Centrum výzkumu konkurenční schopnosti české ekonomiky
Research Centre for Competitiveness of Czech Economy

WORKING PAPER č. 01/2011

A DSGE Model View of the Czech Business Cycle

Tomáš Motl, Osvald Vašíček

Červen 2011

Řada studií Working Papers Centra výzkumu konkurenční schopnosti české ekonomiky je vydávána s podporou projektu MŠMT výzkumná centra 1M0524.

ISSN 1801-4496

Vedoucí: prof. Ing. Antonín Slaný, CSc., Lipová 41a, 602 00 Brno,
e-mail: slany@econ.muni.cz, tel.: +420 549491111

Centrum výzkumu konkurenční schopnosti české ekonomiky
Research Centre for Competitiveness of Czech Economy

A DSGE MODEL VIEW OF THE CZECH BUSINESS CYCLE

Abstract:

This paper uses a simple New Keynesian DSGE model as a means to examine the sources of the Czech business cycle from 1996 to 2010, focusing on the output gap. We estimate the DSGE model in order to obtain trajectories of exogenous shocks. Based on the model, we decompose the deviation of Czech output from trend into contributions of these shocks. We show that since 2000, the foreign demand shock and exchange rate shock have been increasingly important for the domestic business cycle.

Overall, domestic shocks account for more than a half of the variance in the domestic output gap. We contrast the recession of 1997-1998, caused primarily by domestic shocks, to the recession of 2009, which was caused by a drop in the foreign demand. We also find that the Czech economy is sensitive to the exchange rate movements, as documented by the year 2002.

Abstrakt:

Tento článek používá jednoduchý neokeynesiánský DSGE model k určení příčin českého hospodářského cyklu mezi lety 1996 a 2010, se zaměřením na mezeru výstupu. DSGE model je odhadnut, čímž dostáváme trajektorie exogenních šoků. Na základě modelu poté dekomponujeme odchylky české mezery výstupu mezi příspěvky exogenních šoků. Analýza ukazuje, že od roku 2000 mají zahraniční šoky a šok ve směnném kurzu rostoucí význam pro český hospodářský cyklus.

Domácí šoky vysvětlují více než polovinu variability české mezery výstupu. Zatímco recese z let 1997-1998 a následné oživení lze přičíst zejména domácím šokům, recese roku 2009 byla téměř zcela způsobena prpadem zahraniční poptávky. Dále také ukazujeme, že česká ekonomika je citlivá na pohyby směnného kurzu, jak dokumentuje rok 2002.

Recenzoval:
Ing. Karel Musil, Ph.D.

Introduction

Since the beginning of the transition to market based economy, the Czech economy has experienced two recessions and several years of moderate growth around three per cent but also a few years of a rapid economic growth over six per cent (figure 1). What were the causes of these events? We use a simple dynamic stochastic general equilibrium (DSGE) model to answer this question.

The DSGE model is derived from microeconomic principles. It is estimated by Bayesian methods and tested for its data matching properties. The advantage of the DSGE model is that it provides a structural view of the economy. It decomposes data volatility into primitive drivers such as technological shocks, demand shocks or monetary policy shocks. The model is replicated from Justiniano and Preston (2010).

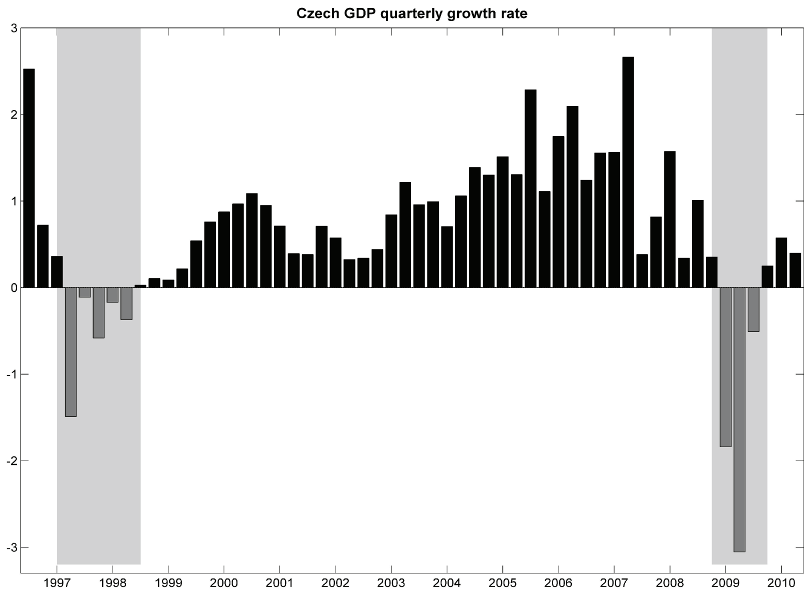

Figure 1: Annualized quarterly growth rates of the seasonally adjusted Czech GDP. Shaded areas indicate recessions.

In this paper, we estimate the trajectories of domestic and foreign technological shocks, demand shocks, monetary policy shocks and an exchange rate shock. We decompose the output gap fluctuations in terms of these shocks. Our analysis provides an insight into which of these shocks can explain recession, recovery or expansion in the domestic output. Based on the model, our assumptions and observed data, we shed light on the basic factors that could influence the stability and growth of the Czech economy.

Our analysis suggests that the two recessions mentioned earlier had different sources. The recession of 1997-1998 was triggered by a domestic monetary policy shock, which however resulted from monetary crisis and we do not interpret it as a monetary policy error. The monetary shock was then followed by a negative contribution of domestic technological shock which suggests that the recession was caused by problems on the supply side of the Czech economy. On the other hand, the recession of 2009 was caused primarily by a negative foreign demand shock. We therefore see the first recession as caused primarily by internal shocks and the second recession as caused primarily by shocks from abroad.

