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

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Abstract

In this paper, we examine the effects of Czech monetary policy on the economy within VAR, structural VAR, and the Factor-Augmented VAR framework. 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 contractionary monetary policy shock has a negative effect on the degree of economic activity and price level, both with a peak response after one year or so. Regarding the 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 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 domestic currency after monetary tightening with a gradual depreciation afterwards.

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

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1 Introduction

Understanding the transmission of monetary policy to inflation and other real economic variables is key for central bankers to conduct monetary policy effectively. Not surprisingly, there is extensive theoretical as well as empirical literature studying the effects of monetary policy shocks on the 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 a somewhat mixed evidence regarding monetary policy transmission, as many studies estimate standard vector autoregression (VAR) models mixing the data from two distinct policy regimes, i.e. from fixed exchange rate regime under which the Czech National Bank conducted its policy until May 1997 and from inflation targeting regime that was adopted in January 1998.[1] Not surprisingly, the identification of monetary policy shock then becomes somewhat cumbersome and *all* these studies exhibit 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 the 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 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 these are typically more precise, but 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 the 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-

[1] See Coats, Laxton and Rose (2003) and Kotlán and Navrátil (2003) on the overview of Czech monetary policy.
[2] We therefore utilize the real-time estimates of the output gap available from the Czech National Bank (CNB hereafter). Using the central bank output gap is advantageous for monetary policy shock identification, as the central bank conducts its policy based on *their* estimate of the degree of economic activity, not the estimate of other institutions or individuals. Note that price indices are not revised *ex-post* by the Czech Statistical Office. Additional rationale for using the output gap is that in the environment of the changing potential growth of the economy, as it is the case in our sample, actual GDP growth does not necessarily give an accurate picture about the degree of economic activity.

intensive, the reaction of non-tradable prices is likely to be more persistent (see e.g. Barro (1972) or Martin (1993) on models relating the degree of competition to price rigidity).[3]

In this paper, we examine the effects of monetary policy within vector autoregression (VAR), structural VAR (SVAR), and factor-augmented VAR (FAVAR) during inflation targeting regime period in the Czech Republic. More specifically, we especially focus on assessing the persistence and magnitude of monetary policy shocks on output (including real-time output gap), prices (both at the aggregate and sectoral level) and exchange rate controlling for a standard set of factors.

The paper is organized as follows. Section 2 discusses the related literature. 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 conclusions in section 6 and the appendix follows.

2 Related VAR Literature

Vector autoregressions (VAR), 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, 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 latter 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, Mojon and Terlizzese, 2003). The research on monetary transmission in the euro area either focuses on euro area-wide analysis (Peersman and Smets, 2001) or studies in a detail-specific country (Mojon and Peersman, 2001).

The economic theory suggests that output and prices should temporarily fall after monetary contraction. Nevertheless, as regards prices, a number of papers document that, to the contrary, prices rise after monetary contraction, which has been labeled as the "price puzzle". The literature typically argues that the price puzzle is a consequence of some model misspecification

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

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

A number of approaches to deal 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 specification, one is able to obtain responses to the monetary policy that are consistent with the theory. The rationale for inclusion of 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 shocks identification. Monetary policy makers react to the information set available at the time of making the 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 main forecasting model of CNB (so-called Quarterly Projection Model) indeed contains an output gap in its reaction function (Coats *et al.*, 2003). Second, GDP growth may still remain useful as the measure of the degree of economic activity, if the potential output growth is not changing much.

[4] In case a firm has to borrow to finance its production, interest rates enter the firm's cost function. Consequently, 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 price puzzle does not have to be caused by the model misspecification. In general, see Coricelli *et al.* (2006) for more specific explanations to the price puzzle.

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, Hajkova and Hurnik, 2006).

Next, there has been a lot of research focusing on the sensitivity of 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 the monetary policy at the more disaggregate level. Erceg and Levin (2006) find that the durable goods sector is more sensitive to the interest rate changes than the non-durable goods sector in the U.S. Based on this empirical finding, they investigate the impact of the 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 the sectors in terms of their magnitude and persistence. This result is also 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 output response as well as the asymmetry of 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 the 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 a response of services inflation to monetary policy shock 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 responses of disaggregate prices to monetary policy shocks.

Several papers study the monetary policy effects for the Czech Republic within VAR framework.[5] Using the sample period after the adoption of inflation targeting (1998-2004), Arnostova and Hurnik (2005) find that prices respond with a peak after around 5-6 quarters from the time of shock, albeit there is some evidence for a price puzzle in the first two quarters after the shock.

[5] See Coricelli, Egert 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.

Output falls after monetary contraction with a peak after one year or so. There is a delayed overshooting in the exchange rate, as it depreciates only after 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 shock across two monetary policy regimes. In our paper, we use 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 real-time output gap in the benchmark specification as opposed to an ex-post revised GDP used by Arnostova and Hurnik (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 euro zone, in particular. Contrary to Arnostova and Hurnik (2005), we do not find evidence for a price puzzle in Czech Republic.

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

Among the studies that do not find evidence of 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 indebtness. 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 10 Central and Eastern European countries. For the Czech Republic, they find a hump shaped response of prices, an exchange rate

[6] European Forecasting Network (2004)

appreciation, and a fall in industrial production after a monetary policy innovation. Next, financial structure is found to be of little importance for the 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 an inflation targeting framework has been adopted by the Czech National Bank (previously, it operated a fixed exchange rate regime until May 1997). Our sample thus spans from 1998:1 to 2006:5 at the monthly frequency. While studies in this stream of literature often employ quarterly data, given the length of our sample we decided to work at the monthly frequency. As a result, we have 101 observations. The source of our data is the public database ARAD of the CNB (except for the output gap, which is available only internally within the CNB). The plots of all series are available in Appendix 1.

