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2019

WORKING PAPER SERIES 1

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2019

CZECH NATIONAL BANK

WORKING PAPER SERIES

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1/2019

CNB WORKING PAPER SERIES

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Project Coordinator: Jan Babecký

The Czech Exchange Rate Floor: Depreciation without Inflation?

Jaromír Baxa and Tomáš Šestořád *

Abstract

After the introduction of an exchange rate commitment and an immediate 7% depreciation of the Czech koruna of in 2013, output growth resumed but inflation remained low. Consequently, the Czech National Bank did not return policy to normal for more than three years. Using a time-varying parameter VAR model with stochastic volatility, we show that this was not surprising. The exchange rate pass-through to prices had been rather low and gradually decreasing since the early 2000s, suggesting limited potential effects of the exchange rate commitment on inflation. On the other hand, the pass-through to output growth increased. These results hold even when the period of the exchange rate floor and the zero lower bound is excluded from the sample, and they are robust to other sensitivity checks. Our results are consistent either with a flattened Phillips curve, or rising quality of the Czech exports and participation in global value chains, or a small effect of the exchange rate commitment on inflation expectations when not paired with temporary price-level targeting. Moreover, we highlight the usefulness of models accounting for time variation of parameters for policy analysis.

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We acknowledge the support by the Grant Agency of the Czech Republic, Grant No. 402/16-02392S. The opinions and views expressed in this paper are only those of the authors and do not necessarily reflect the position and views of the Czech National Bank or any other institution with which the authors are associated. We are grateful to Jan Brůha, Michal Franta, Roman Horváth, Tomáš Havránek, Tomáš Holub, Haaron Mumtaz, Karel Musil, Dominika Kolcunová, Marek Rusnák, and Jaromír Tonner for helpful comments and suggestions. The responsibility for all remaining errors and omissions rests solely on the authors.

Abstrakt

Po zavedení kurzového závazku a okamžitém oslabení české koruny v roce 2013 o 7 % sice došlo k obnovení ekonomického růstu, avšak inflace zůstala nízká. V důsledku toho Česká národní banka vrátila svoji měnovou politiku k normálu až po více než třech letech. Za pomoci modelu VAR s časově proměnlivými parametry a se stochastickou volatilitou ukazujeme, že tento vývoj nebyl překvapivý. Průsak směnného kurzu do cenové hladiny se po roce 2000 postupně snižoval, což naznačovalo omezené potenciální dopady kurzového závazku na inflaci. Na druhou stranu se zvyšoval průsak kurzu do ekonomického růstu. Tyto výsledky platí i v případě, kdy ze vzorku vyloučíme období trvání kurzového závazku i období nulové dolní meze úrokových sazeb, a jsou robustní vůči dalším citlivostním analýzám. Naše výsledky je možné vysvětlit buď zploštělou Phillipsovou křivkou, nebo rostoucí kvalitou českého vývozu a účastí v globálních hodnotových řetězcích, případně malým dopadem poklesu směnného kurzu do inflačních očekávání, když kurzový závazek není doprovázen dočasným cílováním cenové hladiny. Upozorňujeme také na užitečnost modelů zohledňujících časovou proměnlivost parametrů pro analýzu měnové politiky.

JEL Codes: C32, E52, F41.
Keywords: Exchange rate commitment, exchange rate pass-through, time-varying parameters, VAR, zero lower bound.

1. Introduction

Central banks still have several policy options when short-term interest rates are constrained by the zero lower bound. Besides large-scale asset purchases and forward guidance, they can lower interest rates below zero, down to the effective lower bound on interest rates, or they can opt for other unconventional instruments, such as helicopter money. Additionally, in small open economies, exchange rate interventions might be an attractive option, especially when the domestic financial sector is not suffering from a liquidity shortage. Real depreciation will increase GDP growth and inflation, since at the zero lower bound the change in the exchange rate will not be offset by rising interest rates, and the central bank can in this way bring inflation back to its inflation target. These considerations lay behind the proposal of Svensson (2000) and others for a *"foolproof way"* of escaping from a liquidity trap, which inspired the Czech National Bank to resort to one-sided exchange rate commitment as an additional instrument of monetary policy in November 2013 (Franta et al., 2014a), one year after its monetary policy rate reached technical zero. The commitment was set at 27 CZK/EUR, and the exchange rate immediately depreciated by 7 %, from 25.5 to 27.5 CZK/EUR.

Several reasons for resorting to the new instrument were communicated. Prominent among them were the risk of deflation in 2014, the downward revisions of predictions of producer price inflation in the euro area, and the relatively good performance of the domestic financial sector, making alternative policies in the form of liquidity provision inefficient. At the same time, the Czech National Bank expected both output growth to increase and inflation to get back to the inflation target in 2015, when the commitment was supposed to end (Hampl, 2017).

However, subsequent developments differed markedly. While output growth was restored quickly, it took more than three years for inflation to reappear, and the exchange rate floor was finally abandoned in April 2017. The limited impact of the exchange rate commitment on inflation in contrast to the response of output growth and employment is gradually being confirmed by studies (i.e., Opatrný 2017, Hampl 2017, and partly by Brůha and Tonner 2017), but it remains unclear whether the low response of inflation was a consequence of long-term changes in the economy or one-off foreign shocks. Also, the exchange rate commitment was implemented without additional instruments pushing inflation expectations upward, suggesting that some alternative policy options could have helped the central bank achieve its ultimate goal – the return of inflation to the target – more efficiently. The difference between the expectations and the actual developments deserves attention because if the zero lower bound returns, the policymakers will face the same policy dilemmas as they did in 2013.[1]

This paper aims to investigate the exchange rate pass-through to prices and real GDP through the lens of a time-varying parameter VAR model with stochastic volatility. This methodology is sufficiently flexible to account for long-term changes in the economy (Primiceri, 2005), including the effects of EU accession and integration, the long-running appreciation of the Czech koruna, and the impact of the zero lower bound and the exchange rate commitment on the pass-through. Moreover, we revisit the unique experience of the Czech National Bank with using an exchange rate commitment as an instrument of monetary policy under inflation targeting. In particular, the TVP-VAR framework is used to assess whether the exchange rate pass-through decreased, by how much, and when the decrease appeared.

[1] The Czech National Bank considered the positive impact on output growth as side effects "whether welcome or not", while the ultimate objective was to achieve the inflation target (Skořepa et al., 2016).

Furthermore, the methodology of time-varying parameter VAR models provides consistent estimates of impulse responses to an exchange rate shock even at the zero lower bound (Nakajima, 2011a). On the other hand, since late 2013, the dynamics of the exchange rate may have been affected by the one-sided commitment set by the central bank, and in principle, the presence of the commitment could affect our estimates of the exchange rate pass-through. However at least until August 2015, the commitment was considered credible, and the exchange rate fluctuated well above the floor. Hence, the unexpected exchange rate shocks in either direction appeared in the same manner as before the commitment was put in place. Then, in August 2015, the exchange rate hit the floor, but at the same time market participants were increasingly aware that the floor could soon be abandoned and started to bet in expectation of appreciation of the koruna. Therefore, the exchange rate commitment did not constrain unexpected fluctuations of the koruna as much as one might think, and the time-varying parameter VAR model remains a suitable device for estimating the exchange rate pass-through.[2]

Our results suggest that the exchange rate pass-through is incomplete but fast, being completed in less than two years for most of the observations. However, the exchange rate pass-through to consumer prices was declining steadily over time and had become low before the exchange rate commitment was introduced. On the other hand, the pass-through to output has remained high since the late 2000s.[3] These findings are robust across various sensitivity checks, including different specifications of the exchange rate, and are in line with the very recent evidence (CNB, 2017a) obtained from linear models originally introduced in Babecká-Kucharčuková (2009).

From a policy perspective, our results imply that the outcomes of the exchange rate commitment are consistent with the long-term changes in the Czech economy and thus cannot be attributed to one-off foreign shocks only. Quantitatively, we estimate that the seven percent depreciation of the Czech koruna against the euro in November 2013 increased the price level by 0.13 %–0.33 % and output by 0.45 %–1.5 % after two years depending on the specification of the model. Finally, we examine several hypotheses explaining the low exchange rate pass-through to prices, including a flattening of the Phillips curve and changes in the structure of the Czech economy. Furthermore, we discuss the specifics of the exchange rate commitment implemented by the Czech National Bank and their impact on inflation.

The paper is structured as follows. Section 2 provides the motivation for the proposed topic and summarizes stylized facts about the exchange rate pass-through. Section 3 presents the methodology and Section 4 describes the dataset. Section 5 contains our estimates of the time-varying exchange rate pass-through and discusses the monetary policy implications. Possible explanations of the decreasing exchange rate pass-through to consumer prices are provided in Section 6. Section 7 summarizes our findings.

[2] Nevertheless, to make sure our estimates are biased neither by the zero lower bound, nor by the exchange rate commitment, we re-estimated the model on the sample up to 2012, well before the commitment was introduced, and the main results remained robust.

[3] The interpretation of results is driven mainly by median estimates. Except of the nominal interest rate, the hypothesis of stable transmission of the exchange rate shock over time cannot be rejected at common levels of statistical significance. This is given by a nature of the time-varying parameter VAR model which suffers from wide confidence intervals.

2. Literature Review

2.1 Exchange Rate Pass-Through

The impact of a change in the exchange rate on the economy can be measured by the exchange rate pass-through (ERPT), which shows how much the price level (and eventually other macroeconomic variables such as real GDP) responds to a one percent change in the exchange rate (Goldberg and Knetter, 1997). When the pass-through equals one, the exchange rate shock is fully transformed into the price level. On the other hand, a zero pass-through implies that the domestic price level is independent of the exchange rate.

The mechanism of transmission of a nominal depreciation to inflation and output growth in a small open economy is supposed to work through direct and indirect effects, as illustrated in Figure 1. Firstly, prices of imported final goods increase, and imported intermediates become more expensive as well, making the production costs of domestic producers higher. Depending on the size of the pass-through, the price level increases, too. Along with those direct effects, domestic production becomes less expensive than foreign production due to real depreciation, and domestic and foreign demand for domestic goods gradually increases. In response, both the balance of trade and output growth rise and these improved conditions are transmitted to higher employment and wages.

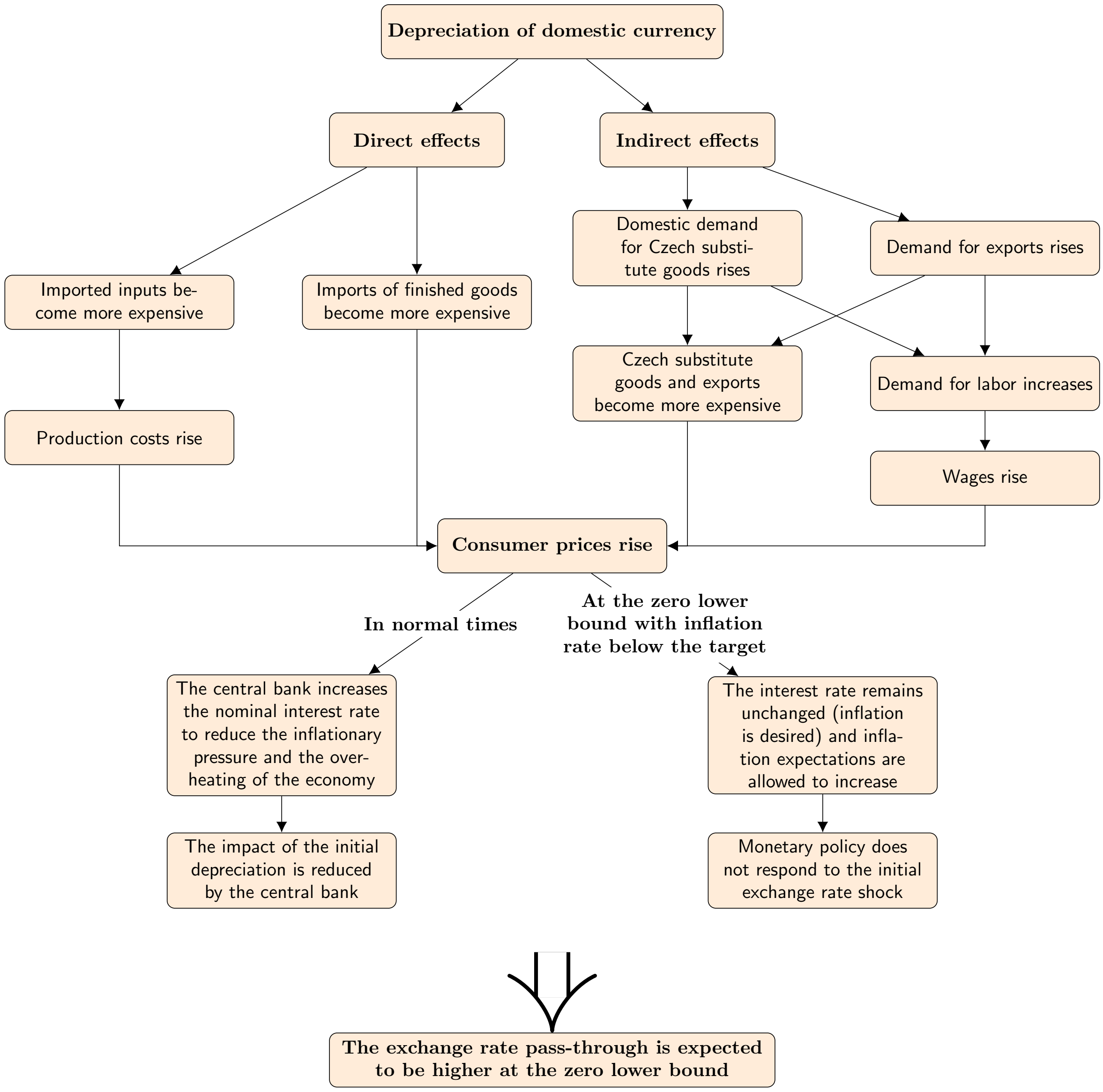
In normal times, the central bank might not be willing to accept higher inflation, especially under inflation targeting. It therefore increases the policy rate and the impact of the initial depreciation on the economy decreases. A completely different situation occurs at the zero lower bound when the central bank desires to raise inflation and, in the case of low inflation expectations, to increase those expectations. In that situation, the central bank keeps the nominal interest rate unchanged and the original depreciation results in a higher price level and higher economic activity. Hence, at the zero lower bound the exchange rate pass-through will be higher than in normal times.

