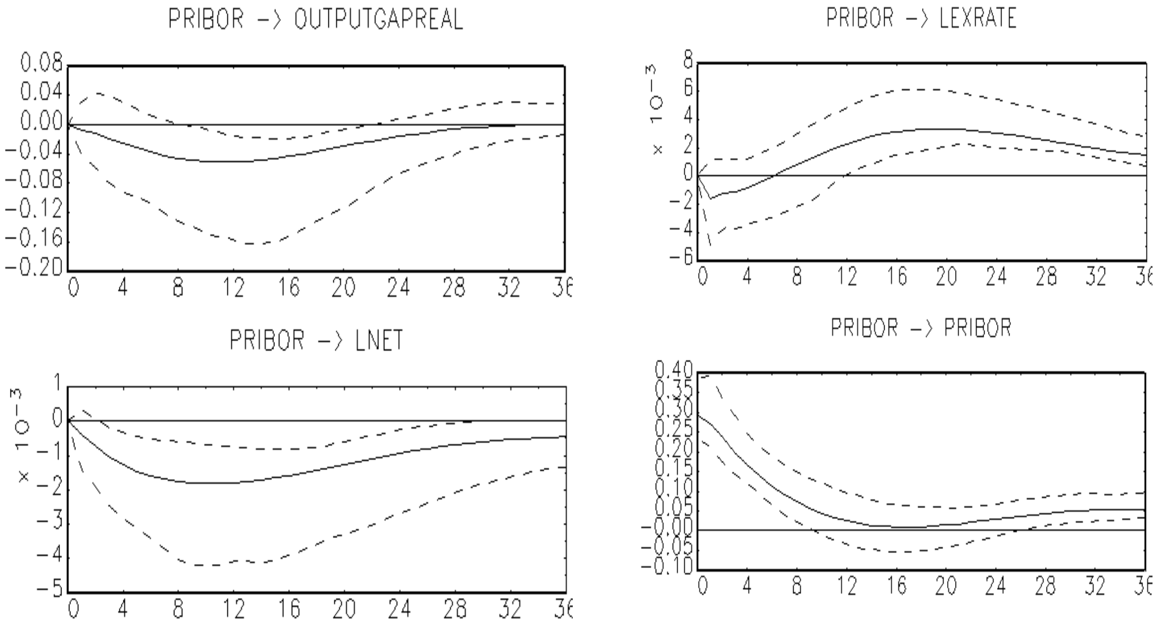


Figure 7: No Exogenous Variables, Sectoral Prices

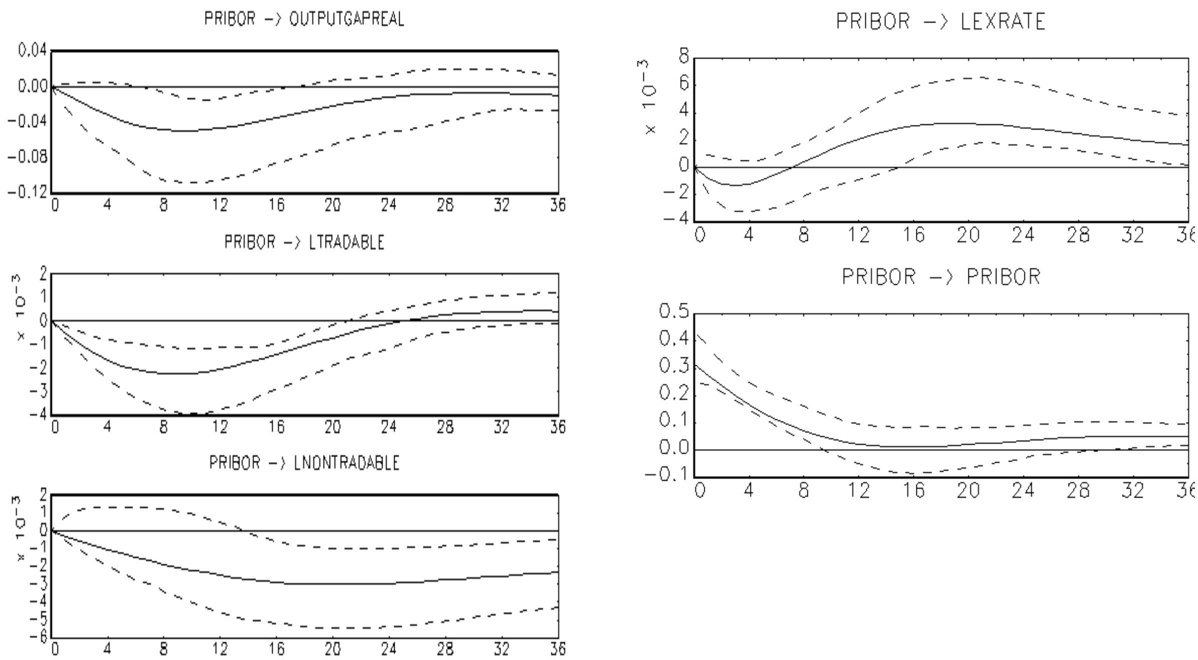