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 the quarterly frequency, we interpolate these two using quadratic-match average procedure.[8] Note that all other variables we use are not revised afterwards.

Next, we employ the net price index, $lnet_t$, (net price index is a 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 the external developments, the 1-year

[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 the multivariate filter; more specifically, by the Kalman filter procedure, when 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] Actual monetary policy instrument of the CNB is 2W repo rate. Since the repo rate is not changed continuously and is censored, we opt for 3M PRIBOR, which is very closely linked to the 2W repo rate; its correlation stands at 0.998 in our sample. In addition, 3M PRIBOR may capture also central bank communication. See Horvath

EURIBOR, *euribor*$_t$, and the commodity price index, *lcommodity*$_t$, are utilized. Forward rate agreement rate (9*12 FRA rate), *fra*$_t$, is 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 a monetary policy rate (2W repo) as it is the case in the U.S., we decided to use forwards on interbank rates that are very closely related to the policy rate. Finally, all data is in logs except the 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, Phillips curve, monetary policy rule and uncovered interest rate parity.

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

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

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 as to represent the assumption that monetary authorities choose the interest rate taking into account the current level of prices and output (as in Mojon and Peersman, 2001). In

(2008) on the discussion related to the use of the monetary policy rate vs. the interbank market rate in the Czech Republic.

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

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

As regards the first sensitivity check, actual GDP data are used instead of output gap. The rationale for this exercise is that output gap, as opposed to GDP, is unobservable. Our second sensitivity check is motivated by degrees of freedom considerations. Here, we assume that the 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 the 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 identity matrix, 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 the forward-looking monetary authority does not consider contemporaneous prices while deciding on the 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 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).

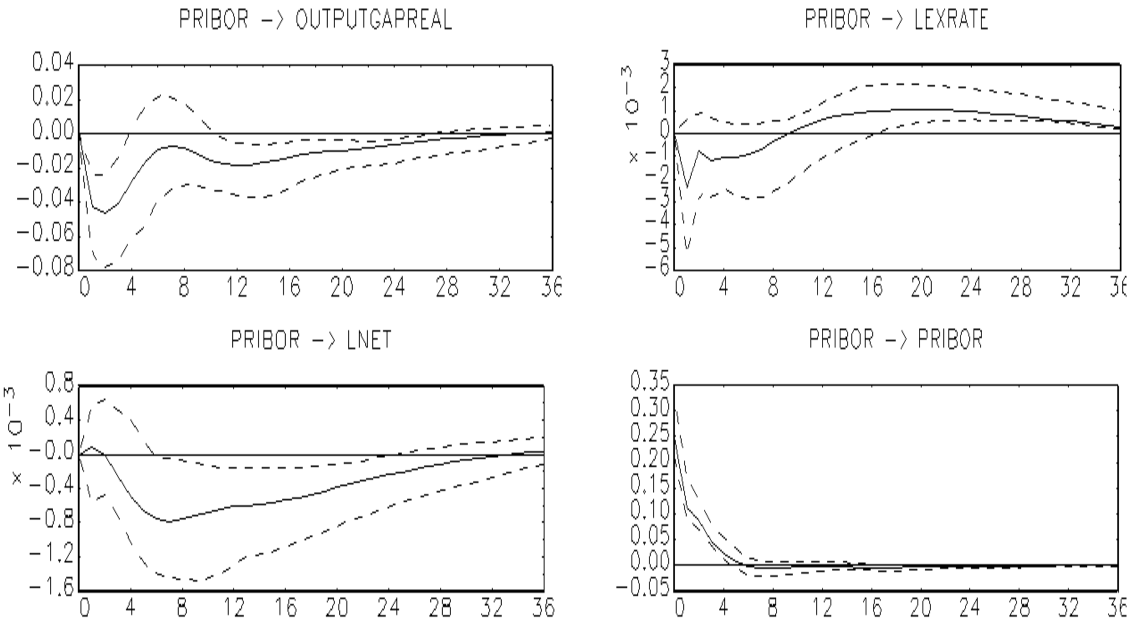
The description of FAVAR model is presented in Appendix 3.

5 Results

In this section, we discuss the estimated effects of the 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, CUSUM of squares test and the recursive coefficient estimation (the results are available upon request).

Figure 1 present our results regarding the effects of 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 that was bootstrapped using 1000 replications according to the percentile method by Hall (1988).