We also find evidence for increasing importance of foreign shocks. Since 2000, foreign shocks and the exchange rate shock played an important role in determining the domestic business cycle. Starting in 2008, the foreign sector has been the most important source of output dynamics. We also find evidence suggesting that the exchange rate shock has been also important, in particular in the economic slowdown of 2002. Overall, we find that the output gap fluctuations are not driven primarily by foreign factors, and more than a half of the volatility in the output gap is related to the domestic shocks.

The rest of the paper is organized in the following way: section 2 presents the DSGE model used for the analysis and discusses the interpretation of the structural shocks. Section 3 discusses the identification of the model, parameter estimation and data fit. Section 4 presents the main findings and section 5 concludes the paper.

The Model

The DSGE model used in this paper is a simple New Keynesian small open economy model presented in Justiniano and Preston (2010), which is closely related to a model in Monacelli (2005). The model consists of two economies – a small open economy and a large foreign economy. The large economy has a strong influence over the small one, whereas the small economy does not affect the large economy. We refer to the small open economy as to the domestic (Czech) economy. The large foreign economy will be approximated by the EA12[1] group of countries, as the foreign trade with these countries accounts for a crucial share of the Czech foreign trade.

The model is derived from the first principles using optimal decision rules of economic agents. Each of the two economies consists of households, firms and a monetary authority. The domestic firms are divided into producers and importers. Both types of firms operate on monopolistically competitive markets.

The domestic economy is influenced by the foreign economy in two ways. First, the foreign interest rate and exchange rate influence the domestic interest rate through the uncovered interest parity condition. Second, foreign goods are imported to the domestic economy and constitute a part of the domestic consumption. Here, we assume incomplete exchange rate pass-through.

Following Monacelli (2005), we model the foreign economy as a closed version of the small economy with identical structural parametrization. Therefore we introduce only the description of the domestic economy and the way the economies are linked together. In order to distinguish foreign and domestic variables inthe text, the variables originating in the domestic economy are denoted by subscript H and variables originating abroad by subscript F. The foreign sector variables are denoted by '*'.

1.1 Households

The domestic economy consists of a continuum of identical infinitely-lived households. The representative agent maximizes his lifetime welfare represented by a utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \tilde{\varepsilon}_{G,t} \left[\frac{(C_t - hC_{t-1})^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\phi}}{1+\phi} \right]. \tag{1.1}$$

Here, C_t denotes household consumption, N_t denotes hours worked, σ is the inverse intertemporal elasticity of substitution between the present and future consumption

[1]The EA12 group consists of Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal and Spain.

and ϕ is the inverse Frisch elasticity of labour supply. The parameter h denotes exogenous habit in consumption and $\tilde{\varepsilon}_{G,t}$ is a preference shock.

The consumption basket is given by domestically produced goods C_H and foreign produced goods C_F aggregated by Dixit-Stiglitz aggregator

$$C_t = \left[(1-\alpha)^{\frac{1}{\eta}} C_{H,t}^{\frac{\eta-1}{\eta}} + (\alpha)^{\frac{1}{\eta}} C_{F,t}^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}, \tag{1.2}$$

The parameter η is the elasticity of substitution between C_H and C_F and α is a share of foreign goods in total consumption.

The representative agent faces a budget constraint

$$C_t P_t + E_t Q_{t,t+1} D_{t+1} = D_t + W_t N_t + T_t. \tag{1.3}$$

where D_t is a nominal income from one period bonds bought in time $t-1$ maturing in time t, and $Q_{t,t+1}$ is the price of the bond. The financial markets are complete here. W_t is the nominal wage, P_t is a price of the consumption basket and T_t are the lump-sum transfers.

The first order conditions of this problem are summarized by the labor supply

$$\frac{N_t^{\phi}}{(C_t - hC_{t-1})^{-\sigma}} = \frac{W_t}{P_t}.$$

and the Euler equation

$$\left(\frac{(C_t - hC_{t-1})}{(C_{t+1} - hC_t)}\right)^{-\sigma} \frac{\tilde{\varepsilon}_{G,t}}{\tilde{\varepsilon}_{G,t+1}} \frac{P_{t+1}}{P_t} = \beta R_t.$$

where we define $R_t = (E_t Q_{t,t+1})^{-1}$.

1.2 Producers

We assume domestic sector to be populated by a $(0,1)$ continuum of monopolistically competitive producers. Each producer makes a decision about how much to produce and how much to charge. Producers share the same production technology

$$Y_t(i) = A_t N_t(i),$$

where $N_t(i)$ denotes the amount of labour hired by the i-th producer and A_t is an economy specific technological process.

Firms are assumed to set prices a la Calvo such that in every period a fraction $(1-\theta_H)$ of domestic producers is able to set optimal price.

The producers maximize profit given by

$$E_t \sum_{T=t}^{\infty} \theta_H^{T-t} Q_{t,T} y_{H,T}(i) \left[P_{H,t}(i) - P_{H,T} MC_T\right], \tag{1.4}$$

where $y_{H,T}(i)$ is the demand for the production of the i-th producer, $P_{H,t}(i)$ is the optimal price set by the i-th producer in period t and MC_T are marginal costs given as a derivative of the total costs.

Differentiating with respect to $P_{H,t}(i)$, we acquire following optimality condition:

$$E_t \sum_{T=t}^{\infty} \theta_H^{T-t} Q_{T,t} y_{H,T}(i) \left[P_{H,t}(i) - \frac{\theta_H}{\theta_H - 1} P_{H,T} MC_T \right] = 0.$$

1.3 Real exchange rate, law of one price relation

The real exchange rate is defined in log terms by

$$q_t = e_t + p_t^* - p_t = e_t + p_t^* - p_{F,t} + (1-\alpha)s_t = \psi_t + (1-\alpha)s_t$$

where q_t is the log of the real exchange rate, $e_t = \log \hat{e}_t$ is the log of the nominal exchange rate, p_t^* is the log of the foreign CPI, $s_t = p_{F,t} - p_{H,t}$ are log terms of trade and ψ_t is the log of the law of one price gap $\psi_{F,t} = e_t + p_t^* - p_{F,t}$.