Figure 8: SVAR

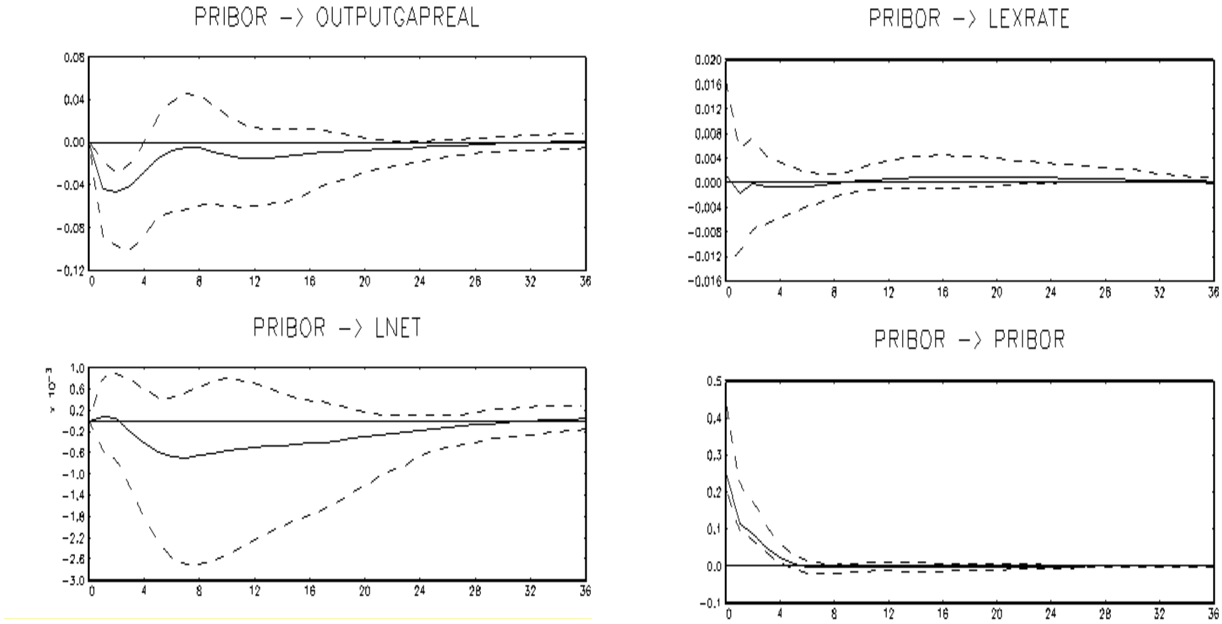
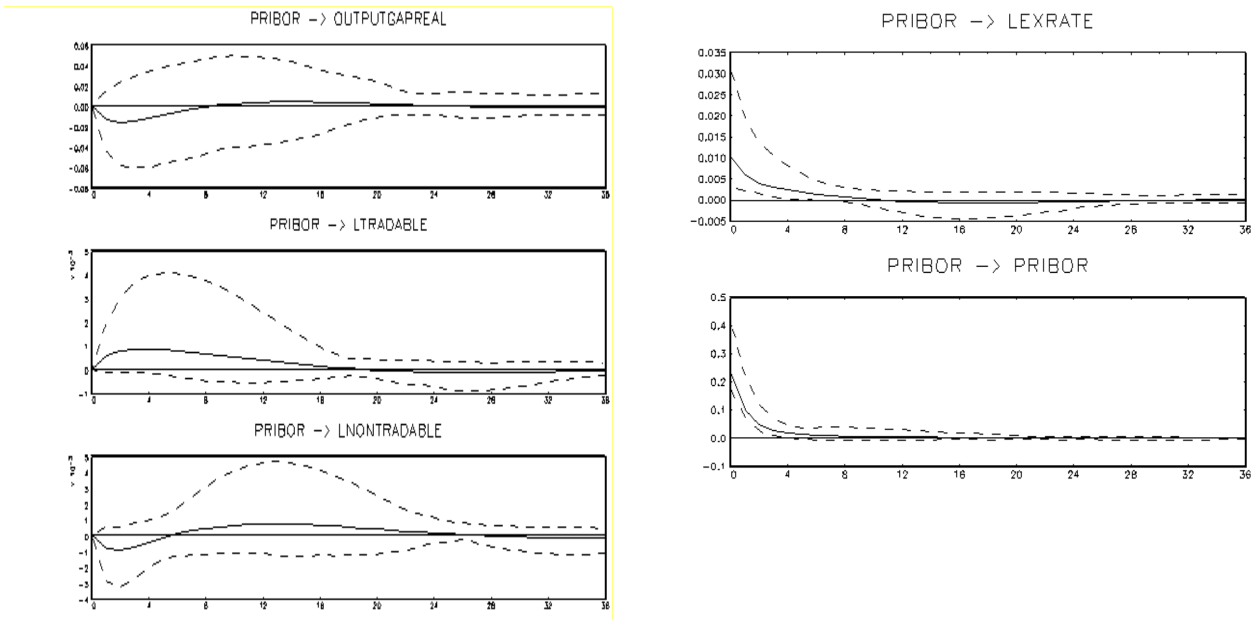