The possibility of higher exchange rate pass-through at the zero lower bound implies that small open economies can resort to exchange rate interventions to accelerate economic growth and escape the zero lower bound, in particular when the central bank does not face severe disruptions on financial markets (Franta et al., 2014a). In that case, liquidity provision via quantitative easing makes little sense, and forward guidance might not be enough when not supported by other apparent policy measures. Another option involves negative interest rates. While the recent experience proves that interest rates can be set below zero, the Czech National Bank considered the uncertainty regarding the impact of this unconventional policy decision on the economy to be too large (Franta et al., 2014a).

The rationale for using exchange rate management as a way to escape the liquidity trap was first provided by Svensson (2000). His proposal, referred to as *"foolproof way"*, suggests that the zero lower bound can be overcome by a temporary exchange rate peg causing real depreciation of the domestic currency and by the temporary adoption of price-level targeting. In this way, inflation is supposed to increase due to rising costs of imported goods, restored economic growth, lowered real interest rates, and higher inflation expectations. Furthermore, Malovaná (2015) studies the effects of alternative exchange rate regimes in a calibrated NK-DSGE model. She confirms that the exchange rate floor is the most effective foreign intervention regime when a small open economy is facing deflationary pressures, primarily by preventing real appreciation and loss of price competitiveness.

So far, only the Czech National Bank has resorted to a one-sided exchange rate commitment as a way to escape deflation and bring inflation back to its target. Although the policy implementation

Figure 1: Exchange Rate Shock Transmission Mechanism (Partially Based on Savoie-Chabot and Khan 2015)



did not follow Svensson's *"foolproof way"* completely, as formally the Czech National Bank did not resort to price-level targeting (Franta et al., 2014a), it is interesting to evaluate the impact of the exchange rate commitment on the Czech economy by analyzing changes in the exchange rate pass-through.[4]

[4] The Czech National Bank considers its experience to be a unique experiment in the use of foreign exchange rate interventions under inflation targeting: "The Swiss National Bank de facto set a minimum exchange rate (floor) for the franc in 2011 after a series of none too successful ad-hoc interventions. However, its primary motive was to respond to the strong appreciation caused by the franc's safe haven status, not to hit the inflation target. With its action, the Czech National Bank is, therefore, creating a unique experience, and the aim of this study is to share that experience with the academic community and other central banks that might be considering using the same instrument in the future" Franta et al. (2014a, p. 2).

2.2 Determinants of the Exchange Rate Pass-Through

There are essentially two main estimation strategies for assessing the size of the exchange rate pass-through. The first is a simple one-equation model derived from the backward-looking Phillips curve for an open economy (Devereux et al., 2003). Since this approach might not capture the exchange rate shock transmission mechanism adequately, many authors resort to VAR models (McCarthy, 1999). Then, the short-run pass-through is defined as the value of impulse response functions at a given point in time, while the cumulative value of the impulse responses measures the long-run pass-through.

The size of the pass-through is known to be affected by several factors, including macroeconomic variables and the reactions of monetary policy, and it is likely to change over time, too. Firstly, the price level is found to be more sensitive to depreciation than to appreciation (Dellate and Lopez-Villavicencio, 2013). In the case of appreciation, domestic importers do not have any strong incentive to reduce their prices, because the change in the exchange rate leads to higher profits. Secondly, the size of the change in the nominal exchange rate has a positive impact on the pass-through, since large exchange rate shocks cannot be internalized as easily as smaller ones (Correa and Minella, 2010; Caselli and Roitman, 2016). For the same reason, expectations of a long-term change in the exchange rate increase the pass-through as well (Correa and Minella, 2010; Ozkan and Erden, 2015). Third, Taylor (2000), Edwards (2006), and Shintani et al. (2013) point out that the size of the exchange rate pass-through depends positively on the inflation rate. In particular, lower pass-through is associated with the adoption of inflation targeting as a credible monetary policy regime (Takhtamanova, 2008). Sekine (2006) confirms declining pass-through in G7 countries. A positive relationship between inflation and the pass-through is also evident on a cross-country level, the pass-through being higher in emerging economies, where higher inflation often prevails (Ca'Zorzi and Hahn, 2007; Ozkan and Erden, 2015). Similarly, for the euro area, the pass-through is higher in Spain and Italy than in the core economies of the euro area such as France and Germany (Özyurt, 2016).

Furthermore, Jašová et al. (2016) estimate the time-varying pass-through separately for advanced and emerging economies before and after the Great Recession.[5] They find that the pass-through remained relatively stable in advanced economies but decreased in emerging economies along with their inflation rates. On the other hand, according to Özyurt (2016), the exchange rate pass-through in the euro area dropped from 0.3 to 0.22 in 2012, when interest rates reached the zero lower bound.

Regarding the size of the exchange rate pass-through at the zero lower bound, the existing literature comes mainly from Japan, where no clear evidence supporting exchange rate management as an efficient alternative to other unconventional monetary policy instruments has been found (Shioji, 2012, 2015; Iwata and Wu, 2006). Although Japan is a large open economy that has experienced specific developments over the past decades, these results cast some doubt on the possibility of achieving a long-term increase in the inflation rate by making exchange rate interventions.

The exchange rate pass-through for the Czech Republic has been estimated several times. Babecká-Kucharčuková (2009) uses a series of VAR models on different samples and finds a pass-through of no higher than 0.3, depending on the specification and the sample. Hájek and Horváth (2016) replicate the approach used by Babecká-Kucharčuková (2009) and their estimated exchange rate pass-through equals 0.18 on average. Franta et al. (2014b) resort to a time-varying parameter VAR model and their results indicate that the response of output to an exchange rate shock gradually increased between 1996 and 2010, while the pass-through to consumer prices remained stable.

[5] The Central European countries were included among emerging economies.

Nevertheless, the authors do not report any explicit estimate of the long-term pass-through either to output or to the price level, and their sample ends before interest rates hit the zero lower bound.

Several attempts have recently been made to evaluate the effectiveness of the exchange rate commitment in the Czech Republic. Lízal (2015) provides a counterfactual analysis for different scenarios and supports the view that exchange rate management was the only possible way to avoid deflation. More recent estimations based on the methodology of synthetic control by Opatrný (2017) and Brůha and Tonner (2017) suggest a significant and positive impact of the commitment on GDP growth, but the effects on headline inflation were mostly insignificant, although somewhat positive. Brůha and Tonner (2017) find a significant positive impact at least on core inflation. These results are much more skeptical about the impact of the commitment on both core and headline inflation than the results from structural models – see Brůha and Tonner (2017) for a direct comparison. Only Caselli (2017) finds an increase in headline inflation (of about 1 %) due to the exchange rate floor.

Following the experience of repeated extensions of the exchange rate commitment due to inflation rates being well below the target, the Czech National Bank has revised its estimates of the exchange rate pass-through downward as well. In CNB (2017a), the new estimates based on the model by Babecká-Kucharčuková (2009) imply an exchange rate pass-through of "below 0.1," i.e., one-third of the 2009 estimates. Finally, it has been argued that inflation remained low and the commitment was in place for longer than initially expected because of disinflationary pressures from the euro area (CNB, 2017b). In particular, both the GDP and PPI growth rates in the euro area were lower than expected when the exchange rate floor was introduced.

All in all, the evidence for the Czech Republic is still rather heterogeneous. The existing studies either do not cover the period of the zero lower bound, at which the behavior of the economy might be different to that in normal times, or focus solely on the impact of the introduction of the exchange rate commitment in 2013. However, estimates of the effect of the exchange rate commitment itself cannot provide an assessment of long and medium-term changes in the exchange rate pass-through, so they might lead to different policy implications. The muted response of the price level may simply be considered an effect of one-off shocks rather than a consequence of long-term structural changes. We aim to contribute to the debate by providing estimates of time-varying parameter models that can offer an indication of the scale and timing of potential shifts in the size of the exchange rate pass-through. This appears to be essential for assessing the role of exchange rate commitments under inflation targeting.

3. Methodology

3.1 Time-Varying VAR with Stochastic Volatility

We estimate the exchange rate pass-through using a time-varying parameter VAR model with stochastic volatility (TVP-VAR). We opted for this methodology because it allows us to deal with time variation in coefficients and thus to study changes in the exchange rate pass-through without the need to resort to subsample estimation. The main benefit of the TVP-VAR model is that it provides a unique set of impulse response functions for each point in time in the dataset, thus capturing changes in the transmission mechanism which are not restricted to any particular form of potential nonlinearity (Primiceri, 2005).

To trace out the development of the exchange rate pass-through, we use the following vector of macroeconomic variables

$$\{y, p, i, s\},$$

where y is output, p is the price level, i is the nominal interest rate, and s is the exchange rate.

When taking the VAR model to a small open economy, it is suggested to include foreign variables and to apply block-exogeneity restrictions (Cushman and Zha, 1997). In the model without the foreign block, one can interpret structural shocks to the other domestic variables as a combination of shocks of domestic and foreign origin as well. While such an interpretation is not convenient when trying to learn about the effects of monetary policy, it does not cause any complication when interpreting the impact of the exchange rate. Hence, we decided not to extend the already richly parameterized model for the foreign block or exogenous variables, and we supplemented our results with estimates of linear VAR models with various exogenous variables instead. In line with our intuition, the results were largely intact.[6]

Importantly, the time-varying parameter VAR model with stochastic volatility can be used for estimating the exchange rate pass-through even when fluctuations of the interest rate are truncated by the zero lower bound and those of the exchange rate are truncated by the exchange rate floor.[7] Regarding the zero lower bound, Nakajima (2011a) shows that only the impulse responses of monetary policy shocks are affected, so he supports the view that time-varying parameter VAR models remain useful for evaluating the exchange rate pass-through.[8]

The truncation of exchange rate fluctuations under the commitment is, however, of a different nature than the zero lower bound on the interest rate. In principle, even with the floor, unexpected exchange rate fluctuations cannot be ruled out: the exchange rate might be well above the floor, or the central bank might shift or abandon the floor, as the Swiss National Bank did. In the case of the Czech koruna, market participants counted on those options. First, until August 2015, the CZK/EUR rate was persistently about 2.5 % weaker than the floor without any need for continuing exchange rate interventions, because the commitment was generally considered credible. Later, when the economy recovered and wages and housing prices started to rise, expectations that the floor would be abandoned fueled speculation on appreciation of the koruna. Hence, the time-varying parameter VAR measuring the effects of unexpected changes in the exchange rate will be applicable to the period of the exchange rate floor as well, because the fluctuations of the koruna were not as constrained as one might think. Anticipating our results, let us note that even the volatility of the structural exchange

[6] Although the arguments for including the foreign sector are well grounded in the literature, in the case of the Czech Republic the differences between the VAR models with and without the block of foreign variables are not large. Borys et al. (2009) show that in linear VAR models, a monetary policy shock can be well-identified even without the foreign block, and adding several exogenous variables does not affect the results. Following their work, Franta et al. (2014b) also exclude the foreign block from the TVP-VAR for the Czech Republic, and the results again indicate reasonably identified monetary policy shocks.

[7] Obviously, one might argue that the interest rate can be set as negative as well. However, those options were indicated neither in the official communication of the Czech National Bank nor in the papers written by its staff at the time of the exchange rate floor as often as exchange rate interventions. Additionally, even the zero lower bound might not be binding, as an effective lower bound determined by the costs of holding cash presumably exists (Kolcunová and Havránek, 2018).

[8] Nakajima (2011a) compares the TVP-VAR-SV model with a model accounting for the zero lower bound by truncating the impulse response of the interest rate at 0.5 %. His results are twofold: the estimated effects of the interest rate shock can be misleading when the zero lower bound is not accounted for; on the other hand, the conventional TVP-VAR-SV model is appropriate for investigating the dynamics of the relationships between other macroeconomic variables even at the zero lower bound.

rate shocks during the first two years of the commitment was comparable to that in previous periods. Nevertheless, to make sure our results are indeed biased neither by the zero lower bound period nor by the exchange rate commitment, we check whether our results change when the period of the zero lower bound and the exchange rate floor is excluded from the sample as part of our sensitivity analysis.