The uncovered interest parity condition requires that

$$i_t - i_t^* = E_t(e_{t+1}) - e_t$$

which after plugging for e_t, defining inflation as $\pi_t = p_t - p_{t-1}$ and adding exchange rate shock $\varepsilon_{Q,t}$ gives

$$i_t - i_t^* + E_t \pi_{t+1}^* - E_t \pi_{t+1} = E_t(q_{t+1}) - q_t + \varepsilon_{Q,t}$$

1.4 Importers

In the domestic economy there is a $(0,1)$ continuum of monopolistically competitive importers. Each importer imports a unique good denoted by the index j bought for the price $\hat{e}_t P_{F,t}^*(j)$ which holds "at the docks".

Firms are also assumed to set prices a la Calvo such that in every period a fraction $(1-\theta_F)$ of importers is able to set optimal price.

The problem of the importers is to maximize

$$E_t \sum_{T=t}^{\infty} Q_{t,T} \theta_F^{T-t} C_{F,T}(i) \left[P_{F,t}(i) - \hat{e}_t P_{F,t}^*(i) \right]$$

given the demand for their goods $C_{F,T}(i)$.

The first order condition to this problem is

$$E_t \sum_{T=t}^{\infty} Q_{t,T} \theta_F^{T-t} C_{F,T}(i) \left[P_{F,t}(i) - \frac{\theta_F}{\theta_F - 1} \hat{e}_t P_{F,t}^*(i) \right] = 0.$$

1.5 General equilibrium

The domestic consumption demand is given in a log-linearised form by

$$c_{H,t} = -\eta(p_{H,t} - p_t) + c_t = \eta \alpha s_t + c_t.$$

Similarly, the foreign demand for domestic goods is given by

$$c^*_{H,t} = -\eta(p_{H,t} - p^*_t) + c^*_t = \eta(s_t + \psi_{F,t}) + c^*_t.$$

where c^*_t is the overall foreign consumption and $c^*_{H,t}$ is the foreign consumption of domestic goods. The market clearing requires

$$y_t = (1-\alpha)c_{H,t} + \alpha c^*_{H,t}. \tag{1.5}$$

Plugging the demands into 1.5 and employing some additional identities gives the final form of the goods-market clearing condition

$$(1-\alpha)c_t = y_t - \alpha\eta(2-\alpha)s_t - \alpha\eta\psi_{F,t} - \alpha y^*_t.$$

where y^*_t is the foreign output.

1.6 Monetary policy

Monetary policy in the foreign economy described by a Taylor rule with a lagged interest rate and a focus on the output and the inflation:

$$i^*_t \quad = \quad \rho^* i^*_{t-1} + (1-\rho^*)(\psi^*_\pi \pi^*_t + \psi^*_y y^*_t) + \epsilon^*_{M,t}$$

Here ρ^* is parameter of interest rates smoothing, ψ^*_π (ψ^*_Y) measures the magnitude of the reaction of the monetary authority to the inflation (output), and $\epsilon^*_{M,t}$ is an exogenous monetary policy shock.

Monetary policy in the domestic economy focuses only on the inflation:

$$i_t \quad = \quad \rho i_{t-1} + (1-\rho)\psi_\pi \pi_t + \epsilon_{M,t}$$

1.7 Exogenous shocks

The model features seven exogenous stochastic shocks. We describe only the domestic shocks and the exchange rate shock. The foreign shocks are identical to their domestic counterparts.

- The shock in preferences ε_G increases the present household utility, which makes the households more impatient and causes them to shift their consumption from future to present. This shift increases present demand and output. This shock can be interpreted as a demand shock.
- The technological shock ε_A enters the firms' production function, increases the labor productivity and lowers the marginal costs of producers which in turn affect the inflation. This shock is sometimes referred to as a cost-push shock, but because it is present in the production function, we call it the technological shock. This shock can be interpreted as a supply shock.

- The monetary policy shock ε_M enters the Taylor rule and relates to the nominal interest rate dynamics. If the monetary policy shock becomes positive, the nominal interest rate is above the appropriate level given by the Taylor rule.
- The exchange rate shock ε_Q affects the uncovered interest parity.

The monetary shocks are modelled as iid. Other shocks are introduced as exogenous stochastic AR(1) processes with innovations ϵ. The innovations have zero mean and finite variance. Note that the shocks that are not introduced as iid are not exogenous variables, but their innovations are.

$$\begin{aligned}
\varepsilon_{G,t} &= \rho_G \varepsilon_{G,t-1} + \epsilon_{G,t} \\
\varepsilon^*_{G,t} &= \rho^*_G \varepsilon^*_{G,t-1} + \epsilon^*_{G,t} \\
\varepsilon_{A,t} &= \rho_A \varepsilon_{A,t-1} + \epsilon_{A,t} \\
\varepsilon^*_{A,t} &= \rho^*_A \varepsilon^*_{A,t-1} + \epsilon^*_{A,t} \\
\varepsilon_{Q,t} &= \rho_Z \varepsilon_{Q,t-1} + \epsilon_{Q,t}.
\end{aligned}$$

1.8 Log-linear equations

The model presented in previous subsections is approximated by the following set of log-linear equations

1. Market clearing condition

$$(1-\alpha)c_t = y_t - \alpha\eta(2-\alpha)s_t - \alpha\eta\psi_{F,t} - \alpha y^*_t$$