Figure 1: Contractionary monetary policy shock, impulse responses



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

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

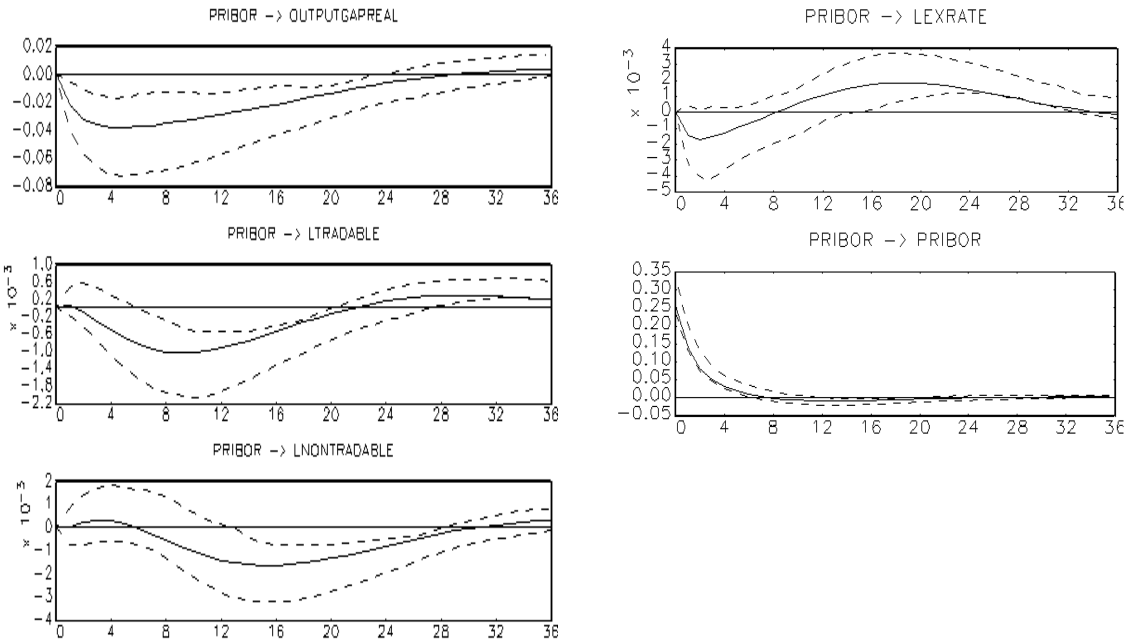
The degree of economic activity, as measured by the output gap, falls after a contractionary monetary policy shock with a bottom after about four months (this is however not confirmed in our sensitivity analysis, which identifies the bottom after about twelve months, which is more sensible). The results indicate that a monetary shock of 30 basis points decreases the output gap by about 5%. The responses of output and price 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 domestic currency after 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

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

interpreting the results. Nevertheless, we can see that irrespective of specification and estimation technique, the exchange rate depreciates over the longer-term horizon, which conforms to uncovered interest rate parity hypothesis (Kim and Roubini, 2000).

Figure 2: Contractionary monetary policy shock, impulse responses: Tradable vs. non-tradable prices



Notes: This figure shows impulse responses to a one standard deviation contractionary monetary policy shock. Time (on 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-tradables to monetary contraction. While the bottom response of tradable prices is around one year or so (even 9-10 months), the non-tradable prices' bottom response occurs only after one and a half year. This result complies with the findings based on micro level data (Alvarez and Hernando, 2006; Coricelli and Horvath, 2006), which show that the frequency of non-tradable prices' changes is relatively 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 non-tradable prices' reaction 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 sensitivity of our benchmark models, with all results reported in Appendix 2. First, we investigate how our results change when we include ex-post revised data (GDP) instead of real-time output gap in our data vector. Real-time variables are part of the information set available at the time of policy-making and hence by using these variables in the VAR analysis we avoid likely contamination of the results caused by data revisions[12]. There is no statistical significant reaction of GDP to 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 real-time output gap in VAR specification as it improves the precision of the empirical analysis.

Second, we estimate very parsimonious model without exogenous variables, including the forward-looking component. The rationale behind it is merely the degrees of freedom considerations. Interestingly, we find that 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 rather backward-looking manner. This is somewhat surprising, but one has to consider the transition process of Czech economy and the corresponding greater uncertainty in economic development, which could make the agents to rely more on current data rather then the 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 the impulse responses close to those of VAR, but with much larger confidence intervals.

Next, we compare our results with other recent studies that analyze monetary policy shocks in the Czech Republic within VAR approach. The comparison is summarized in Table 1. Most of existing studies ignore the monetary policy regime change in the Czech Republic (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 policy shocks across these two regimes; i.e. they do not deliver plausible results and all exhibit price puzzle (some of them even report positive reaction of output to monetary tightening).[14]

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

[13] The output gap and prices fall after a contractionary monetary policy shock with a bottom after about twelve months. The exchange rate first appreciates, but later depreciates significantly, which is 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 the non-tradable prices' reach the bottom response a bit later (about two years).

[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 fixed exchange rate regime. As a result, we

This suggests that price puzzle in these studies is associated with monetary policy regime change. This is further confirmed by two papers that employ the data from inflation targeting period (Elbourne and Haan (2006) and this paper), as their results do not exhibit price puzzle. Finally, the results in Table 1 indicate that the bottom response of output and prices seem to be around 4 quarters, which is in line with our findings.

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.
Hericourt (2005)	1995-2004	No	VAR	(-), sig.	(+), sig.	1Q/---
Hurnik and Arnostova (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 statistically significant decline and increase of the variable after monetary policy shock, respectively. The column 'Single monetary policy regime' indicates, whether the sample period of the study comes from single monetary regime or spans across different regimes (fixed exchange rate regime until May 1997 and inflation targeting regime adopted in January 1998). Abbreviations: TVC-SVAR - time-varying coefficient SVAR, Sig. - the reaction of variable to a monetary policy shock is statistically significant at 5% level, and Q - quarters. If the reaction of variable to monetary shock does not have correct sign, the bottom reaction of variable is not reported (denotes as '----' in Table, n.a. indicates that the corresponding estimates were not available in the original study).