In accordance with Primiceri (2005) and Nakajima (2011b), we construct a time-varying vector autoregressive model with stochastic volatility:

$$A_t y_t = c_t + \sum_{i=1}^{p} F_{i,t} y_{t-i} + u_t, \tag{1}$$

where y_t is a $k \times 1$ vector of endogenous variables, c_t is a $k \times 1$ vector of time-varying intercepts, and $A_t, F_{i,t}$ for $i = 1, ..., p$ are $k \times k$ matrices of time-varying coefficients. The number of lags in the model is defined by p. The disturbance u_t is the vector $k \times 1$ of structural shocks, which follows a normal distribution $u_t \sim N(0, \Sigma_t \Sigma_t)$, where

$$\Sigma_t = \begin{pmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \sigma_{2,t} & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \sigma_{k,t} \end{pmatrix}.$$

Simultaneous relations of the structural shocks are identified recursively by the lower triangular matrix A_t,

$$A_t = \begin{pmatrix} 1 & 0 & \cdots & 0 \\ a_{21,t} & 1 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ a_{k1,t} & \cdots & a_{k\,k-1,t} & 1 \end{pmatrix}.$$

Hence, we can rewrite the structural model into its reduced form:

$$y_t = c_t + \sum_{i=1}^{p} B_{i,t} y_{t-i} + A_t^{-1} \Sigma_t \varepsilon_t \qquad u_t = A_t^{-1} \Sigma_t \varepsilon_t, \tag{2}$$

where $B_{i,t} = A_t^{-1} F_{i,t}$. Stacking the intercepts c_t and matrices of coefficients $B_{i,t}$ for all t into a vector β_t of length $k(kp+1)$, and defining $X_t = I_k \otimes (1, y'_{t-1}, ..., y'_{t-p})$, the model can be rewritten as

$$y_t = X_t \beta_t + A_t^{-1} \Sigma_t \varepsilon_t. \tag{3}$$

To define the evolution of time-varying parameters, the unknown parameters of the lower triangular matrix A_t are stacked to a vector $\alpha_t = (a_{21,t}, a_{31,t}, a_{32,t}, a_{41,t}, ..., a_{k\,k-1,t})$ of length $\frac{1}{2}(k-1)k$. The diagonal elements of Σ_t represent volatility and are restated in logs $h_{jt} = \log \sigma_{jt}^2$ for $j = 1, ..., k$ and stacked into a $k \times 1$ vector $h_t = (h_{1t}, ..., h_{kt})$, too. Finally, the vectors β_t, α_t, h_t for $t = s+1, ..., n$ follow a random walk without drift:

$$\beta_{t+1} = \beta_t + u_{\beta,t+1}, \tag{4}$$

$$\alpha_{t+1} = \alpha_t + u_{\alpha,t+1}, \tag{5}$$

$$h_{t+1} = h_t + u_{h,t+1}. \tag{6}$$

The standard deviation σ_t follows a geometric random walk which belongs to the class of stochastic volatility models (Primiceri, 2005). The vector of error terms ε_t and the innovations of the time-varying coefficients $u_{\alpha,t}, u_{\beta,t}, u_{h,t}$ are normally distributed

$$\begin{pmatrix} \varepsilon_t \\ u_{\beta,t} \\ u_{\alpha,t} \\ u_{h,t} \end{pmatrix} \sim N \left(0, \begin{pmatrix} I_k & 0 & 0 & 0 \\ 0 & \Sigma_\beta & 0 & 0 \\ 0 & 0 & \Sigma_\alpha & 0 \\ 0 & 0 & 0 & \Sigma_h \end{pmatrix} \right).$$

Here, I_k is an identity matrix of dimension $k \times k$. Matrix Σ_h is diagonal, while matrices $\Sigma_\beta, \Sigma_\alpha$ depict the covariance structure of innovations.

The number of unknown parameters of the model is very large, making analytical estimation impossible. Instead, we resort to the Bayesian approach with an MCMC algorithm (Koop, 2003; Greenberg, 2008).[9] To enable Bayesian estimation, prior beliefs about the parameters have to be elicited. We follow the widely used strategy that priors β_t, α_t, h_t at $t = s+1$ have normal distribution with mean and variance set according to estimates of a linear VAR model (Primiceri, 2005; Canova, 2003):[10]

$$\beta_{s+1} \sim N(\hat{B}_{OLS}, 4 * V(\hat{B}_{OLS})), \tag{7}$$

$$\alpha_{s+1} \sim N(\hat{A}_{OLS}, 4 * V(\hat{A}_{OLS})), \tag{8}$$

$$h_{s+1} \sim N(\hat{h}_{OLS}, 4 * I_k), \tag{9}$$

where $\hat{A}_{OLS}, \hat{B}_{OLS}, \hat{h}_{OLS}$ are ordinary least squares estimations of a linear vector autoregressive model. The variance of the starting values is multiplied by an arbitrary value of four to take into account the uncertainty about the initial values. The prior distribution of the variance of innovations is defined in the following way:

$$\Sigma_\beta \sim IW\left(k_\beta^2 * \tau * V(\hat{B}_{OLS}), \tau\right), \tag{10}$$

$$\Sigma_h \sim IG\left(k_h^2 * (k+1) * I_k, k+1\right), \tag{11}$$

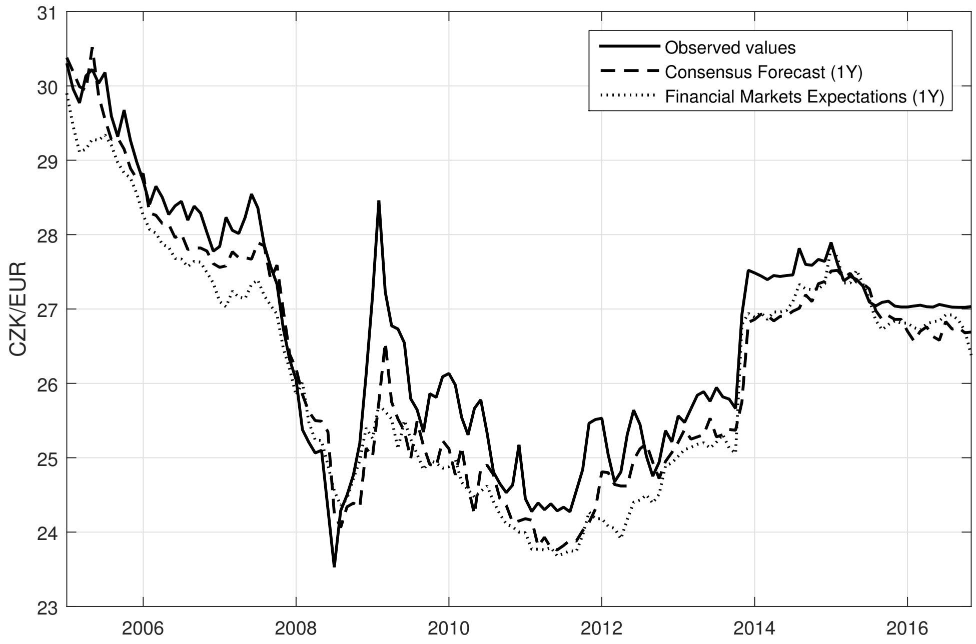
$$\Sigma_{\alpha,l} \sim IW\left(k_\alpha^2 * (1 + dim(\Sigma_{\alpha,l})) * V(\hat{A}_{l,OLS}), 1 + dim(\Sigma_{\alpha,l})\right), \tag{12}$$

where hyper-parameters k_α, k_β, k_h specify prior beliefs about the amount of time variation and τ is the number of observations used for estimation of the prior. Inverse-Wishart distribution of innovations is assumed. For large τ, the prior beliefs about innovations of the time-varying coefficients β become too tight, which might result in underestimated time variation of the β coefficients. If this issue arises, a higher value of k_β is an option for obtaining less restrictive priors. Innovations of simultaneous relations α are specified by blocked covariance matrices in equation (12), where $l \in \{1, 2, ..., k-1\}$ and k is the number of endogenous variables.

[9] We use Primiceri's (2005) MCMC algorithm.

[10] Since our series are rather volatile at the beginning of the sample, we opted for priors based on full-sample information instead of using the first observations as a training sample.

Figure 2: Comparison of the Observed Exchange Rate and Its Expected Value at the One-Year Horizon (CZK/EUR)



3.2 Structural Identification of Model

To identify the exchange rate shock, we use the recursive identification scheme with lower triangular Cholesky decomposition of matrix $A_t^{-1}\Sigma_t$. This structural identification is widely used in the context of time-varying parameter VAR models (Nakajima, 2011a), despite having been criticized from time to time (i.e., Kim 1999). However, most of this criticism is focused on its ability to accurately trace an interest rate shock via recursive identification. Since our main focus is on the effects of an exchange rate shock, many of the objections, i.e., whether the central bank reacts to changes in the exchange rate within a given month or not, do not apply.[11]

Furthermore, we checked whether the depreciation that followed the announcement of the exchange rate commitment in November 2013 was anticipated or not. The evidence from Consensus Forecasts and the expectations of financial market analysts are reported in Figure 2. Apparently, the depreciation was clearly unexpected even a month before the announcement of the commitment, hence we do not need to modify our identification scheme to account for potential endogeneity of the largest shock in our sample.

The sign restriction approach is often used as an alternative to recursive ordering and structural VAR. However when interest rates are constrained by the zero lower bound, this option is not available anymore. At the zero lower bound, even constant interest rates might imply monetary restriction.

[11] Since the monetary VAR is commonly estimated on quarterly data, it is sometimes argued that recursive identification is not appropriate in the case of a small open economy. In such economies, it is reasonable to expect that the central bank will adjust the nominal rate to a large movement of the exchange rate in the same quarter (Kim, 1999; Kim and Roubini, 2000; Christiano et al., 1998). However, if monthly data are used, recursive identification seems to be sufficient. Members of the central bank board meet less than once per month, and they usually need time to evaluate the possible outcomes of changes in the exchange rate and to decide whether to adjust the interest rate or not. Therefore, restricting the contemporaneous correlation between the interest rate and the exchange rate to zero as a consequence of the recursive identification can be considered plausible.

Hence, the monetary policy shock can no longer be identified as a decrease in the GDP and price levels, an increase in the interest rate, and appreciation of the exchange rate.[12]

3.3 Estimation Strategy

The number of lags is chosen with regard to the frequency of the data and the necessity to construct the smallest possible model. Although TVP-VAR-SV is usually estimated with only two lags of endogenous variables as the lowest acceptable number to capture the dynamics of the multivariate system (Nakajima, 2011b), we decided to include four lags, which ensures that the model contains sufficient information about interpolated GDP. Our choice of the number of lags is supported by the information criteria for linear VAR, which suggest including at least three lags.

Priors are elicited from linear VAR, which is estimated on the whole sample instead of using a training sample. Although this approach is typically used when the number of observations is low (Canova, 2003), we chose this option for different reasons. Firstly, we do not want to rely on the training sample, which includes observations preceding January 1998, because the monetary policy transmission mechanism worked quite differently before the adoption of inflation targeting, so the priors obtained could be misleading for our model. Secondly, if the first two years of our sample were used as a training sample, linear VAR would not be able to provide reasonable coefficient estimates, because at that time the interest rate was high and quickly decreasing.

A large training sample also implies excessively tight priors regarding the time variation of the β coefficients (see equation 10). To obtain the desired time variation in the estimations, we set the hyperparameter more loosely than is typical (Primiceri, 2005; Franta et al., 2014b). The model is estimated for three different values of hyperparameter $k_\beta = \{0.1, 0.2, 0.3\}$, where $k_\beta = 0.2$ serves as the baseline specification and the other two values are used to assess robustness. We set k_α and κ_h equal to 0.05. The estimates are robust with respect to different values of k_α and κ_h.

The estimation process for each model specification consists of 20,000 iterations of the Gibbs sampler, of which the first 10,000 iterations were discarded. Additionally, to minimize autocorrelation of draws, only each fifth iteration is retained. The reported results are thus based on the 2,000 remaining iterations.

To identify the exchange rate pass-through, orthogonalized cumulative impulse responses are computed. In line with the existing literature (Babecká-Kucharčuková, 2009; Babecká-Kucharčuková et al., 2013; Hájek and Horváth, 2016), the time horizon for assessing the long-term pass-through is set to two years. The exchange rate shock is defined as a one percentage point depreciation.

[12] Moreover Franta et al. (2014b) identify the exchange rate shock as a decrease in output and the price level, and the interest rate decreases as well. With the interest rate at the zero lower bound, however, the sign restriction would become indistinguishable from the monetary policy shock. The alternative would be to use another proxy for monetary policy, i.e., the money supply as in Franta (2011), but this option does not make much sense for the Czech National Bank, for which the interest rate is its primary instrument of monetary policy. Note that Franta (2011) uses identification of the monetary shock via a restriction imposed on the response of the money supply when investigating the effects of monetary policy in Japan. Finally, the main motivation for identification via sign restrictions in Franta (2011) stems from the criticism of recursive identification when quarterly data are used. By using monthly data, we believe we alleviate much of this criticism.

4. Data

4.1 Dataset

Our dataset encompasses the period between January 1998 and November 2016. The initial observation coincides with the official announcement of the policy of inflation targeting, so the monetary policy regime is consistent across the sample. Our baseline specification contains real GDP, the CPI as an indicator of the price level,[13] and the three-month interbank rate (3M PRIBOR) to represent the interest rate. The exchange rate is represented by the nominal effective exchange rate, because it reflects the changes in the exchange rates with all the main trade partners weighted by their shares in foreign trade.

We consider three alternative exchange rate specifications. The bilateral CZK/EUR rate is chosen because the euro area is the destination for more than two-thirds of Czech exports (Lízal, 2014). The CZK/USD rate identifies the importance of non-euro trade partners and furthermore takes into account the re-exportation of Czech intermediates to non-euro area countries. According to Baldwin and Lopez-Gonzalez (2013), 60 % of Czech exports involve intermediates, so depreciation of the CZK/USD rate, which closely follows the EUR/USD rate, might also stimulate external demand for Czech production. Lastly, the real effective exchange rate is used as well.

We briefly experimented with the inclusion of other exogenous variables, especially oil prices and the HICP of the euro area, which were used by Babecká-Kucharčuková (2009) and Hájek and Horváth (2016). Furthermore, we also used the producer price index, the output growth of the effective euro area,[14] and the 3M EURIBOR, because the Czech National Bank considered the unexpected development of these variables to be the main foreign deflationary shock (CNB, 2017b).

Real GDP is interpolated from quarterly to monthly frequency by the cubic spline with not-a-knot end conditions for the first and last observations (de Boor, 1978). The NEER and the REER are multiplied by minus one to ensure the same interpretation of a positive exchange rate shock as depreciation of the Czech koruna. The GDP and CPI are seasonally adjusted. Except for the interest rate, all variables are transformed to monthly growth rates, so the model is estimated in stationary form. Following McCarthy (1999), the cumulative impulse responses of all the variables are presented in levels rather than in first differences.