Figure 9: SVAR, Sectoral Prices



Appendix 3: Factor-Augmented VAR

In this Appendix, we briefly document our attempt to study monetary policy effects within factor-augmented VAR (FAVAR). However, as documented below, we find that the results based on FAVAR are very sensitive and the confidence intervals for the impulse responses are rather large.

We follow an approach developed by Bernanke *et al.* (2005).[16] FAVAR can be represented in the following form:

$$\begin{bmatrix} F_t \\ Y_t \end{bmatrix} = \Phi(L) \begin{bmatrix} F_{t-p} \\ Y_{t-p} \end{bmatrix} + v_t$$

Vector Y_t contains observable economic variables, whereas F_t represents unobserved factors which provide additional economic information not fully captured by the Y_t. We estimate these unobservable factors using a principal components approach, which exploits the assumption that information about the unobservable economic factors can be inferred from a large number of economic time series X_t. Specifically, we can think of the unobservable factors in terms of concepts such as "economic activity" or "investment climate." They can be represented not by a single economic variable, but rather by several time series of economic indicators.

The FAVAR methodology allows us not only to use a richer information set in the model specification, but also to analyze the effects of a monetary policy shock on a greater number of economic variables. There are two main approaches to estimating FAVAR: a two-step principal components approach and a one-step approach that estimates (3) and a dynamic factor model jointly. As Bernanke *et al.* (2005) do not find any particular differences between these two estimators in terms of inference, we opt for the computationally simpler two-step approach.[17]

In our FAVAR specification, X_t consists of a balanced panel of 40 series that have been transformed in order to ensure their stationarity. The description of these series and their transformations is included in Table 2. The data is at monthly frequency and spans the period from February 1998 to May 2006. Following Bernanke *et al.* (2005), we assume that the monetary policy instrument (the 3-month interest rate) is the only observable factor, hence the only variable included in Y_t. For identification purposes the monetary policy instrument is ordered last, which implies that latent factors do not respond contemporaneously (within a month) to innovations in monetary policy. As in Bernanke *et al.* (2005), we distinguish between "slow-moving" and "fast-moving" variables. A "slow-moving" variable is assumed not to react contemporaneously to shocks, while the "fast-moving" variables react instantaneously to changes in monetary policy or economic conditions. The classification of the variables into these two categories is included in Table 2.