6 Concluding Remarks

In this paper, we analyze the transmission of monetary policy shocks in the Czech Republic within the VAR, SVAR and FAVAR framework. In general, monetary transmission in the Czech Republic seems to be similar, in terms of persistence of responses of economic variables to

code his sample in Table 1 as coming from single monetary policy regime. Another approach to deal with monetary policy changes is presented by Darvas (2005), who estimates time-varying coefficient VAR. Indeed, his results suggest that the value of estimated parameters changes rather abruptly around the year 1997 and remain relatively stable afterwards (This is also confirmed in this study by the recursive estimation of parameters. The results are available upon request).

monetary shocks, to the transmission 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 monetary tightening with a bottom response occurring after about one year. Such 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 those of non-tradables. While the maximum effect of 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 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 rather with model misspecification than with representing 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. fixed exchange rate regime and inflation targeting regime mixed together) exhibit price puzzle.

Next, there is a rationale in 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 interest rate shock are less precisely estimated, and thus our findings point to an importance of real-time data in monetary policy analysis. Finally, our results also indicate a persistent appreciation of the domestic currency after monetary tightening ("delayed overshooting", Eichenbaum and Evans (1995)), albeit the confidence intervals are in this case rather wide, with a gradual depreciation afterwards.

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

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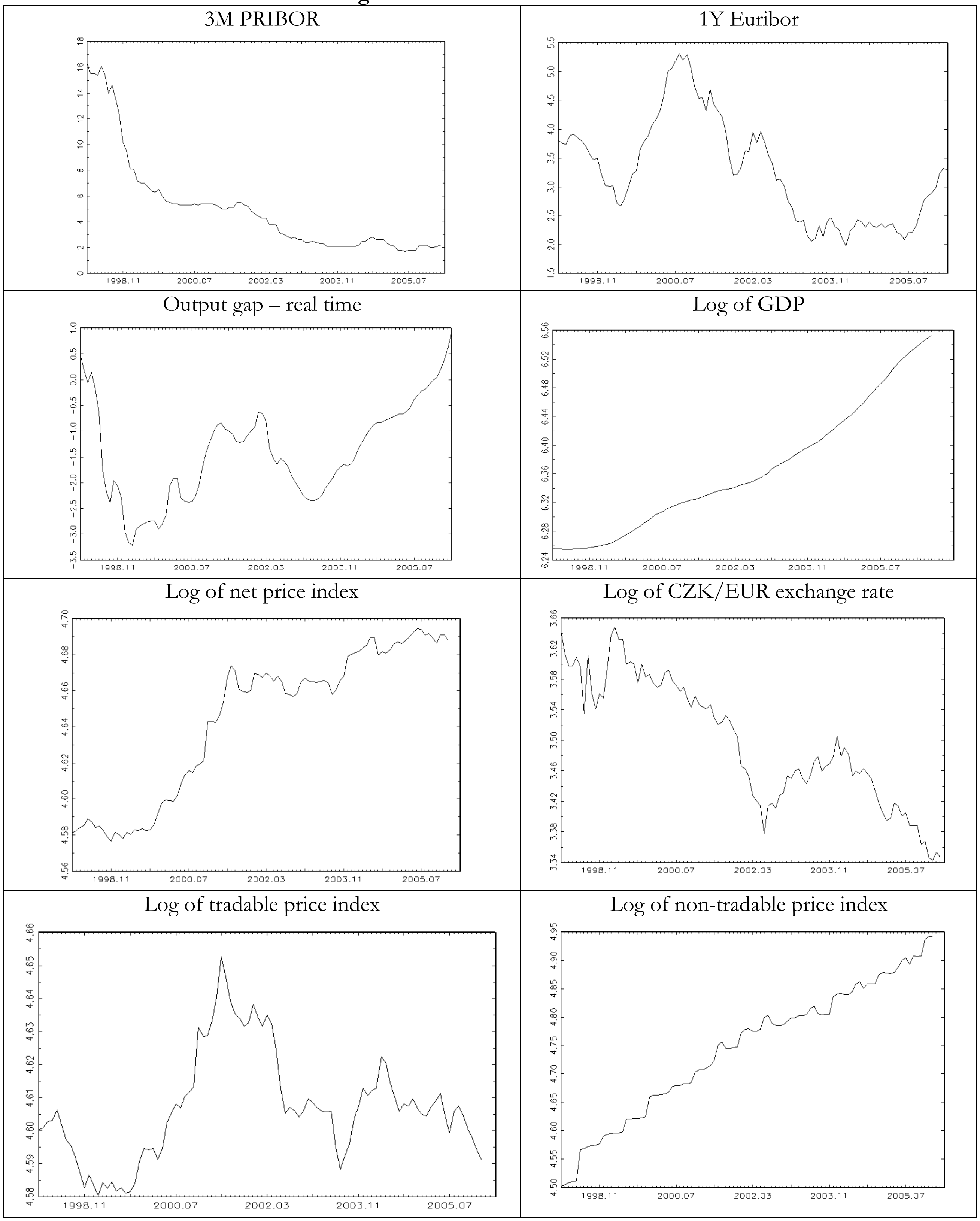
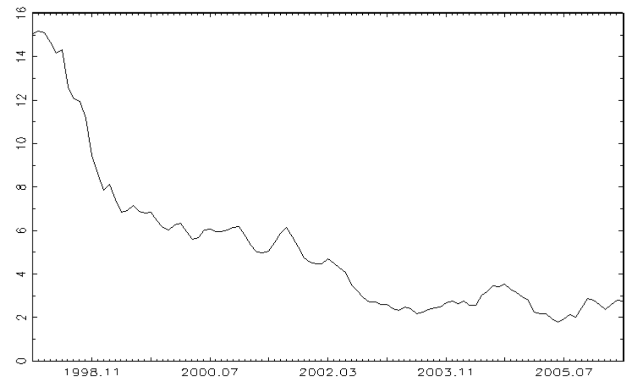
Appendix 1