4.2 Nonlinearity Test

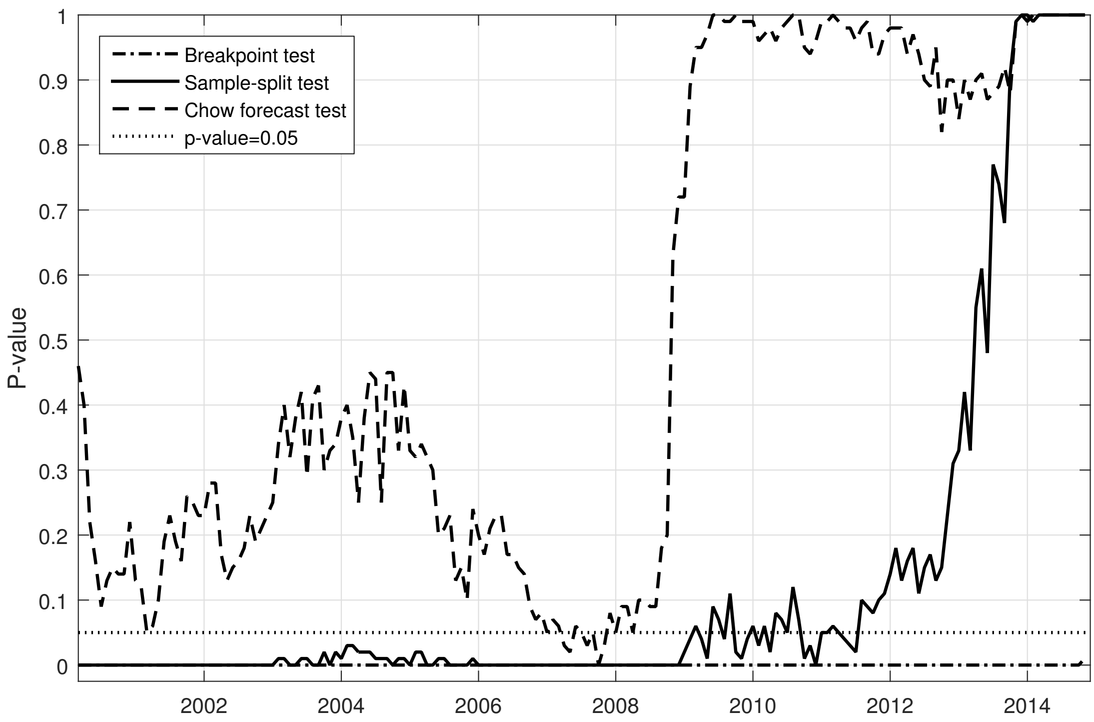
To confirm the appropriateness of the time-varying approach, a set of multivariate Chow tests is run to identify potential structural breaks in the coefficients (Candelon and Lütkepohl, 2001). We estimate the breakpoint test, the sample-split test, and the Chow forecast test from the residuals of the linear VAR.[15] The null hypothesis of the tests is that the system is stable, while the alternative assumes time variation in the coefficients. The breakpoint, sample-split, and Chow forecast statistics impose different assumptions regarding the residual covariance matrix. Under the alternative hypothesis of the Chow forecast test, all the coefficients, including the residual covariance matrix, may vary. The alternative hypotheses of the sample split and breakpoint tests allow only for time variation of the VAR coefficients. Each observation between January 2000 and December 2014 is

[13] The PPI is used as a sensitivity check.

[14] According to CNB (2018), the weights used in the calculation are equal to the shares of the individual euro area countries in the total exports of the Czech Republic to the euro area.

[15] The estimation strategy for the linear VAR is the same as in the case of the time-varying approach, and four lags are included.

Figure 3: Results of Chow Multivariate Tests (Bootstrapped p-values)



considered for the possibility of a structural break in the coefficients. Bootstrapped p-values are used because the distributions of the test statistics under the null hypothesis may be different from the asymptotic χ^2 or F-distributions when the number of observations is small relative to the number of parameters in the model (Candelon and Lütkepohl, 2001).[16]

The results strongly support the hypothesis of a structural break in the data. Hence, the VAR coefficients are not constant over time (the p-values of the tests are depicted in Figure 3). Furthermore, the multivariate ARCH-LM test identifies heteroskedasticity in the residuals of the linear VAR. Hence, our methodology relying on time-varying VAR with stochastic volatility appears to be appropriate.

5. Results

5.1 Time-Varying Exchange Pass-Through

The virtue of the time-varying parameter VAR model is its ability to provide impulse response functions for each observation of the sample, so changes in the exchange rate pass-through can be easily retrieved. The estimated responses to a unit depreciation of the NEER are presented in Figure 4, while Figure 5 shows the median time-varying exchange rate pass-through for different horizons. The time-varying pass-through obtained is rather fast: more than half of the pass-through to output and consumer prices is realized during the first six months after a unit depreciation. Furthermore, the pass-through to output is almost finished after one year. The responses of the interest rate to the exchange rate shocks appear to be more persistent. The posterior means of the standard deviation of the structural shocks can be found in the Appendix (Figure A1). Interestingly, the volatility

[16] One hundred bootstrapped replications are computed for each test. We provide results only for the model with the NEER. Alternative specifications of the exchange rate lead to the same conclusion.

Table 1: Impact of Exchange Rate Commitment (Two-Year Horizon)

Exchange rate	Output 1% shock	Output 7% shock	Price level 1% shock	Price level 7% shock
NEER	0.094	0.660	0.047	0.331
CZK/EUR	0.214	1.497	0.023	0.160
CZK/USD	0.064	0.446	0.019	0.134

of the nominal effective exchange rate structural shocks during the exchange rate commitment is comparable with the mid-2000s.

Furthermore, the exchange rate pass-through to the price level is incomplete (a 1% depreciation leads to a less-than-proportional increase in the price level) and, perhaps more importantly, is steadily decreasing until 2010/2011. Prices did not respond by more than 0.11 % to a unit depreciation at the beginning of the sample. The pass-through to the price level then started to decline. Its value stabilized around 0.05 in 2011, and it did not increase when the zero lower bound became binding. Our results correspond to Jašová et al. (2016), who find lower pass-through in emerging economies after the Great Recession. Similarly, Özyurt (2016) observes a sharp drop in the ability of a depreciation to stimulate inflation in the euro area in 2012. Furthermore, these results are consistent with linear VARs, both with and without exogenous variables.

The impact of the exchange rate fluctuations on output is markedly higher. Our estimates suggest the pass-through decreased almost to zero around the year 2002, which coincides with a sharp appreciation of the Czech koruna against the euro. The exchange rate pass-through then steadily increased, reaching the interval of 0.08–0.10 in 2008, where it remained until the end of the sample.

Concerning the effects of exchange rate depreciation on the interest rate, its impulse response fell effectively to zero after 2011, when interest rates came close to the zero lower bound. Hence, the model captures the stylized facts here quite well.

Next, Figure 6 provides a comparison of the long-term exchange rate pass-through after 24 months for the alternative specifications of the exchange rate. Besides the NEER, results are reported for the bilateral exchange rates against the euro and the U.S. dollar. Regarding the exchange rate pass-through to output, the results are generally robust, although in the case of the CZK/EUR rate the quantitative effect is twice as large compared with the NEER. The estimated pass-throughs to the price level are more heterogeneous than the pass-through to output, but as with the NEER, the bilateral exchange rates do not suggest any increase in the period characterized by the zero lower bound; rather the opposite. Broadly, the results with bilateral exchange rates confirm our results with the nominal effective exchange rate.

It should be noted that the credible intervals of our time-varying VAR model are rather wide. With 68% credible intervals, only the change in the responses of the nominal interest rate to the exchange rate shocks is statistically significant, and the hypothesis of stable exchange rate pass-through to output or prices cannot be rejected. This, however, is a frequent feature of time-varying parameter models in general. The plots of the confidence intervals can be found in the Appendix.

Table 2: Impact of Exchange Rate Commitment after Two Years: Sensitivity Analysis

	Output		Price level	
	1% shock	7% shock	1% shock	7% shock
PPI & NEER	0.106	0.743	0.017	0.118
PPI & CZK/EUR	0.207	1.447	0.003	0.018
CPI & REER	0.096	0.673	0.048	0.333
ZLB (1998M01–2012M10)	0.101	0.704	0.060	0.422

Finally, our results have interesting implications for the assessment of the exchange rate commitment introduced in November 2013. In particular, the exchange rate pass-throughs to the CPI price level and real GDP implied by that time impulse responses are summarized in Table 1. The reported values are the median cumulative impulse response to a one and seven percent exchange rate shock with a time horizon of two years. The seven percent exchange rate shock corresponds to the depreciation of the koruna after the introduction of the exchange rate commitment. Since the commitment was defined in terms of the exchange rate against the euro, we primarily focus on the model with the CZK/EUR rate. We find that the seven percent depreciation increased the price level by only 0.16 % after two years. On the other hand, real GDP increased by an additional 1.497 %. These results suggest a relatively low power of the exchange rate commitment to increase the inflation rate back to the inflation target, and they are at odds with the time predictions. However, due to increasing awareness of the use of VAR impulse responses to evaluate the dynamic causal effects of macroeconomic shocks (Ramey, 2016; Stock and Watson, 2018), the implied estimates of the effects of the introduction of the exchange rate commitment should be taken with a grain of salt and in the context of other results in the literature. Such comparison is provided in subsection 5.3. It turns out that the low response of the price level to the exchange rate shock is quite in line with some of the recent evidence, especially that from the synthetic control method. Hence, we contribute mainly by providing a long-term perspective on changes in the exchange rate pass-through.

5.2 Sensitivity Analysis

Our results were subjected to a comprehensive sensitivity analysis to address their robustness and reliability. First, we tested the sensitivity of the results to prior beliefs about time variation in the exchange rate pass-through, then we checked whether the pass-through to the producer price index is stronger than that to headline consumer price inflation. We also replaced the nominal effective exchange rate with the real effective exchange rate, and we restricted our sample to end in 2012, before monetary policy started to be constrained by the zero lower bound. Lastly, we compared our results with VAR models with constant parameters, extended to include various exogenous variables representing potential foreign deflationary pressures.

First, we re-estimated the model with looser and tighter priors determining the amount of time variation of the coefficients (parameter k_β in equation 10). The pass-through two years after the initial unit depreciation of the NEER is depicted in Figure 7. Generally, the responses of the variables to the exchange rate shock remain qualitatively consistent with our baseline, although the quantitative predictions are slightly different. The tight prior suggests somewhat higher pass-through to prices and lower pass-through to output, and for the loose prior the effect is exactly the opposite. Also, the model with a looser prior indicates moderately higher exchange rate pass-through to output growth at the end of the sample, characterized by the zero lower bound. The tightness of prior beliefs also

Figure 4: Cumulative Median Impulse Responses to a Unit Depreciation (NEER)

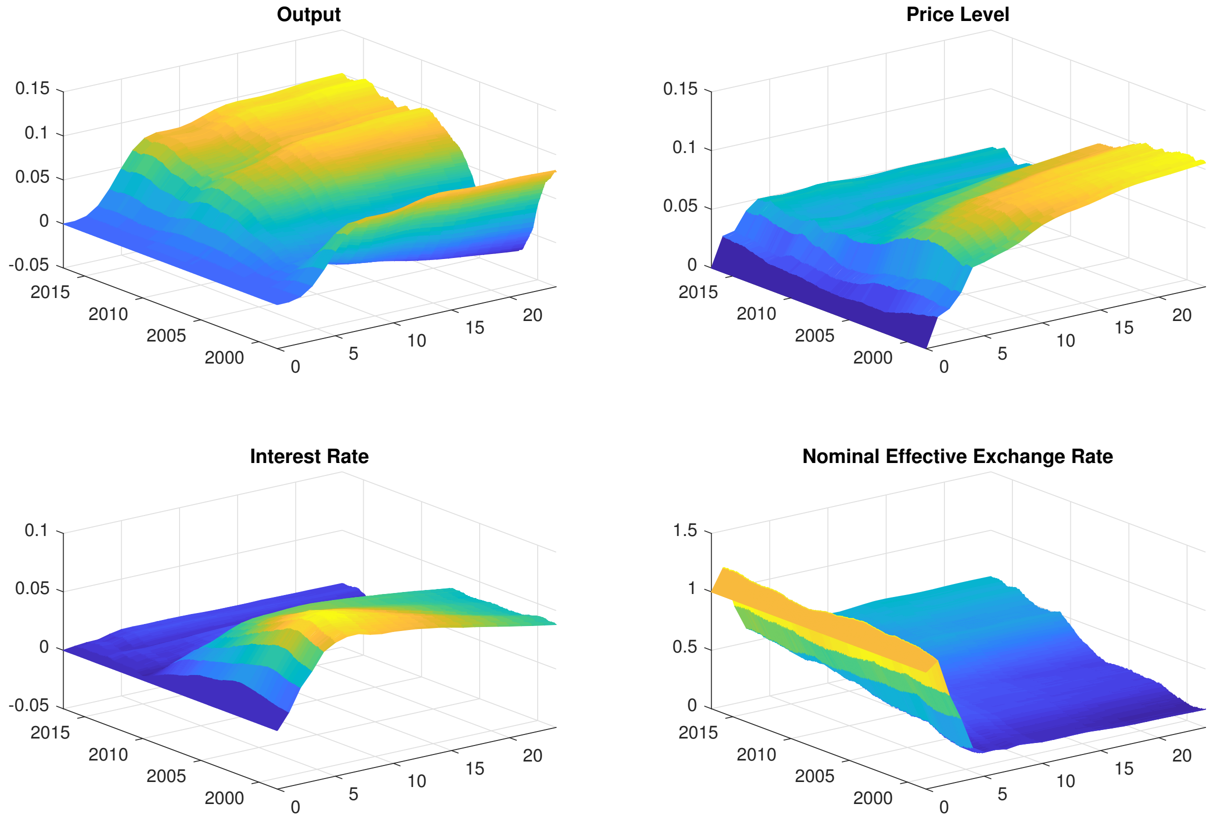


Figure 5: Time-Varying Exchange Rate Pass-Through (NEER)