2. Terms of trade

$$s_t - s_{t-1} = \pi_{F,t} - \pi_{H,t}$$

3. Terms of trade, real exchange rate, law of one price gap relation

$$q_t = \psi_{F,t} + (1-\alpha)s_t$$

4. Domestic producers price setting

$$\pi_{H,t} = \left((1-\theta_H)\frac{(1-\beta\theta_H)}{\theta_H} \right) mc_t + \beta E_t(\pi_{H,t+1})$$

5. Dometic real marginal costs

$$mc_t = \varphi y_t - (1+\varphi)\varepsilon_{A,t} + \alpha s_t + \left(\frac{\sigma}{1-h}(c_t - hc_{t-1}) \right)$$

6. Importers price setting

$$\pi_{F,t} = (1-\theta_F)\frac{1-\beta\theta_F}{\theta_F}\psi_{F,t} + \beta E_t(\pi_{F,t+1})$$

7. Complete markets assumption

$$c_t - hc_{t-1} = y_t^* - hy_{t-1}^* + \frac{1-h}{\sigma}\left(\psi_{F,t} + (1-\alpha)s_t\right) + \varepsilon_{G,t}$$

8. Uncovered interest parity

$$(i_t - E_t(\pi_{t+1})) - \left(i_t^* - E_t(\pi_{t+1}^*)\right) = E_t(q_{t+1}) - q_t + \varepsilon_{Q,t}$$

9. Dometic monetary policy rule

$$i_t = \rho i_{t-1} + (1-\rho)\psi_\pi \pi_t + \varepsilon_M$$

10. Domestic inflation

$$\pi_t = \pi_{H,t} + \alpha(s_t - s_{t-1})$$

11. Foreign Euler equation

$$y_t^* - hy_{t-1}^* = E_t(y_{t+1}^*) - hy_t^* - \frac{1-h}{\sigma}\left(i_t^* - E_t(\pi_{t+1}^*)\right) + (\varepsilon_{G,t}^* - \varepsilon_{G,t+1}^*)$$

12. Foreign producers price setting

$$\pi_t^* = \left((1-\theta^*)\frac{(1-\beta\theta^*)}{\theta^*}\right) mc_t^* + \beta E_t(\pi_{t+1}^*)$$

13. Foreign real marginal costs

$$mc_t^* = \varphi y_t^* - (1+\varphi)\varepsilon_{A,t}^* + \alpha s_t + \left(\frac{\sigma}{1-h}(y_t^* - hy_{t-1}^*)\right)$$

14. Foreign monetary policy rule

$$i_t^* = \rho^* i_{t-1}^* + (1-\rho^*)(\psi_\pi^* \pi_t^* + \psi_y^* y_t^*) + \varepsilon_M^*$$

15. Exogenous stochastic process for the domestic shock in preferences

$$\varepsilon_{G,t} = \rho_G \varepsilon_{G,t-1} + \epsilon_{G,t}$$

16. Exogenous stochastic process for the foreign shock in preferences

$$\varepsilon_{G,t}^* = \rho_G^* \varepsilon_{G,t-1}^* + \epsilon_{G,t}^*$$

17. Exogenous stochastic process for the domestic technological shock

$$\varepsilon_{A,t} = \rho_A \varepsilon_{A,t-1} + \epsilon_{A,t}$$

18. Exogenous stochastic process for the foreign technological shock

$$\varepsilon_{A,t}^* = \rho_A^* \varepsilon_{A,t-1}^* + \epsilon_{A,t}^*$$

19. Exogenous stochastic process for the monetary policy shock

$$\varepsilon_{Q,t} = \rho_Q \varepsilon_{Q,t-1} + \epsilon_{Q,t}$$

Estimation and data fit

We estimate the model using Bayesian techniques in order to acquire the estimated trajectories of structural shocks. In this section, we describe the data and their link to the model variables, then discuss prior and posterior distribution of parameters and potential issues with the model identification. Finally, before presenting our analysis, we assess the data matching properties of the model.

2.1 The Data

The model is estimated on Czech and EA12 economy data. The sample ranges from 1996Q1 to 2010Q2. We measure quarterly domestic and foreign real GDP per capita, domestic and foreign consumer price inflation, domestic and foreign nominal interest rate and real exchange rate. Table 2.1 summarizes the mapping between the model variables and the observed variables.

Model variable	Observed time series
y	Czech real GDP per capita
y^*	EA12 real GDP per capita
π	annualized Czech HICP inflation
π^*	annualized EA12 HICP inflation
i	annualized three months PRIBOR
i^*	annualized three months EURIBOR
q	real exchange rate

Table 2.1: Link of observed time series to the model variables.

The observed data are detrended using the Hodrick-Prescott filter and all variables are expressed in percentage deviation from the HP trend. To avoid the beginning-of-sample filtration problem, we estimate the HP trend using observations from 1994Q1. For output and HICP inflation, historical(pre 1996) data are not available – we construct dummy observations assuming GDP and HICP evolved similarly to the four earliest observations. To avoid the end-of-sample problem, we add dummy observations to the ends of the observed time series using the Czech National Bank forecast as of 2010Q4. Except for nominal interest rates and real exchange rate, all time series were seasonally adjusted using X-12 ARIMA. The plot of model consistent data and details on data preparation can be found in the appendix.

We equal the output gap to the detrended output. An alternative and perhaps better method would be to use dynamic steady state. Such method would not be subject to potential problems arising from using Hodrick-Prescott filter. However, due to practical difficulties with modelling dynamic steady state, it is common to use the Hodrick-Prescott filter. We check the estimated values of output gap with the ones reported by Czech National Bank and find a good correspondence. Specifically, the CNB reports tightening of the output gap in 2000-2001 and subsequent widening. The CNB also reports that the output gap became positive in the second half of 2005 and turned negative again in 2009Q1[2].