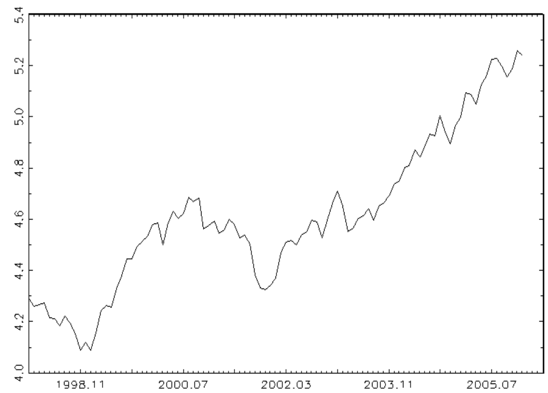
Figure 3: Time Series



Forward rate agreements



Log of commodity price index



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

Figure 4: GDP instead of output gap

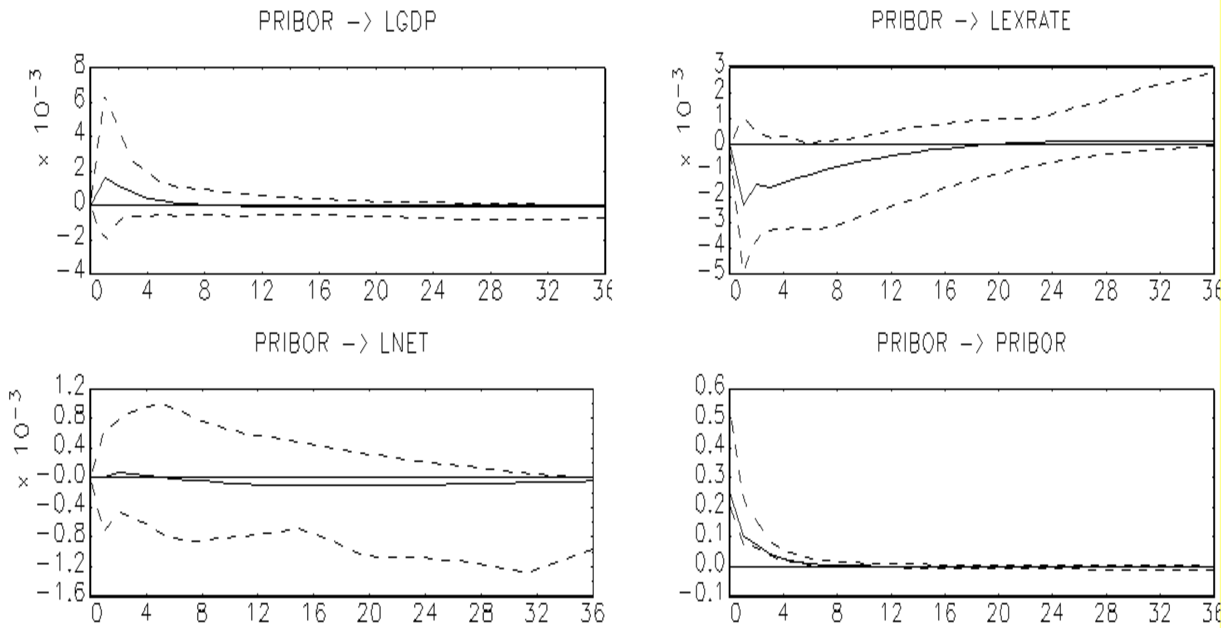


Figure 5: GDP instead of output gap, sectoral prices

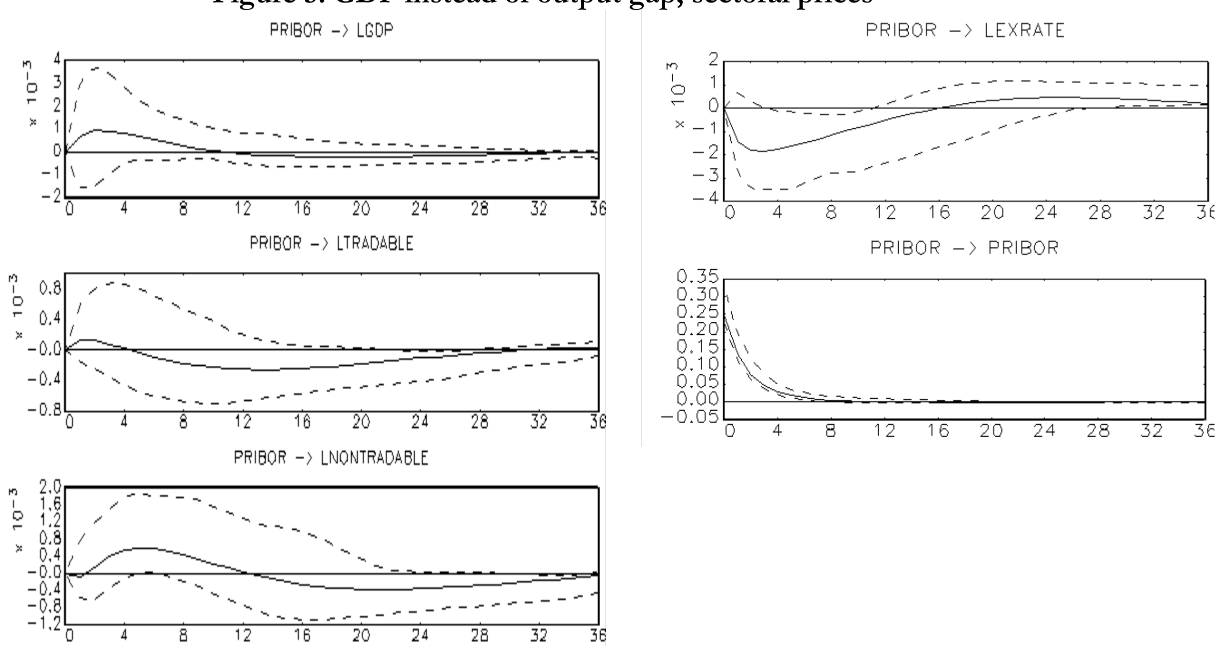


Figure 6: No exogenous variables