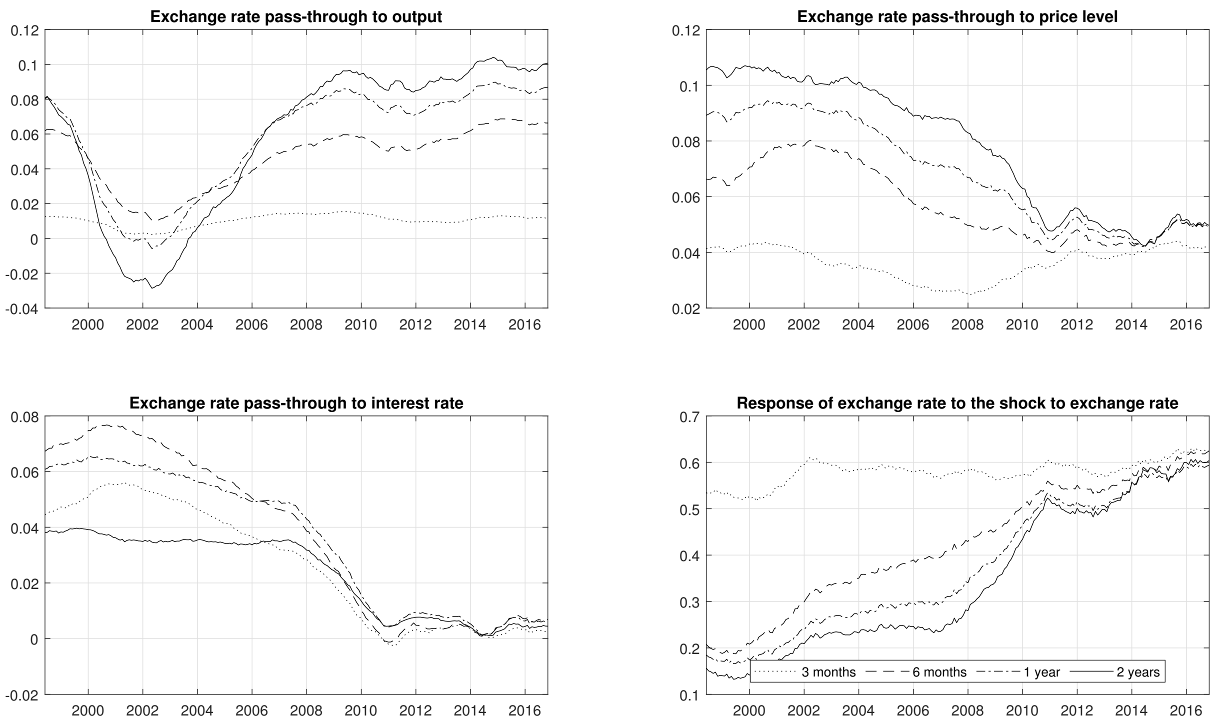


Figure 6: Time-Varying Pass-Through for Different Exchange Rate Specifications

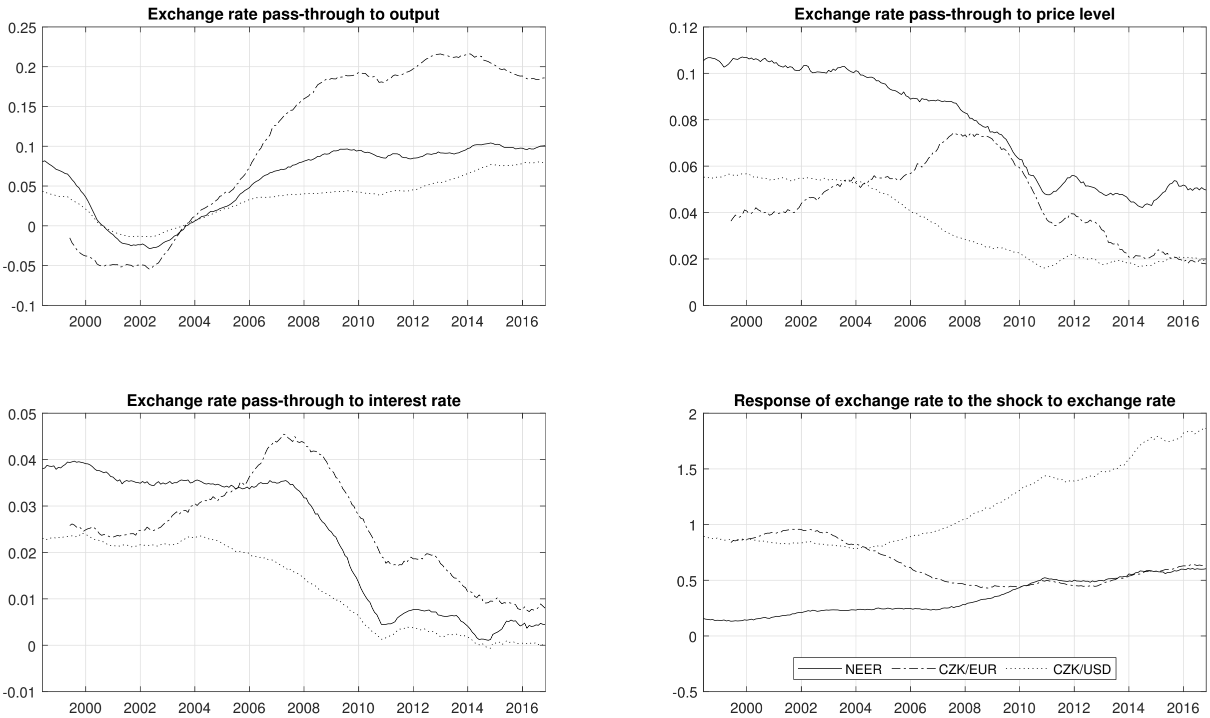


Figure 7: Time-Varying Exchange Rate Pass-Through: Sensitivity to Priors

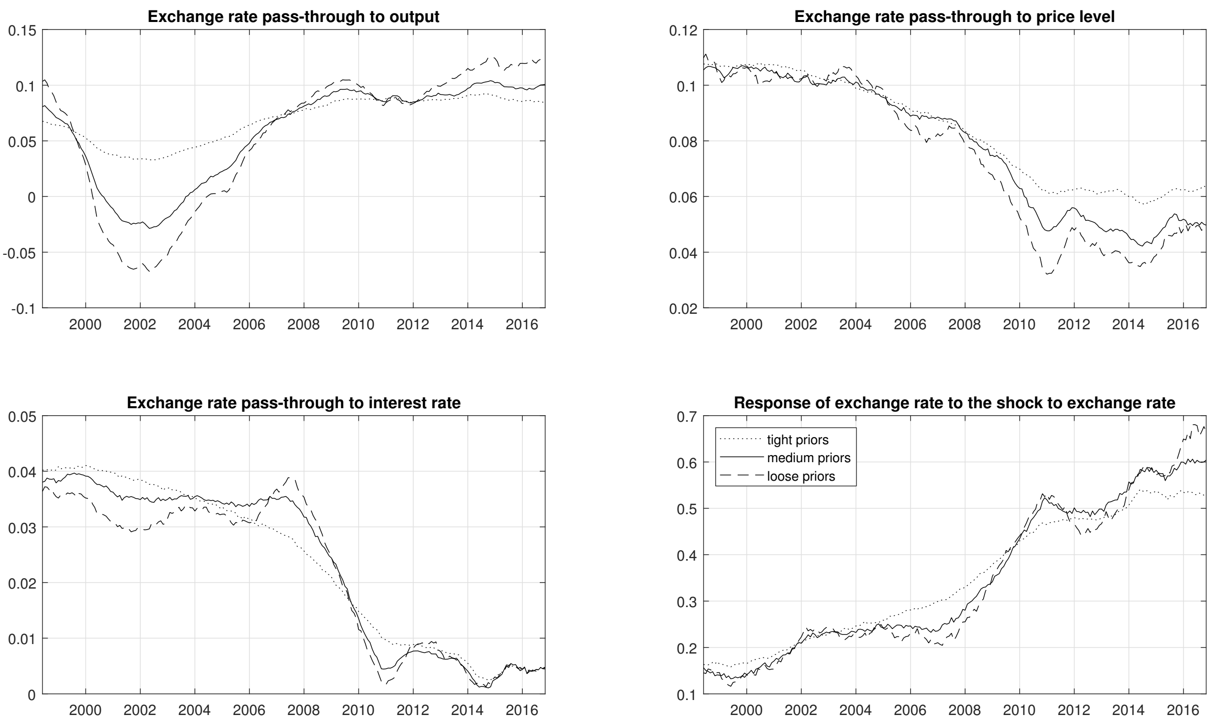
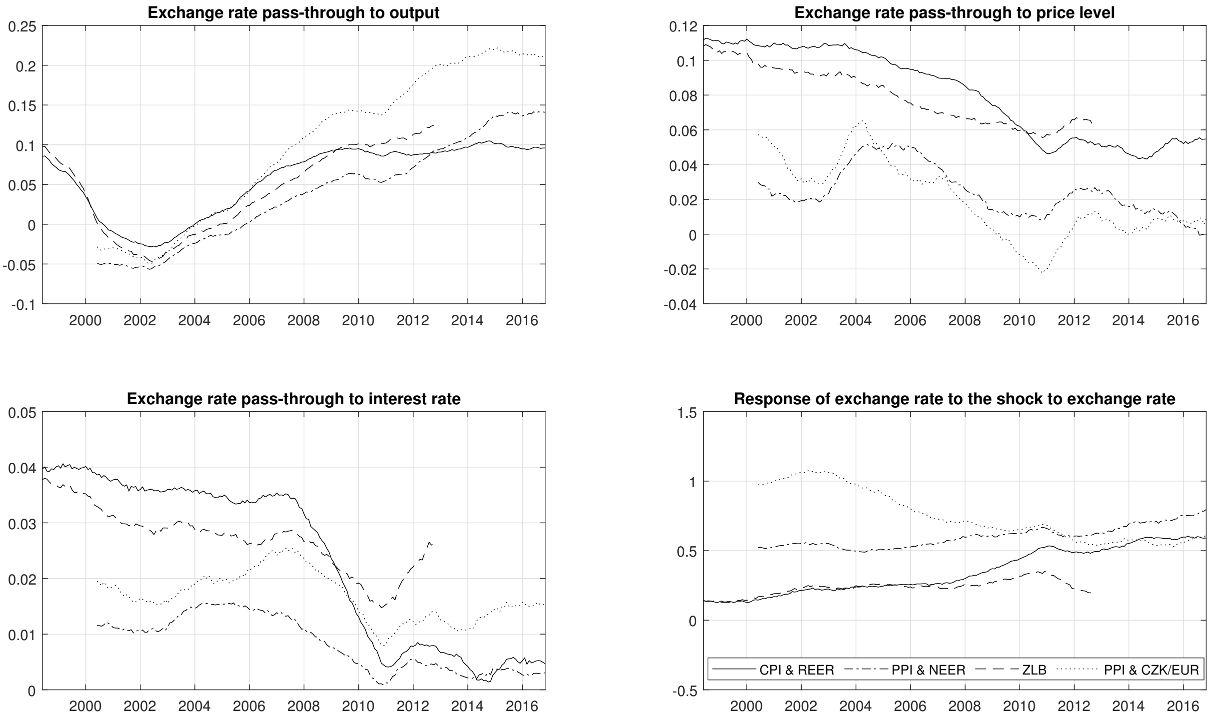


Figure 8: Time-Varying Exchange Rate Pass-Through: Sensitivity Analysis



influences the width of the credible intervals. The estimates become more uncertain when the prior time variation of the pass-through is assumed to be larger.

Second, we consider the response to the producer price index rather than to the consumer price index, assuming that the PPI could reflect tradables prices, which will be affected more by a depreciation. The results are presented in Figure 8 and in Table 2. Somewhat surprisingly, the overall exchange rate pass-through is even smaller than in the case of the CPI. This result implies that tradables might not be as sensitive to exchange rate movements as previously thought.[17] On the other hand, the response of output to the exchange rate shock is higher at the end of the sample when the PPI is used instead of the CPI.

Third, the *"foolproof way"* of escaping the liquidity trap by Svensson (2000) considers real, not nominal, depreciation to be the main driving force. Hence, we replaced the NEER with the REER in our model. Nevertheless, even in this case, our main results were largely intact.

We then restricted our sample to end in 2012, before the zero lower bound was reached and well before the exchange rate floor was introduced. The main reason was to investigate whether the results of the TVP-VAR model are biased by truncated fluctuations of the interest rate and of the exchange rate as well. Again, our results were broadly consistent with our baseline results presented in the previous section. The response of output growth was very similar, and the gradual decline in the exchange rate pass-through to the price level is both qualitatively and quantitatively comparable as well, even when the pre-ZLB and pre-commitment data are considered.

[17] In particular, our results contrast with the intuition of the supply chain mechanism as stressed by Babecká-Kucharčuková (2009), which assumes that the exchange rate pass-through is mainly evident in tradables. Still, our results are consistent with those presented in Figure 4 of her paper.

From the policy perspective, the results based on the data up to 2012 matter as well, as they represent the data that were available to the Czech National Bank before its decision to resort to the exchange rate commitment policy.[18] They imply that even in 2012 there was some indication that the response of the price level might be muted because of the gradual decrease in the exchange rate pass-through in the past. Thus, our results contrast with the views presented in the Bank's reports that inflation should have returned to the inflation target in 2015, at the end of the monetary policy horizon (Hampl, 2017, see, for instance,). Moreover, our results indicate that a coherent explanation for the repeated extensions of the commitment due to the still muted response of the price level not only has to account for the possible effect of one-off factors such as foreign disinflationary shocks, but also has to consider the gradual decline in the exchange rate pass-through before the commitment was introduced.