2.2 Parameter identification and estimation

The estimation of parameters is an important step in our analysis because the realisation of exogenous shocks depends on the values of structural parameters. For example, we could observe different trajectories of exogenous shocks with equal likelihoods and no guidance on how to qualify these two results. We therefore use the methodology by Iskrev (2010) to assess whether there are potential identification issues.

The methodology is based on two matrices of first derivatives with respect to the parameters. The first matrix is based on derivatives of the vector of entries that determine the solution of the model. The second matrix is based on derivatives of the vector of entries that determine model implies restrictions on the first two moments in data. A column of zeros in any of these matrices indicates that the corresponding parameter does not affect the solution of the model or the implied restrictions on the data. Such parameter can not be identified. High multicollinearity among individual columns of the matrices indicates weak identification. For detailed description of the method, the reader is encouraged to consult Iskrev (2010).

The results of the analysis show that all parameters are identified both structurally and from the data. The analysis of multicollinearity in figure 7 in the appendix indicates that there might be weak identification issues concerning the estimation from data. We therefore check the quality of identification using Gelman-Brooks convergence diagnostics, which show that the estimates of the parameters in the Random Walk Metropolis Hastings Algorithm are stable and the model is well identified (figure 9 in appendix).

The method by Iskrev (2010) also allows us to check pairwise correlation of columns in matrices introduced above. High correlation suggests similar effects of the corresponding parameters and thus potential identification issues. Figure 8 shows that there are possible issues with three pairs of parameters: σ and h and domestic and foreign Taylor rule parameters ρ and ψ_π. The effects of these parameters partially "overlap" and the parameters might be difficult to distinguish. Our findings are partly similar to Iskrev (2010), who provides the Taylor rule coefficients as an example of known identification issues.

[2]CNB Inflation report III/2010

2.3 Priors and estimates

The bayesian methodology requires specification of prior distributions over parameters and standard deviations of shocks. Priors affect the posterior values of the parameters. Before discussing our posterior estimates, let us first discuss our motivation for the choice of priors.

For the elasticity of substitution between domestic and foreign goods η and habit parameter h we set prior means to 0.6 and 0.8 according to Remo (2008), who estimated similar model for the Czech economy. Also according to Remo (2008), we set prior means of inverse elasticity of substitution σ and inverse Frisch elasticity ϕ to 0.5 and 2.0. For Taylor rule parameters, we set priors according to Justiniano and Preston (2010). Price stickiness parameters priors have means 0.7 to reflect high price stickiness both in Czech economy and the eurozone. AR parameters for shocks ρ have prior means equal to 0.5 to bear no special information about the nature of the AR processes for shocks.

We decided to calibrate two parameters: the economy openness α is calibrated to the value of 0.65 which equals the average share of nominal imports to nominal GDP in Czech economy over the estimated period. It has been documented in the literature (among others by Justiniano and Preston) that the cross-equation restriction within the model push the estimates of this parameter towards zero – the closed economy case. The estimation of this parameter would likely result in a lower estimate of the openness which would understate the influence of the foreign economy on the domestic economy. We also calibrate β to 0.9935 implying data consistent real interest rate of 2.65 per cent, which corresponds to the average real output growth in the estimated period.

Now turning to the posterior estimates, the estimation results are summarized in the table 2.2. The estimates are based on two runs of the Random Walk Metropolis Hastings Algorithm implemented in DYNARE[3]. We generate 1,500,000 draws in each run and discard first 60%. There are few estimates worth closer look.

The estimates of the parameters θ_H, θ_F and θ^* show fairly high degree of price stickiness. This indicates that the volatility of inflation will be captured in technological shocks, which seems to be true according to the standard errors of the shocks. Similarly, a high value of habit parameter h shows that there is a significant habit in consumption. The standard errors of the technological shocks and the domestic preference shock are notably larger than the other standard errors. However, the variance decomposition discussed in the next subsection shows that these shocks do not dominate the model.

2.4 Data fit and variance decomposition

To add to the credibility of the model, we assess the data matching properties of the model. In our strategy, we compare the performance of statistical models on both real

[3] Version 4.1.3

Parameter	Distribution	Prior mean	Prior std	Posterior mean	Conf. interval	
θ_H	beta	0.70	0.10	0.7104	0.6473	0.7754
θ_F	beta	0.70	0.10	0.7811	0.7000	0.8666
θ^*	beta	0.70	0.05	0.8971	0.8744	0.9211
h	beta	0.80	0.20	0.8508	0.7612	0.9438
σ	gamma	0.50	0.30	0.4899	0.1466	0.8094
ϕ	gamma	2.00	0.50	2.3724	1.5875	3.1662
η	gamma	0.60	0.10	0.3228	0.2363	0.4063
ψ_π	gamma	1.50	0.25	1.5122	1.1259	1.8628
ψ_π^*	gamma	1.50	0.25	1.4358	1.0386	1.8089
ψ_y^*	gamma	0.25	0.10	0.1527	0.0716	0.2316
ρ	beta	0.50	0.15	0.8036	0.7498	0.8598
ρ^*	beta	0.50	0.15	0.8101	0.7519	0.8700
ρ_G	beta	0.50	0.20	0.2801	0.1146	0.4397
ρ_G^*	beta	0.50	0.20	0.3732	0.2012	0.5412
ρ_A	beta	0.50	0.20	0.5452	0.3770	0.7144
ρ_A^*	beta	0.50	0.20	0.3902	0.1764	0.5920
ρ_Q	beta	0.50	0.20	0.6863	0.5747	0.7996
σ_{ϵ_G}	inv. gamma	1.00	∞	3.6177	2.7652	4.4271
$\sigma_{\epsilon_G^*}$	inv. gamma	1.00	∞	0.8932	0.7399	1.0431
σ_{ϵ_A}	inv. gamma	1.00	∞	3.4833	1.8931	5.0679
$\sigma_{\epsilon_A^*}$	inv. gamma	1.00	∞	4.9174	2.2733	7.4778
σ_{ϵ_Q}	inv. gamma	1.00	∞	1.0114	0.6488	1.3725
σ_{ϵ_M}	inv. gamma	1.00	∞	0.3638	0.3032	0.4241
$\sigma_{\epsilon_M^*}$	inv. gamma	1.00	∞	0.1353	0.1176	0.1511

Table 2.2: Prior and posterior distributions of parameters.

data and artificial data generated by the estimated model.