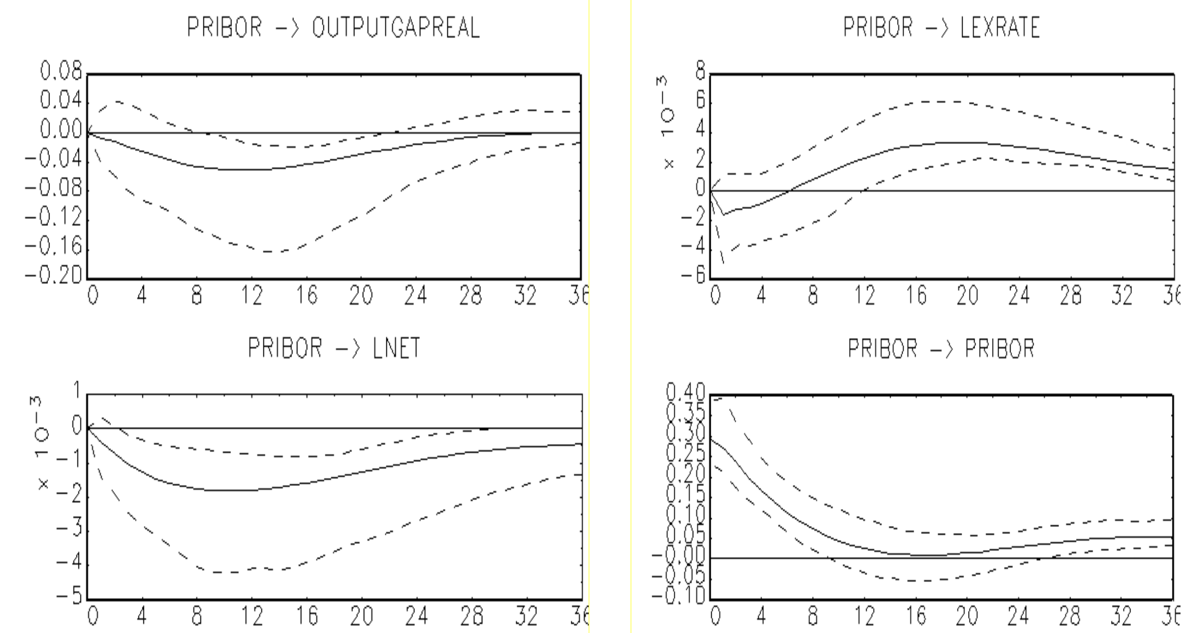


Figure 7: No exogenous variables, sectoral prices

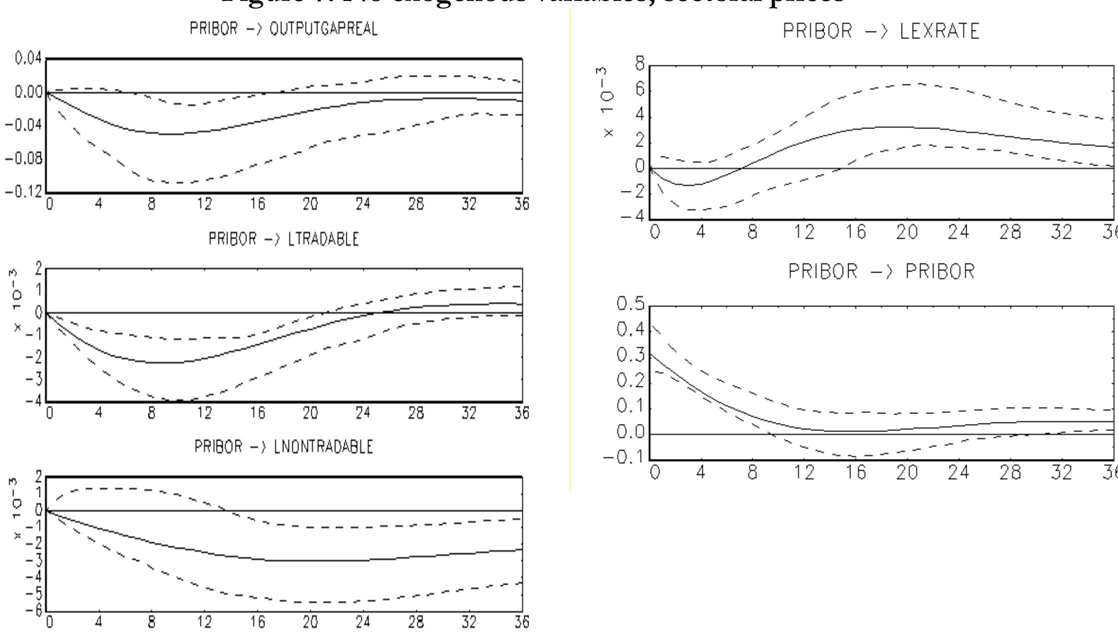


Figure 8: SVAR

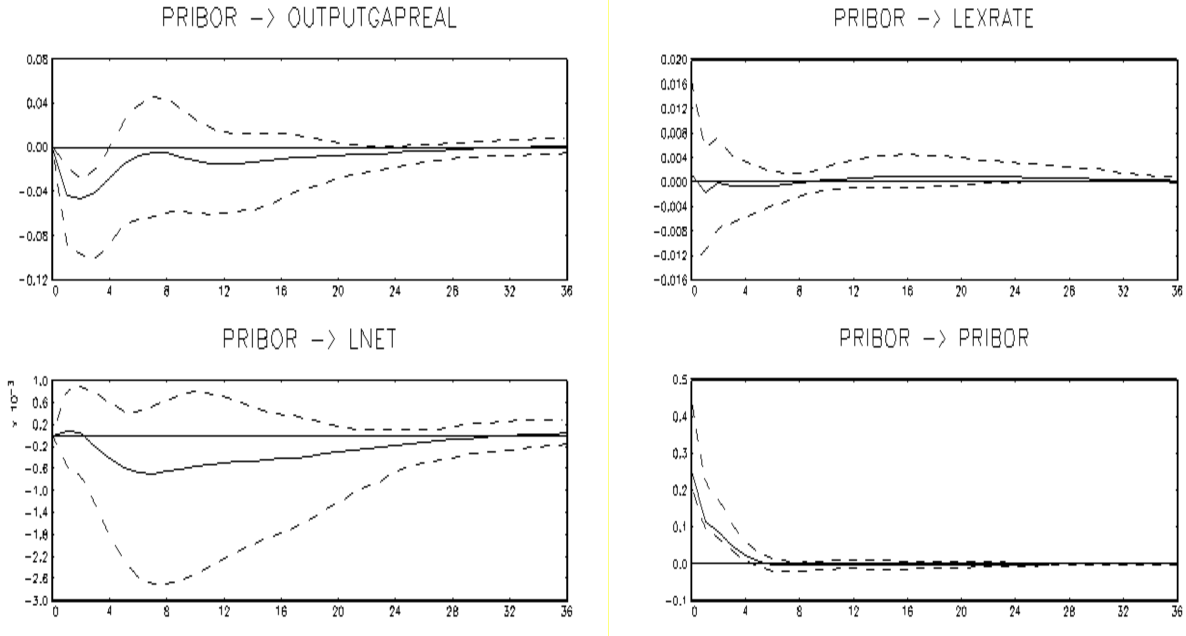
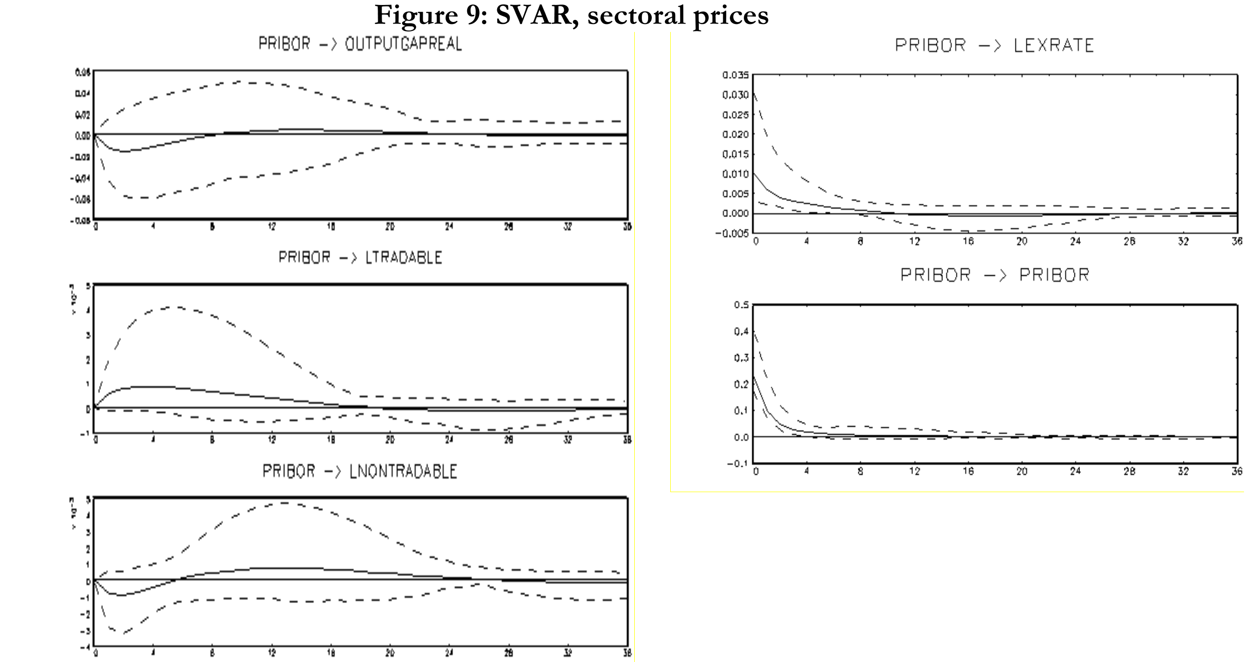


Figure 9: SVAR, sectoral prices



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 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 the information about the unobservable economic factors can be inferred from a large number of economic time series X_t. Specifically, we can think of unobservable factors in terms of concepts such as "economic activity" or "investment climate". They cannot be represented by a single economic variable but rather by several time series of economic indicators.