Finally, the results from the TVP-VAR are compared with linear VAR models estimated both on the full sample and on subsamples and extended to include variables representing the potential contribution of foreign shocks as well. In general, the results of the VAR models without exogenous variables are consistent with our baseline results from the time-varying parameter model and confirm the decrease in the exchange rate pass-through to the price level. Controlling for the impact of foreign variables, i.e., the PPI of the euro area, the GDP of the euro area, the EURIBOR, and oil prices, did not push the rather low exchange rate pass-through to the price level any higher. The results are reported in Tables A1–A3 in the Appendix.

5.3 Comparison with Other Literature

Alternative estimates of the exchange rate pass-through in the Czech Republic are provided in Babecká-Kucharčuková (2009) and in Hájek and Horváth (2016). Both estimate the pass-through with VAR models based on the supply chain hypothesis, but without time variation in coefficients and volatility. Their VAR models include output, the exchange rate, prices (disaggregated), and exogenous variables, among them the interest rate and prices in the euro area. According to Babecká-Kucharčuková (2009), the ERPT is between 0.25 and 0.30 in most specifications, but when the interest rate is included and this transmission is thus controlled for, the pass-through to the CPI falls to just 0.11. It should also be noted that Babecká-Kucharčuková (2009) finds lower and even negative pass-through when the latter part of her sample is used.

Hájek and Horváth (2016) replicate the study by Babecká-Kucharčuková (2009) with the data up to 2013 and arrive at an estimated exchange rate pass-through ranging from 0.11 to 0.27, with an average effect of depreciation on the price level equal to 0.18 after two years. Their results suggest that the 7% devaluation of the Czech koruna should have increased the price level by 1.4 %. Furthermore, their estimate is close to the predictions presented by the Czech National Bank in its Inflation Report 1/2014, where the long-term effect is estimated at 1.6 % as well (see Skořepa et al. 2016).[19] However, the most up-to-date replication of the methodology by Babecká-Kucharčuková (2009) appears in CNB (2017b). There, on the sample from 2000 to 2017, the estimated exchange rate pass-through to the price level falls below 0.1 and becomes more comparable with our estimates than the previous calculation. These results also support our result of diminishing pass-through to prices.

[18] We are aware that we do not use real-time data. Although the effects of the revisions may be significant in some periods, the time series for the CPI price level and real GDP are not affected as much as the output gap is.

[19] Note that this comparison abstracts from the difference between the exchange rate shock in the VAR model by Hájek and Horváth (2016) and the permanent 5% depreciation assumed in the CNB Inflation Report.

Higher exchange rate pass-through than ours appears in Franta et al. (2014b), who estimate the TVP-VAR with identification via sign restrictions on a sample up to 2010 (precise estimates of the pass-throughs are not provided in the paper). Furthermore, the authors suggest that the response of output increased over time, while the pass-through to prices remained rather stable. Nevertheless, it needs to be said their sample ends well before interest rates hit the zero lower bound, so in that respect their results do not contradict ours either.

On the other hand, the recent evidence based on the synthetic control method usually supports a limited impact on CPI inflation. Opatrný (2017) finds an insignificant but positive effect of the CNB's commitment on the price level (CPI) and a slightly positive and statistically significant impact on output. Brůha and Tonner (2017) show that a statistically significant effect can be proved only for core inflation (at 5 %) and for output growth (at 10 %). The possibility of a smaller pass-through than was initially expected is also admitted in Tomšík (2016).

To conclude, our results are closer to the recent contributions suggesting rather limited exchange rate pass-through to headline CPI inflation but, at the same time, somewhat higher effects on output. Furthermore, our results imply that these effects were not specific to the one-off event of the exchange rate floor, since they reflect long-term changes and shifts in the Czech economy. In the next section, we provide three alternative explanations of these trends and discuss possible implications for monetary policy.

6. Why Has the Exchange Rate Pass-Through Decreased?

After the adoption of the exchange rate floor, the Czech National Bank became increasingly concerned by the persistently low inflation and its staff tried to provide an explanation for why inflation was not evolving as expected. A summary of these considerations can be found in Skořepa et al. (2016). At least implicitly, it has been suggested that inflation did not return to the target due to external developments that could have been neither predicted nor affected by the central bank. More precisely, Skořepa et al. (2016) argue that the lower-than-expected pass-through was caused by initial overvaluation of the Czech koruna, by the asymmetric impacts of oil shocks on the price levels in the Czech Republic and the euro area,[20] by the negative cyclical position of the economy, and by an initially small effect on expectations. However, our results presented in the previous section suggest the exchange rate pass-through to prices was low and perhaps declining well before the exchange rate commitment was introduced. This implies that the reasons for the low exchange rate pass-through need to be sought in longer-term processes affecting the exchange rate pass-through.

Based on the existing literature, we identify the following hypotheses of why the exchange rate pass-through to prices could have decreased. First, the inflation dynamics in a low inflation environment might differ by comparison with periods with high inflation rates. Second, changes in the structure of foreign trade affected pricing and contracting, and prices became less sensitive to exchange rates. Lastly, we discuss whether the exchange rate commitment could have stimulated domestic inflation more if some additional unconventional tools had been adopted.

6.1 Inflation Dynamics in a Low Inflation Environment

The literature provides increasing evidence that in a low inflation environment, the dynamics of inflation become somewhat different. In line with the menu cost theory of price setting, low inflation

[20] Note that the impact of decreasing oil prices was quantified at about -0.5 %. Even without this effect, the inflation rate would have been below the target (Hampl, 2017).

itself changes the behavior of firms, because the frequency of price adjustments decreases (Jašová et al., 2016). Furthermore, Ozkan and Erden (2015) show that credible inflation targeting reduces the exchange rate pass-through even more.

In addition, the different response of output and the price level to depreciations makes perfect sense if we accept the view that the Phillips curve has flattened, at least in the last decade. The international evidence of the lower importance of economic activity for inflation dynamics is already extensive – see, for example, Simon et al. (2013) – and the implications for monetary policy have already been described by Gilitzer and Simon (2015) and others. First and foremost, this flattening implies that both economic activity and inflation could evolve independently of each other, at least to some extent. Consequently, the robust economic growth caused by real depreciation might not be enough to increase inflation if there are other reasons for low inflation expectations.

The evidence for the Czech Republic supports a lower slope of the Phillips curve as well. Using an estimated New Keynesian Phillips curve with time-varying parameters and stochastic volatility, Baxa et al. (2015) document a relatively weak and barely significant link between inflation and the output gap. Interestingly, the contribution of foreign prices, approximated by changes in the terms of trade, was rather low. The main result of their analysis is that over time, Czech inflation became a more and more forward-looking phenomenon, thus pointing to a prominent role of inflation expectations for inflation itself.

On the other hand, Baxa et al. (2013) with a slightly longer sample report a moderately increasing predictive ability of the output gap for inflation at very short horizons, and perhaps a somewhat increasing coefficient on the output gap in the Phillips curve equation after the Great Recession, as acknowledged in Franta et al. 2014a. However, the R^2 of their dynamic model averaging model with several other variables representing economic activity and foreign factors (oil prices and the nominal effective exchange rate) did not exceed 0.3. Note also that the primary focus of their model was to find the drivers of the inflation gap, and more secular trends in inflation remained untouched.

Hence, the hypothesis of a flattened Phillips curve might be a natural candidate for explaining why the very low inflation rates persisted despite the exchange rate commitment. It shows that in a low inflation environment, central banks cannot rely on the link between output and inflation when trying to escape deflation and bring inflation back to the target.

6.2 Changes in the Structure of Foreign Trade

The second class of explanations attributes the low exchange rate pass-through to prices to rising integration of the Czech economy in global value chains and other changes in the composition of foreign trade that have taken place in the last decade. Although empirical evidence on the contributions of these changes to inflation dynamics in the Czech Republic is still missing, the support for this hypothesis originates in the international evidence on, and theoretical models of, international trade.

The role of factors such as import penetration, substitutability between foreign and domestic goods, the competitive structure of industry, and barriers to trade in the strength of exchange rate pass-through are stressed by Osbat and Wagner (2006).

The ongoing modernization and convergence of the Czech economy toward the core of the EU could have reduced the exchange rate pass-through as well. The international evidence suggests almost complete pass-through in commodities and highly sophisticated export products with relatively low price elasticities, but very limited pass-through in manufacturing (Pula and Santabárbara, 2011). In that case, local currency pricing dominates and exporting firms adapt their mark-ups depending on the destination market to offset at least partially the exchange rate movements, thus reducing the exchange rate pass-through to prices (Devereux et al., 2015; Özyurt, 2016).

Furthermore, Auer et al. (2017a) and Auer et al. (2017b) focus on the implications of rising participation in global value chains for monetary policy. They show that this integration leads to higher international propagation and spillovers of shocks. Moreover, the rising integration implies that central banks need to consider the fact that domestic inflation is increasingly affected by inflation and the output gap in other countries, hence monetary policy has limited power to affect domestic inflation. Similar findings are provided by Georgiadis et al. (2017), who show that the exchange rate pass-through is declining with rising global value chain participation using a two-country DSGE model and empirical data from the OECD countries.

For the Czech Republic, the implications of rising global value chain participation for monetary policy may be more striking than in other countries. The global value chain participation index based on the share of intermediates in exports and imports presented in Karadeloglou et al. (2015) supports these concerns: the value of the index for the Czech Republic rose from 0.40 to 0.57 between 1995 and 2011. Also, according to Auer et al. (2017b), the contribution of foreign inflation to domestic producer price inflation in the Czech Republic is the third highest, and a 1% increase in foreign inflation translates to a 0.33% increase in domestic PPI. On the other hand, recent research, i.e., Bäurle et al. (2017) for Switzerland and Kapuściński (2017) for Poland, shows that the role of domestic policy and domestic factors should not be underestimated. Hence, precise quantification is still needed to assess the relative contribution of changes in foreign trade in comparison with other, notably domestic, policy factors.

6.3 Would Another Policy Have Made a Difference?

The Czech National Bank considered applying the exchange rate commitment policy as an instrument within its inflation targeting regime when the conventional instrument, the short-term interest rate, was constrained by the zero lower bound and the inflation rate was predicted to remain below the inflation target. In a tradition of inflation targeting where the primary goal, the inflation rate, is affected mainly by one instrument, the interest rate, the central bank decided to use the exchange rate commitment as an additional instrument of its monetary policy.

By doing so, the Czech National Bank (Franta et al., 2014a) deliberately kept its distance from the *"foolproof way"* proposed by Svensson (2000), who recommended enhancing the possible effects of the exchange rate floor by temporarily switching to price-level targeting. According to Svensson (2000), price-level targeting should increase inflation expectations and lower real interest rates directly, without the need to rely solely on the link between inflation and economic activity. Hence, in the era of a flat Phillips curve and an increasingly forward-looking nature of inflation, price-level targeting offered a way of bringing inflation back to the target. Once inflation had re-appeared and the price-level target had been achieved, the central bank could abandon the peg and return to the conventional inflation targeting regime.[21]

[21] The CNB's public commitment was made solely in terms of the nominal exchange rate as a monetary policy instrument, not in terms of the future price level. In this regard, the CNB's approach differed significantly from Svensson's (2000) recommendations, even though "the latter were a significant source of inspiration from the economic literature." See Franta et al. (2014a, p. 35).

Since the low exchange rate pass-through to the price level prevailed even after the adoption of the exchange rate commitment, we argue that a commitment not paired with price-level targeting was unable to return inflation to its target. Our hypothesis is somewhat supported by the evolution of implicit inflation expectations in the Czech Republic in 2014 and 2015. Contrary to the original expectations, implicit inflation expectations decreased below 0.5 % in 2014 and remained below 1 % until mid-2016.[22] Seemingly, without an additional anchor in the form of a price level target, inflation expectations may have been influenced by disinflation in the euro area.

Why did the Czech National Bank decide not to switch to price-level targeting along with its exchange rate commitment? Franta et al. (2014) point out that the chosen nominal exchange rate may have been consistent with a different domestic price level than expected, especially with foreign disinflationary shocks. Hence, the Czech National Bank was afraid of facing a dilemma of whether to adhere to its price-level target or the nominal exchange rate target, "a situation that would be highly undesirable from the perspective of monetary policy credibility." See Franta et al. (2014a, p. 41).

It should be noted that Svensson's *"foolproof way"* proposes to adhere to both targets as long as the price level is not being fulfilled. Hence, the dilemma of two independent targets does not arise, but there is a risk of inflation being above the previous inflation target for an extended period. While a temporary increase in the inflation rate was acceptable to the Czech National Bank, a longer period could have been perceived as risky to its credibility.[23]

Another option available to the Czech National Bank involved negative interest rates and a devaluation of the Czech koruna of more than 7 %. Although recent research contributions suggest that interest rates of slightly below zero might not necessarily induce a switch to cash (see the evidence provided by Kolcunová and Havránek, 2018), the power of slightly negative interest rates to affect inflation remains unclear. On top of that, there were legal obstacles to adopting negative interest rates, as that time penalty interest was often defined as a multiple of the Czech discount rate. Regarding the possibility of devaluing the Czech koruna by even more than 7 %, our results suggest inflation could have been rising faster, but the same holds for output growth and perhaps for other variables, including housing prices, as well. Given the already high growth of housing prices fueled by the low interest rates and capital inflows, both instruments could have had a detrimental effect on the financial stability of the Czech economy. Nevertheless, a proper evaluation of the costs and benefits of these alternative options is beyond the aim and scope of our paper and left for future research.

All in all, price-level targeting could have been an important addition to the exchange rate commitment in the Czech Republic. It could have affected inflation expectations directly. In doing so, it could have broken the vicious circle of low inflation expectations translating to low inflation itself, especially amid low inflationary pressures from abroad due to the weak recovery in the euro area.

[22] Implicit inflation expectations are derived from financial markets' expectations about future GDP growth and wage growth. For the Czech Republic, they are available in CNB (2017c).

[23] Franta et al. (2014a, p. 35) illustrate that the Czech National Bank expected inflation to be above its 2% target for several quarters in 2015, so they believe that its policy "contained an element of temporary price-level targeting," although not communicated explicitly.