We estimate a VAR(1) model on original data and on artificial data and take fitted values. For each time series, we compute model implied autocorrelation and cross-correlation with respect to the GDP. The results are summarized in tables 5 and 6 in the appendix. We can see that the DSGE model approximates well the autocorrelations in output, interest rates and real exchange rate, but fails to replicate the high autocorrelation of inflations.

The cross-correlation coefficients in table 6 show similar results. The cross-correlation between domestic output and foreign output, domestic interest rate and real exchange rate is similar for both original and artificial data. We find it particularly encouraging that the model matches the data in the international dimension well. The cross-correlation between domestic output and foreign output is satisfactory. However, the model can not replicate the relationship between output and inflations.

The variance decomposition in table 4 in the appendix shows a breakdown of variance of endogenous variables into contribution of exogenous shocks. All variables are driven by appropriate shocks with the exception of the real exchange rate where there is a large influence of the domestic preference shock.

Shock decomposition

The goal of this paper is to analyse the structural sources of the Czech business cycle. Based on the estimated model we compute relative contributions of structural shocks to the domestic output gap identified by Hodrick-Prescott filter. We acquire the model view on which factors influence the stability of the Czech economy and which factors stood behind periods of economic growth.

The outcome of our analysis is depicted in figures 3.2, 3.3 and 3.4. The black line shows the values of the output gap. The coloured columns denote the contributions of structural shocks to this deviation. Foreign shocks are summed together for simplicity because the contributions of foreign monetary and technological shock are negligible (see variance decomposition in table 4).

The shocks influence the output in two ways. First, a rapid change in the contribution of a shock induces a change in the output gap, typically in recessions (e.g. domestic technological shock in 1997Q1 - 1997Q3). Second, a lasting positive or negative influence of a shock pushes the output gap into positive or negative values (e.g. foreign demand shock in 2007Q1 - 2008Q3).

Our analysis presents one of the possible interpretations of the history, which is conditioned on the model use and the simplifying assumptions we make. The overall picture is one of gradually rising importance of the foreign shocks for the Czech business cycle. The recession of 1997 is attributed mainly to the technological shock. In the following years, the foreign shocks become increasingly important. The exchange rate shock had a significant impact in 2002 and the foreign demand shock was the main driver of the Czech business cycle in 2006-2010.

An overview of the relative importance of individual shocks is given by the variance decomposition in table 4 in the appendix. Half of the variance of the Czech output gap is attributed to the domestic shocks. However, the most influential shock is the domestic demand shock responsible for 36 per cent of the variance. The foreign demand shock and the exchange rate shock together account for 40 per cent of the variance. The foreign technological and monetary policy shocks have negligible influence on the Czech business cycle.

The following subsections present the analysis divided into two time periods:

3.1 1996-2004

The period from 1996 to 2004 brought the first recession, recovery and then moderate growth to the Czech economy.

In 1996, the Czech economy enjoyed moderate growth of about 4 per cent, although with a number of warning signs such as growing external imbalances. In May

1997, after a run on the Czech currency, the Czech National Bank (CNB) was forced to change the exchange rate regime from fixed to floating. The Czech currency devalued by more than 10 per cent. The CNB tightened monetary policy in response to the devaluation and resulting inflationary pressures, while the government enacted austerity measures. Interest rates remained elevated for another 6 periods. As the result, the Czech economy plunged into recession. The real GDP was falling in two consecutive years and did not recover to its previous level until 1999.

Comprehensive discussion of the events was provided by Dědek (2003), who argues that the monetary crisis and subsequent recession was partly the result of structural and institutional problems in the Czech economy that were not properly dealt with by the government.

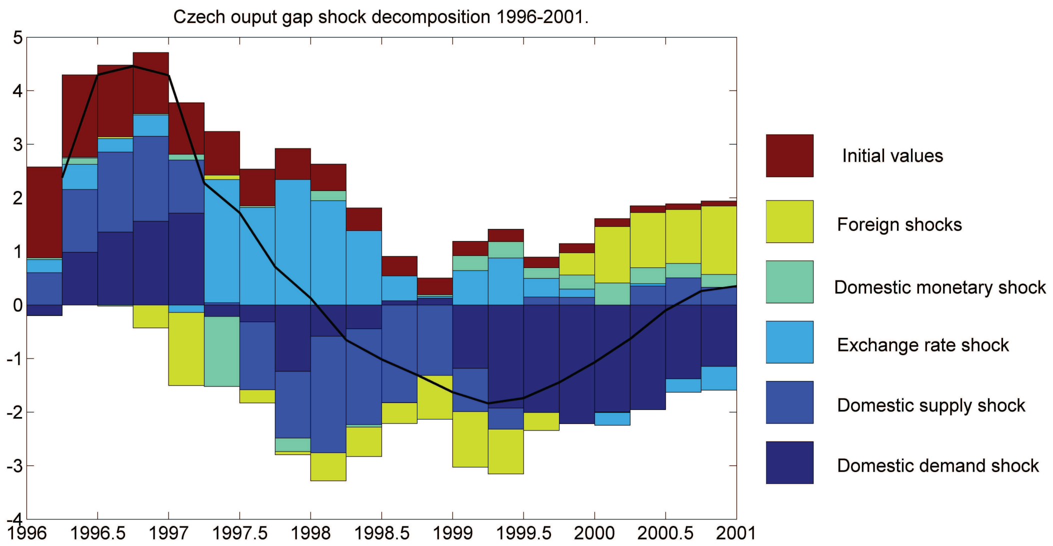

Figure 3.2: Domestic output gap shock decomposition 1996-2001.