FAVAR methodology allows us not only to use richer information set in a 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 one-step approach that estimates (3) and 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 a 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 in monthly frequency and spans the period from February 1998 to May 2006. Following Bernanke *et al.* (2005), we assume that the monetary policy instrument (3-month interest rate) is the only observable factor, hence the only variable

[16] We have followed the algorithm developed by Bernanke *et al*. (2005) to estimate FAVAR, which is available at 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 the principal component analysis and FAVAR.

included in Y_t. For the identification purposes monetary policy instrument is ordered last, which implies that latent factors do not respond contemporaneously (within a month) to the 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 variables into each of 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 common factors C_t from all the variables in X_t. Second, after dividing the series in X_t into slow- and fast-moving, we estimate "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 a $\widehat{C}_t - \widehat{b}_Y Y_t$. In the second step, we estimate the VAR in $\widehat{F}_t$ and Y_t, using a recursive assumption.

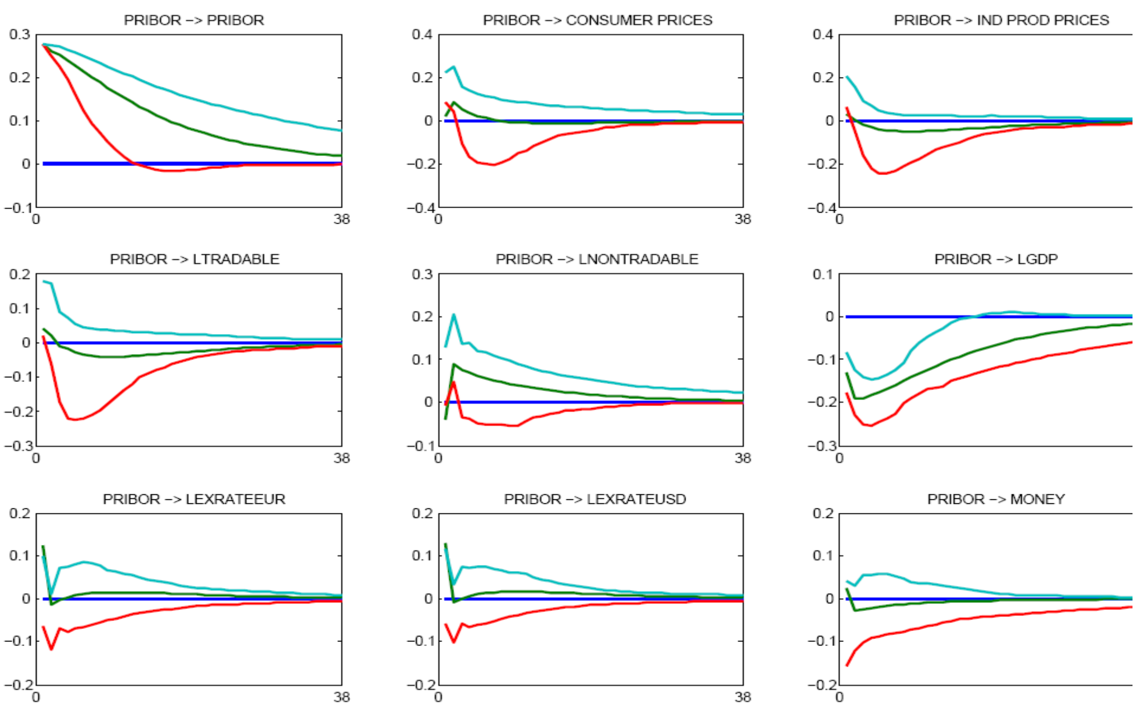
One caveat in our analysis is the fact that we have only 40 series available for principal component analysis as compared with 120 used in Bernanke *et al.* (2005). While this may be viewed as a weakness at first sight, it has been argued by Boivin and Ng (2006) that more series do not necessarily ensure better quality of data due to cross-correlation of idiosyncratic errors. In one of their tests, they show that the factors extracted from 40 pre-screened series may yield in some cases 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 in Figure 9. Each panel shows impulse responses of selected macroeconomic variables to a monetary policy shock with 90% confidence intervals. FAVAR model in Figure 9 includes 3 principal factors but the results were not different when the number of factors was changed. In the benchmark specification we use 1 lag and 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 impact of the monetary policy change on the macroeconomic variables. This is with the exception of 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 FAVAR estimation for the Czech economy. One reason is likely to do with a relatively short span of available data; other may be the quality of data as discussed by Boivin and Ng (2006). Our dataset, as it is at the monthly frequency, 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*	ouputgap real - interpolated from quartely values	2	ARAD
var21*	GDP - interpolated from quartely 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 yea	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 days Interbank Rate PRIBOR(%)	1	ARAD
var33	14 days Interbank Rate PRIBOR(%)	1	ARAD
var34	1 month Interbank Rate PRIBOR(%)	2	ARAD
var35	2 months Interbank Rate PRIBOR (%)	2	ARAD
var36	6 months Interbank Rate PRIBOR(%)	2	ARAD
var37	9 months Interbank Rate PRIBOR (%)	2	ARAD
var38	1 year Interbank Rate PRIBOR(%)	2	ARAD
var41	3 months 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 they 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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