7. Conclusion

This paper has provided insight into the exchange rate pass-through to the price level and output in the Czech Republic, and its time variation. The size of the exchange rate pass-through is highly relevant for monetary policy, particularly when the exchange rate is used as an additional instrument of monetary policy. This has been the case of the Czech National Bank, which introduced a one-sided exchange rate floor in November 2013 that led to an immediate depreciation of the Czech koruna by 7 %. At that time, the goal was to use the exchange rate as an additional instrument to weaken the monetary policy stance when nominal interest rates were constrained by the zero lower bound while the inflation rate was far below the target of 2 %. However, contrary to that time predictions, the rise in inflation did not materialize until late 2016, about one year later than initially expected.

To estimate the time variation in the exchange rate pass-through, we used the time-varying parameter vector autoregression with stochastic volatility. This framework allowed us to estimate the size of the pass-through to the price level and output for each point in time. Thus, we obtained more precise information than from time-invariant models estimated on sub-samples. The nonlinear framework was justified by the multivariate Chow test as well.

First and foremost, we have shown that the exchange rate pass-through to the price level was gradually decreasing well before the exchange rate commitment was introduced.[24] Hence, the limited effect of the exchange rate floor on inflation should be attributed to long-term changes in the Czech economy rather than to the temporary impact of exogenous shocks after the floor was introduced. This result is robust across various sensitivity checks, including alternative exchange rates, different price indices, and when the sample is limited until 2012. On the other hand, the exchange rate pass-through to output increased over time, with some possibility for highest pass-through at the end of a sample characterized by the zero lower bound and the exchange rate floor. Moreover, it is shown that models accounting for time variation can yield important policy insights that models with constant parameters cannot deliver.

Our results have several policy implications. The Czech National Bank considered the return of inflation to the inflation target to be its main goal. It achieved this much later than it had expected and communicated to the public, putting its credibility of being able to bring inflation back to the target into question. Although the contribution of external shocks may have been significant, our results imply that the causes of the low exchange rate pass-through to inflation are of a long-term nature as well. We argue that the discrepancy between the impacts of the exchange rate floor on output and inflation can be easily explained by a flattened Phillips curve, implying that the dynamics of output growth and inflation became increasingly independent of each other. Other reasons, as suggested by the literature, include rising internationalization of production and participation in global value chains. However, the precise contributions of those factors still need to be investigated.

Overall, our results imply that at times of low inflation, a liquidity trap, and possibly a flat Phillips curve, depreciation and an exchange rate floor might jump-start economic growth alone, but might not be sufficient to increase inflation simultaneously. In retrospect, it is also necessary to appraise Lars Svensson's *"foolproof way"*, in which he recommended accompanying the exchange rate floor with price-level targeting as a way of addressing inflation expectations directly and not relying

[24] Only changes of the median estimates have been interpreted. With the 68% credible intervals, we cannot reject the null hypothesis of stable exchange rate pass-through to price level and GDP. Only the change in the responses of the nominal interest rate to the exchange rate shocks is statistically significant.

solely on the indirect effects of depreciation on inflation via stronger output growth. Although it is not clear whether price-level targeting would have changed the outcome of the exchange rate commitment in the Czech Republic, consideration of these alternative policy options is increasingly important, as we cannot rule out a return to the zero lower bound and related policy dilemmas in the future. In such an event, estimates of the potential impacts of other policy choices might be more than useful.

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Appendix

Table A1: Exchange Rate Pass-Through (Linear VAR with Exogenous Variables; Full Sample)

Exogenous variables	Real GDP			CPI		
	Average	Credible intervals		Average	Credible intervals	
no exo var	0.077	-0.029	0.172	0.076	-0.016	0.171
oil (1–4)	0.081	-0.023	0.167	0.081	-0.015	0.168
oil (0–4)	0.079	-0.024	0.153	0.080	-0.017	0.165
hicp (1–4)	0.089	-0.022	0.181	0.067	-0.021	0.148
hicp (0–4)	0.081	-0.028	0.165	0.059	-0.022	0.131
hicp, oil (1–4)	0.104	-0.003	0.189	0.069	-0.021	0.149
hicp, oil (0–4)	0.109	-0.006	0.174	0.055	-0.025	0.125

Note: Linear VAR models include real GDP, CPI, the 3M PRIBOR, and the NEER, all in log differences (except the interest rate). hicp = Harmonised Index of Consumer Prices, oil = oil prices (monthly average, Brent). The range of the lags for exogenous variables is reported in brackets. Four lags are used for endogenous variables. 68% credible intervals are reported (100 bootstrap replications).

Table A2: Exchange Rate Pass-Through (Linear VAR with Exogenous Variables; Subsamples)

Time range	Exogenous variables	Real GDP Average	Real GDP Credible intervals		CPI Average	CPI Credible intervals	
1998M01 – 2007M09	no exo var	0.048	-0.061	0.110	0.140	-0.063	0.279
	oil (1–4)	0.008	-0.087	0.083	0.135	-0.065	0.286
	oil (0–4)	0.008	-0.085	0.084	0.137	-0.063	0.279
	hicp (1–4)	0.031	-0.077	0.097	0.138	-0.055	0.282
	hicp (0–4)	0.027	-0.076	0.095	0.143	-0.048	0.274
	hicp, oil (1–4)	0.010	-0.084	0.077	0.143	-0.055	0.294
	hicp, oil (0–4)	0.014	-0.076	0.080	0.148	-0.047	0.272
2007M10 – 2016M11	no exo var	-0.004	-0.142	0.173	0.028	-0.110	0.150
	oil (1–4)	-0.012	-0.146	0.140	0.040	-0.095	0.167
	oil (0–4)	-0.005	-0.135	0.134	0.047	-0.087	0.163
	hicp (1–4)	-0.020	-0.157	0.127	0.030	-0.108	0.151
	hicp (0–4)	-0.032	-0.162	0.116	0.019	-0.102	0.131
	hicp, oil (1–4)	0.027	-0.120	0.172	0.027	-0.111	0.145
	hicp, oil (0–4)	0.029	-0.108	0.154	0.016	-0.107	0.133
1998M01 – 2012M10	no exo var	0.104	-0.048	0.189	0.080	-0.048	0.170
	oil (1–4)	0.105	-0.047	0.195	0.090	-0.047	0.196
	oil (0–4)	0.101	-0.026	0.190	0.089	-0.047	0.191
	hicp (1–4)	0.106	-0.056	0.191	0.081	-0.047	0.181
	hicp (0–4)	0.100	-0.054	0.188	0.075	-0.042	0.165
	hicp, oil (1–4)	0.117	-0.034	0.200	0.086	-0.049	0.186
	hicp, oil (0–4)	0.128	-0.010	0.210	0.073	-0.045	0.168
2012M11 – 2016M11	no exo var	0.076	-0.213	0.330	0.000	-0.342	0.366
	oil (1–4)	0.100	-0.193	0.341	-0.003	-0.379	0.375
	oil (0–4)	0.107	-0.196	0.352	0.010	-0.383	0.375
	hicp (1–4)	0.128	-0.173	0.401	-0.025	-0.369	0.318
	hicp (0–4)	0.136	-0.193	0.434	-0.020	-0.368	0.310
	hicp, oil (1–4)	0.112	-0.202	0.357	-0.027	-0.411	0.353
	hicp, oil (0–4)	0.107	-0.254	0.364	-0.020	-0.433	0.363

Note: Linear VAR models include real GDP, CPI, the 3M PRIBOR, and the NEER, all in log differences (except the interest rate). hicp = Harmonised Index of Consumer Prices, oil = oil prices (monthly average, Brent). The range of the lags for exogenous variables is reported in brackets. Four lags are used for endogenous variables. The VAR models estimated on the 2012–2016 subsample do not include the interest rate, which was constrained by the zero lower bound. 68% credible intervals are reported (100 bootstrap replications). The first breakpoint is chosen with respect to the minimum p-value of the Chow forecast test (October 2007). The second breakpoint is defined as the beginning of the zero lower bound period (November 2012).

Table A3: Exchange Rate Pass-Through (Linear VAR with Foreign Variables: EMU)

Time range	Exogenous variables	Real GDP Average	Real GDP Credible intervals		CPI Average	CPI Credible intervals	
1999M05	no exo var	0.060	-0.072	0.150	0.081	-0.039	0.166
–	EMU (1–4)	0.154	0.008	0.230	0.013	-0.087	0.131
2016M11	EMU (0–4)	0.102	-0.001	0.152	0.019	-0.073	0.118
1999M05	no exo var	-0.099	-0.197	0.049	0.141	-0.108	0.334
–	EMU (1–4)	0.003	-0.085	0.080	0.141	-0.100	0.306
2007M09	EMU (0–4)	-0.005	-0.088	0.065	0.141	-0.107	0.307
2007M10	no exo var	-0.004	-0.142	0.173	0.028	-0.110	0.150
–	EMU (1–4)	0.043	-0.130	0.206	0.013	-0.144	0.150
2016M10	EMU (0–4)	0.060	-0.095	0.188	0.015	-0.116	0.133
1999M05	no exo var	0.064	-0.094	0.186	0.074	-0.055	0.192
–	EMU (1–4)	0.301	-0.123	0.612	-0.016	-0.169	0.160
2012M10	EMU (0–4)	0.124	-0.030	0.208	0.024	-0.095	0.160
2012M11	no exo var	0.076	-0.213	0.330	0.000	-0.342	0.366
–	EMU (1–4)	0.930	-0.340	0.538	-0.019	-0.623	0.763
2016M11	EMU (0–4)	0.070	-0.353	0.405	-0.022	-0.602	0.515

Note: Linear VAR models include real GDP, CPI, the 3M PRIBOR, and the NEER, all in log differences (except the interest rate). EMU stands for a set of foreign variables depicting economic developments in the European Monetary Union (effective PPI, effective GDP, and the shadow interest rate). The range of the lags for exogenous variables is reported in brackets. Four lags are used for endogenous variables. The VAR models estimated on the 2012–2016 subsample do not include the interest rate, which was constrained by the zero lower bound. 68% credible intervals are reported (100 bootstrap replications). The first breakpoint is chosen with respect to the minimum p-value of the Chow forecast test (October 2007). The second breakpoint is defined as the beginning of the zero lower bound period (November 2012).

Figure A1: Posterior Mean of the Standard Deviation of Structural Shocks

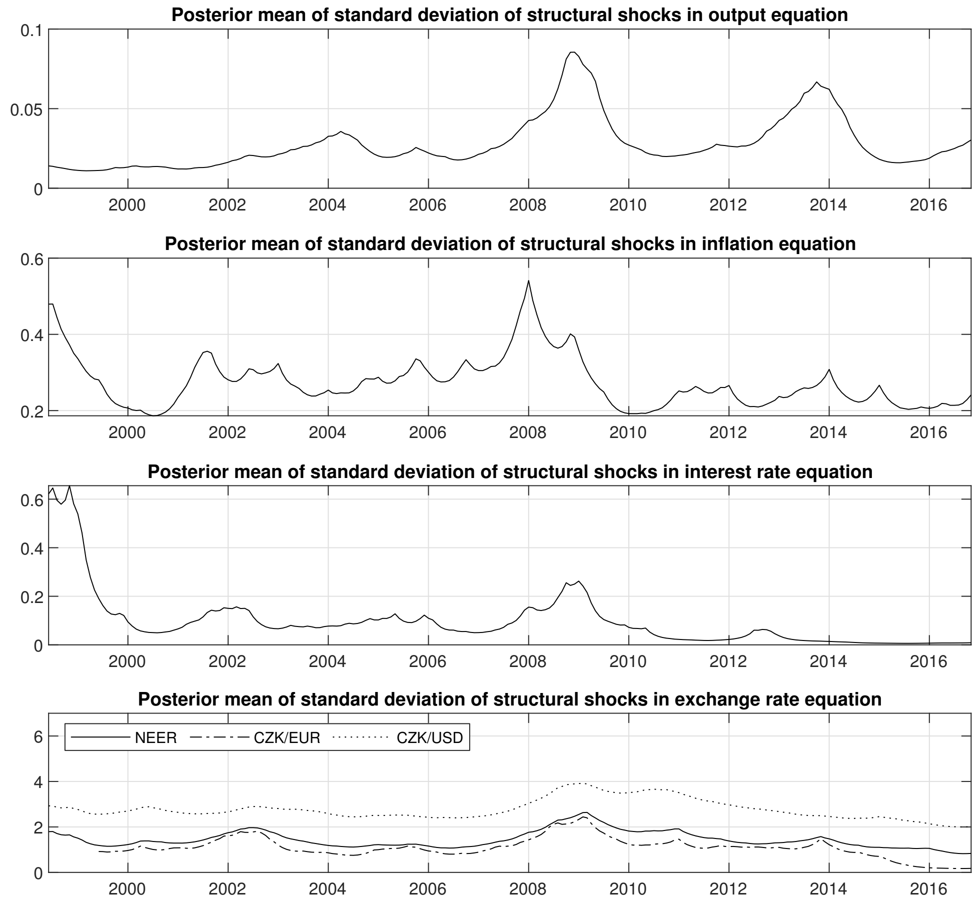


Figure A2: Credible Intervals for Different Prior Beliefs (NEER)