Figure 3.2 shows how this period is viewed using the DSGE prism. What does it tell us about the causes of the recession? The early periods are strongly influenced by the initial values, which can be interpreted as the overall effect of unidentified past shocks. This fact makes the year 1996 harder to interpret but we still find the evidence consistent with the hypothesis presented by Dědek (2003). The technological shock had a decreasing tendency already since the last quarter of 1996 and was the main reason why output fell in 1997 and 1998. The supply side problems helped to trigger the monetary crisis, which then in turn unfolded the supply side problems in the Czech economy.

In the second quarter of 1997, the influence of the domestic monetary shock turned quickly from slightly positive into fairly negative. This sudden change in monetary policy stance was probably induced by monetary crisis that can not be explained using our model. For this reason, we do not see it as an evidence of an error made by the Czech National Bank.

The domestic demand shock contributes to the fall in output in the second quarter of 1997, probably as a results of the austerity measures. On the other hand, the depreciation of the exchange rate had positive influence on the output.

Which factors brought the recovery? The recovery in 1999 was the result of the vanishing negative effect of domestic technological shock and increasing positive influence of the foreign demand shock. The recovery was countered by the domestic demand shock. It is important to notice that foreign shocks play no role in the causes of the recession and only a limited role in the recovery – the 1997-1998 recession and the 1999 recovery had primarily internal sources.

The period of 2000-2004 saw a rise in the importance of the shocks outside of the Czech economy, namely the foreign demand and exchange rate shock. While in 2000 the Czech GDP grew by solid 3.6 per cent annually, in 2001 and 2002 the growth slowed to 2.6 and 1.8 per cent.

Given the model view, we find that in 2000 and early 2001 the foreign demand shock contributed significantly to the renewed growth, more than any other shock. However, the shock's effect faded during 2001 and between 2003 and 2006 the effect was negative.

The exchange rate shock also pushed the output gap into negative values in 2001 and in 2002 it was the main driver of the output slowdown. Looking at figure 6 in the appendix, we can compare this model view with historical data on the nominal exchange rate. The exchange rate appreciated from 36 CZK/EUR to 34 CZK/EUR in 18 months from the second quarter of 2000 on. In the beginning of 2002, the appreciation was even faster. The years 2001 and 2002 document the sensitivity of the Czech economy to the exchange rate movements.

Although the years 2003 and 2004 saw GDP growth of 3.5 per cent and 4.5 per cent annually, our analysis shows that in this period the Czech output gap was still negative. As discussed before, this fact is consistent with the view of the Czech National Bank. As figure 3 shows, weak foreign and domestic demand were responsible for the negative output gap.

3.2 2005-2010

The years 2005-2010 saw another period of economic growth and recession. Contrary to the previous period, however, the dynamics of the domestic output was given mainly by foreign shocks. This is in line with conventional wisdom, but we also find that domestic shocks still have had a role in the domestic business cycle.

The 2005-2007 period was very successful in terms of growth of the output, when the Czech economy grew by over 6 per cent annually. The output gap turned positive in late 2005. The causes of this development can be found both inside and outside of the Czech economy. Figure 3.3 shows that in 2005, closing of the output gap was likely caused by the demand factors. The decreasing negative contributions of both domestic and foreign demand shocks were also important. Subsequently, since 2006 the foreign demand shock positively contributed to the output gap until the third quarter of 2008. We can see in figure 3.4 that the foreign demand was especially influential in the 2007-2008 period.

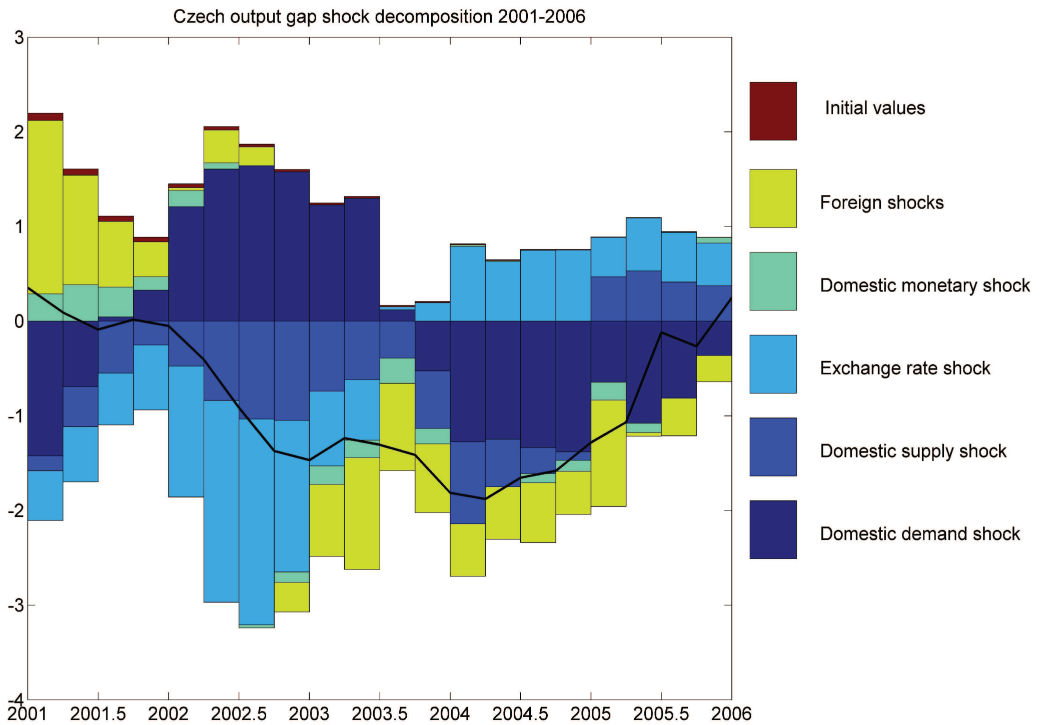

Figure 3.3: Domestic output gap shock decomposition 2001-2006.