In the first step of the two-step estimation, we can distinguish three stages. First, we use principal component analysis to estimate the common factors C_t from all the variables in X_t. Second, after

[16] We followed the algorithm developed by Bernanke *et al.* (2005) to estimate FAVAR, which is available on the personal website of Jean Boivin: http://www2.gsb.columbia.edu/faculty/JBoivin/Personal/

[17] See Bernanke *et al.* (2005) for a more detailed discussion of principal component analysis and FAVAR.

dividing the series in X_t into slow- and fast-moving ones, we estimate the "slow-moving" factors $\widehat{F}_t^s$ as the principal components of the "slow-moving" variables. Finally, we estimate the following regression:

$$\widehat{C}_t = b_{Fs}\widehat{F}_t^s + b_Y Y_{t+e_t}$$

Based on these estimates, $\widehat{F}_t$ is constructed as $\widehat{C}_t - \widehat{b}_Y Y_t$. In the second step, we estimate the VAR in $\widehat{F}_t$ and Y_t, using a recursive assumption.

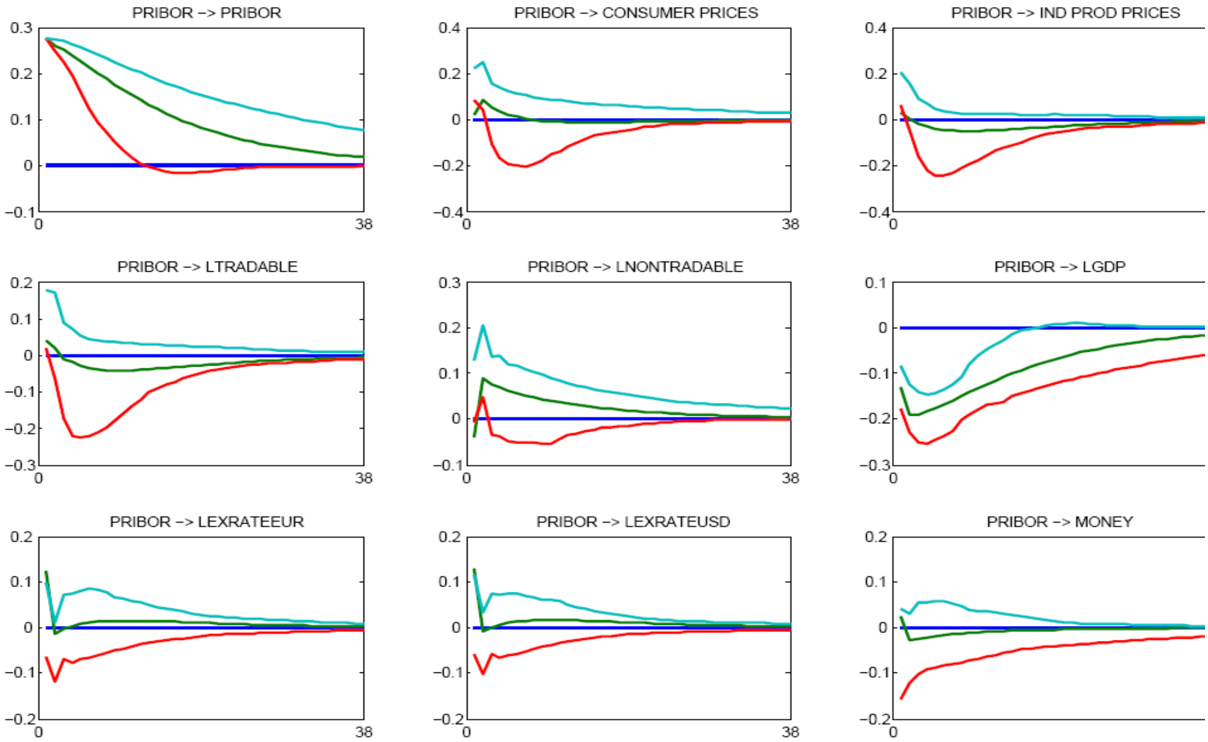
One caveat in our analysis is the fact that we have only 40 series available for principal component analysis, as compared to the 120 used in Bernanke *et al*. (2005). While this may be viewed as a weakness at first sight, it has been argued by Boivin and Ng (2006) that more series do not necessarily ensure better data quality, due to cross-correlation of idiosyncratic errors. In one of their tests, they show that the factors extracted from 40 pre-screened series may in some cases yield better results as compared to using 147 series. Therefore, for the sake of size, 40 series, at least in general, should not pose a problem.

Our main results are given in Figure 9. Each panel shows the impulse responses of selected macroeconomic variables to a monetary policy shock with 90% confidence intervals. The FAVAR model in Figure 9 includes three principal factors, but the results were no different when the number of factors was changed. In the benchmark specification we use one lag. The results are highly sensitive to the numbers of lags used, with more lags resulting in highly improbable results.