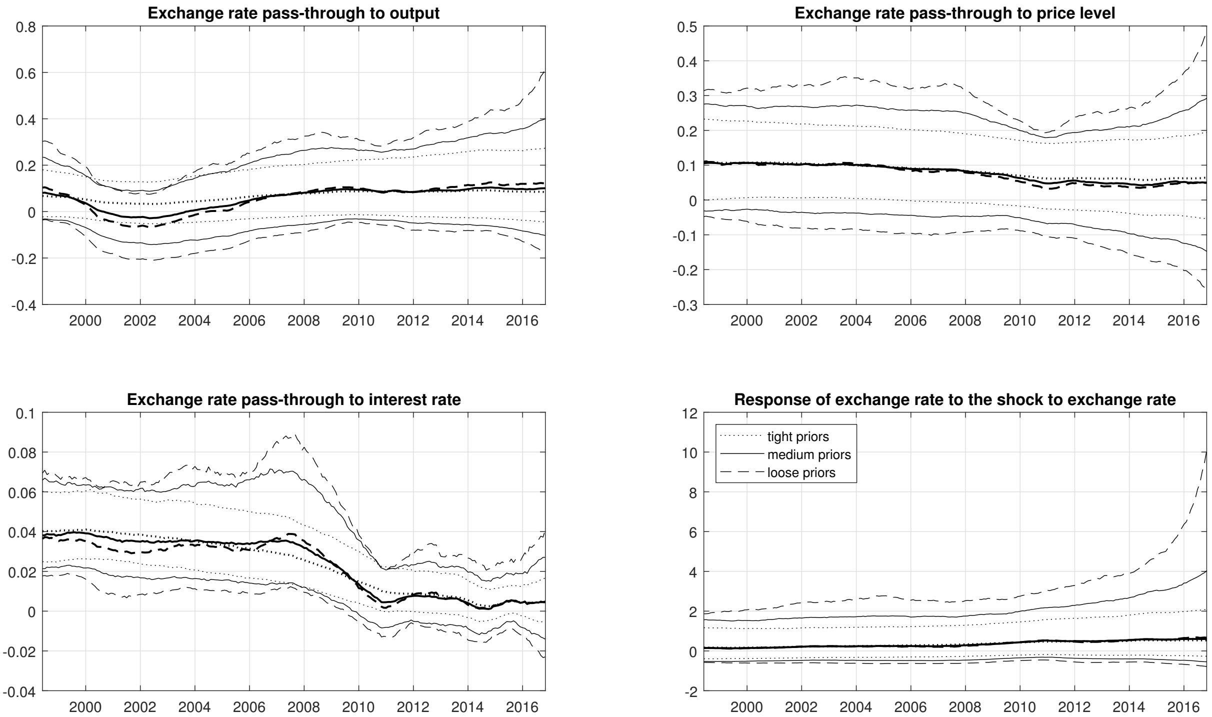


Figure A3: Exchange Rate Pass-Through with 68% Credible Intervals (NEER)

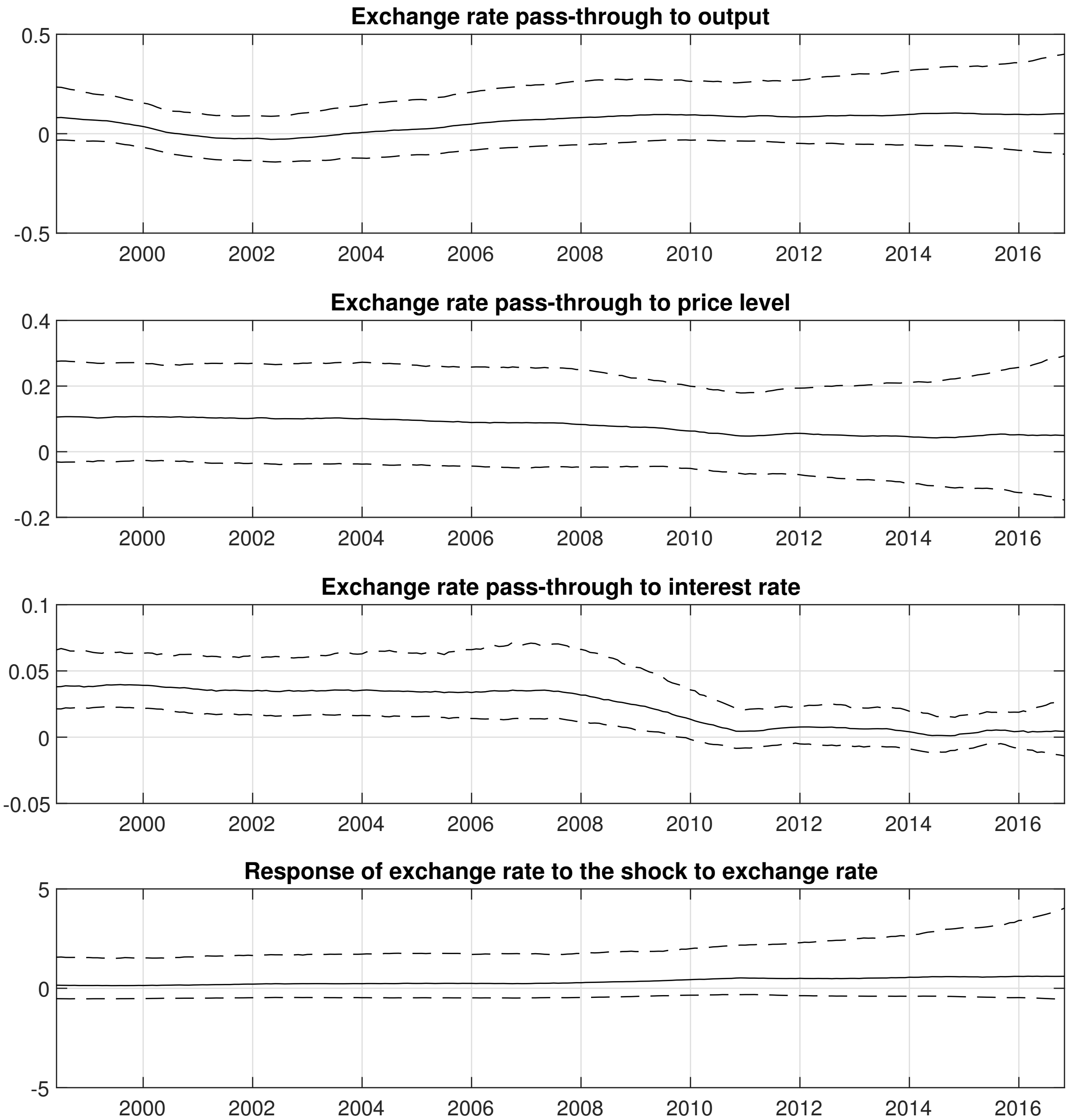


Figure A4: Exchange Rate Pass-Through with 68% Credible Intervals (CZK/EUR)

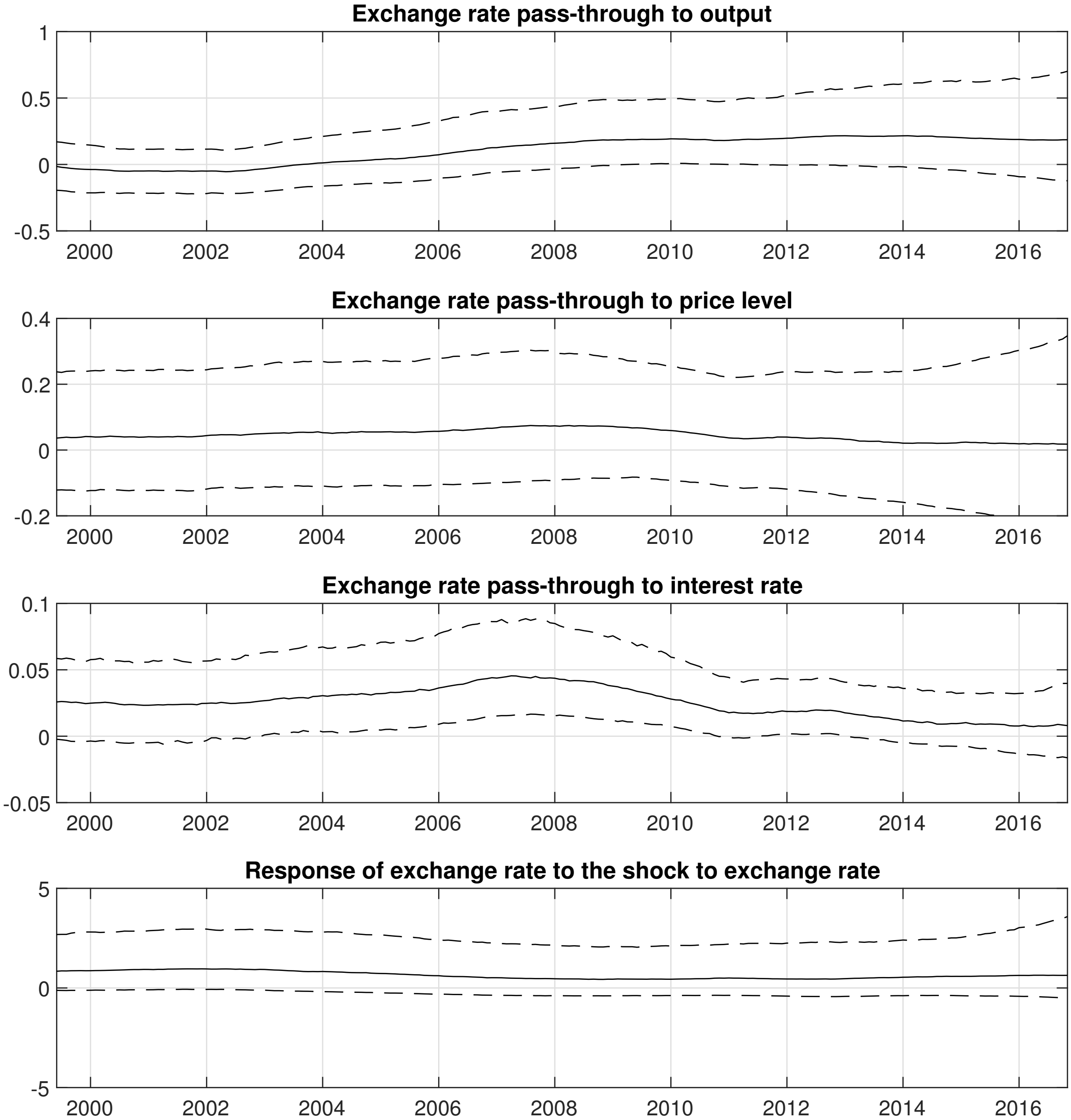
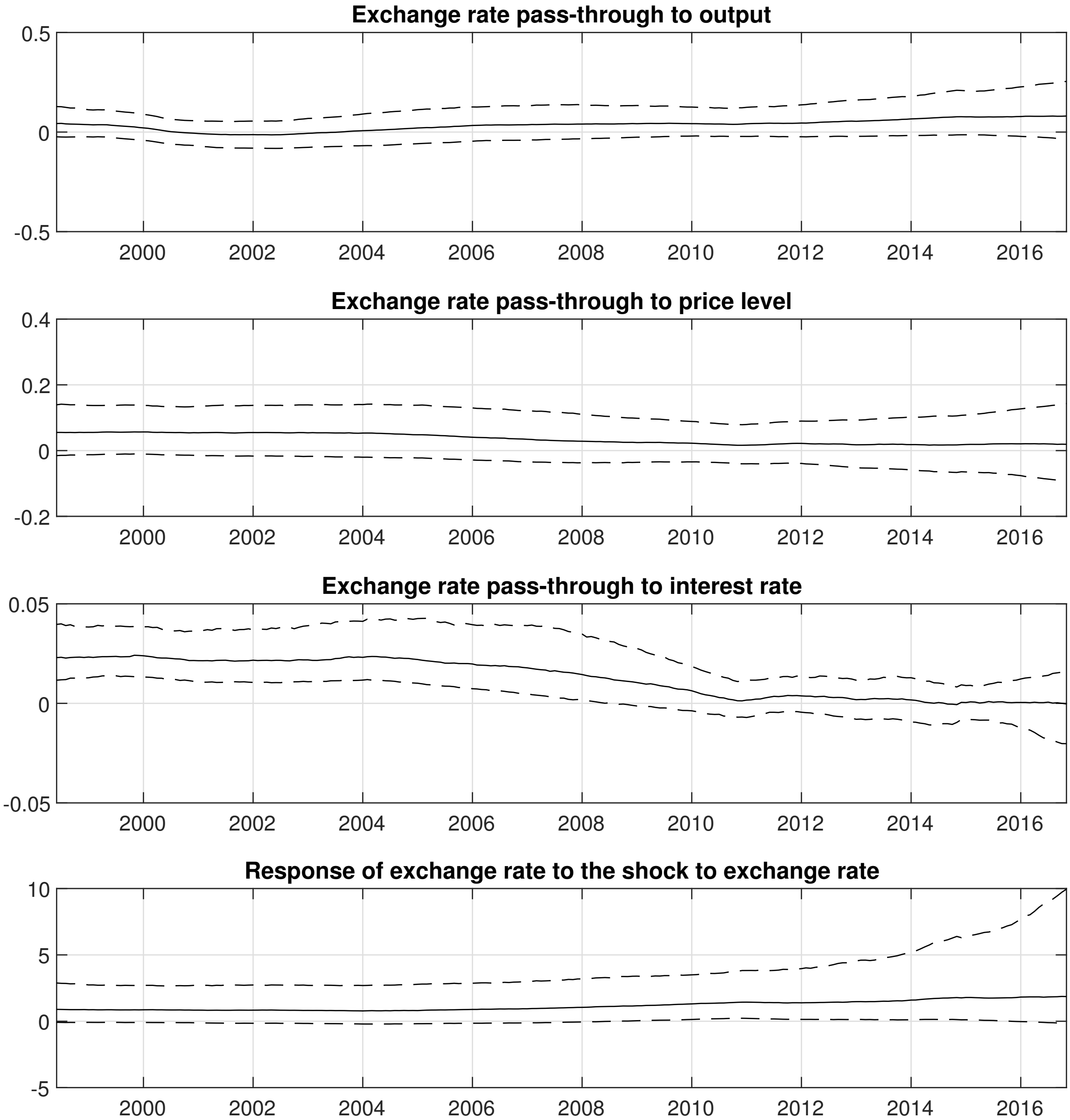


Figure A5: Exchange Rate Pass-Through with 68% Credible Intervals (CZK/USD)



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ISSN 1803-7070