As a result, the FAVAR model does not appear to properly capture the developments in the Czech economy. Most importantly, the confidence intervals are too large to infer the direction of the impact of the monetary policy change on the macroeconomic variables. The exception is actual GDP growth, $lgdp_t$, which declines after monetary policy shock, as predicted by the theory.

There may be several reasons for the lack of significant results in the FAVAR estimation for the Czech economy. One reason is likely to do with the relatively short span of the available data; another may be data quality, as discussed by Boivin and Ng (2006). As it is at monthly frequency, our dataset lacks variables related to consumption, housing starts and sales as well as real inventories and therefore some important economic information may be missing.

Figure 9: FAVAR Results



Note: Impulse responses with 90% confidence intervals are presented.

Table 2: Data Description

VAR	DESCRIPTION	TRANSFORMATION	SOURCE
Real output and income			
var1*	Industrial Production, Index number (sa)	3	IFS
var10*	Construction output, constant prices - % (sa)	1	ARAD
var11*	Contracted construction work in enterprises with 20 employees or more - constant prices - (%) (sa)	1	ARAD
var20*	Outputgap real - interpolated from quarterly values	2	ARAD
var21*	GDP - interpolated from quarterly values (sa)	3	ARAD
var30	Total agricultural goods output (sa)	3	ARAD
Employment and Hours			
var2*	Industrial Employment (sa)	3	IFS
var3*	Unemployment Rate (sa)	1	Eurostat
var12*	Registered job applicants, total (thousand persons, sa)	1	ARAD
var13*	Vacancies (thousand, sa)	3	ARAD
var14*	Newly registered job applicants (thousand persons, sa)	3	ARAD
var15*	Registered job applicants on unemployment benefit (thousand persons, sa)	3	ARAD
Industry Sales			
var6*	Total sales revenues, Index sales in industry-constant price (corresponding period of preceding year=100, sa)	3	ARAD
var7*	Mining and quarrying, Index sales in industry-constant price (corresponding period of preceding year=100, sa)	1	ARAD
var8*	Manufacturing, Index sales in industry-constant price (corresponding period of preceding year=100, sa)	1	ARAD
var9*	Electricity, gas and water supply, Index sales in industry-constant price (corresponding period of preceding year=100, sa)	1	ARAD
Exchange Rates			
var22	Foreign Exchange Rate (Czech Krown per Euro)	3	IFS
var23	Foreign Exchange Rate (Czech Krown per U.S. $)	3	IFS
Interest Rates			
var26	Treasury Bill Rate	3	IFS
var27	Deposit Rate	3	IFS
var28	Lending Rate	3	IFS
var29	Government Bond Yield	3	IFS
var31	1 day Interbank Rate PRIBOR (%)	1	ARAD
var32	7 day Interbank Rate PRIBOR(%)	1	ARAD
var33	14 day Interbank Rate PRIBOR(%)	1	ARAD
var34	1 month Interbank Rate PRIBOR(%)	2	ARAD
var35	2 month Interbank Rate PRIBOR (%)	2	ARAD
var36	6 month Interbank Rate PRIBOR(%)	2	ARAD
var37	9 month Interbank Rate PRIBOR (%)	2	ARAD
var38	1 year Interbank Rate PRIBOR(%)	2	ARAD
var41	3 month Interbank Rate PRIBOR(%); monetary policy instrument	1	ARAD
Money Aggregates			

var24	Money (sa)	3	IFS
var25	Money plus Quasi Money (sa)	3	IFS
Price Indexes			
var16*	Consumer Prices CPI (sa)	3	ARAD
var17*	Industrial Produces Prices (sa)	3	ARAD
var18*	Tradable prices (sa)	3	ARAD
var19*	Nontradable prices (sa)	3	ARAD
var40	Prague Stock Exchange Index PX50, Historical close, average of observations through period	3	IFS
Exports and Imports			
var4*	Exports	3	IFS
var5*	Imports, FOB	3	IFS

All series were tested for unit root and when necessary were transformed to achieve stationarity. The transformation codes are: 1-no transformation, 2-first difference, and 3-first difference of logarithm.

An asterisk (*) next to the mnemonic indicates a variable assumed to be “slow-moving” in the estimation.

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