The domestic shocks also played significant role in the post-2005 period. Untill 2008, the domestic technological shock was an important determinant of the output gap.

There is an interesting correlation between the domestic technological shock and corporate taxes in the 2005-2008 period. The czech corporate tax rate was stable during early 2000s at the level of 31 per cent. Since 2004, the tax rate was lowered in several steps to the final value of 20 per cent in 2009. In 2005, we observe positive contribution of the domestic technological shock which lasts until 2008. The cuts in the corporate tax rate seem to have produced positive boost to the output.

The year 2008 brought a slowdown in output growth to 2.8 per cent annually. We identify two main reasons. First, the exchange rate appreciation by some 15 per cent in one year depressed exports and lowered the output. as obvious from the exchange rate shock. Second, the foreign demand shock turned from a positive contribution in third quarter of 2008 to a significantly negative one in the first quarter of 2009 as the world-wide recession hit the foreign economy before it transpired into the domestic economy. The Czech crown in turn depreciated in 2008Q4 and the exchange rate shock decreased its negative contribution. Thus the main reason for positive, although decreasing output gap in 2008 was the domestic demand shock.

The foreign demand shock transferred the recession to the Czech economy as can be seen from its large negative contribution through the whole 2009 and early 2010. Domestic demand and technological shocks also partly contributed to the recession,

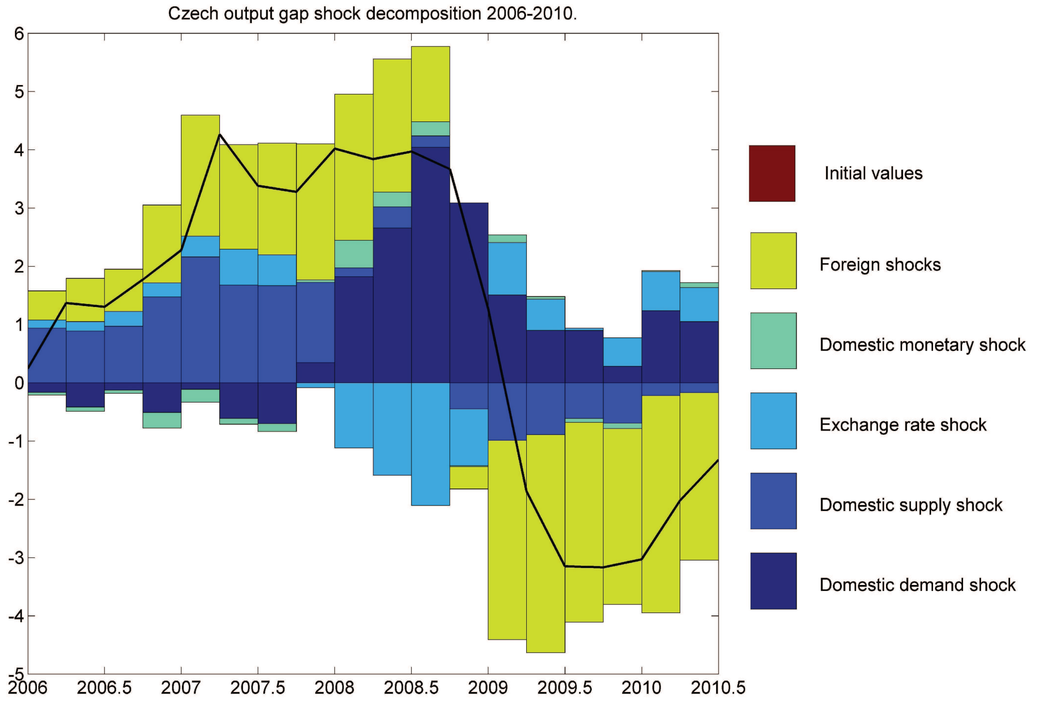

Figure 3.4: Domestic output gap shock decomposition 2006-2010.

but we identify the foreign demand shock as the main cause of the 2009 recession. This is in sharp contrast with the recession of 1997-1998 which was caused by domestic shocks.

Conclusion

Based on the analysis in this paper, we provide several conclusions:

- The recession of 1997-1998 was caused entirely by domestic shocks. The domestic technological shock was the key factor that stood behind the negative GDP growth in 1997-1998. On the contrary, the recession of 2009 was almost entirely caused by a drop in foreign demand. Given the fact that foreign shocks were crucial for the Czech economy in the 2007-2010 period, it is likely that its recovery is dependent on the recovery of the foreign demand.

- Since 2000, the foreign shocks have had increasing importance in determining the domestic output. Most notably, the exchange rate shock was particularly important in 1997 and 2002. Starting in 2007, the foreign demand was the most significant outside factor that determined the domestic output, especially in the late 2008 and early 2009. In general, the Czech economy is sensitive to the foreign shocks.

- Although the Czech economy is sensitive to the foreign shocks, the domestic shocks have played significant role in determining the Czech business cycle. Domestic shocks explain approximately 60 per cent of the variance in the domestic output.

There are several possible extensions to our research. Using more elaborate model with broader set of structural shocks, one can get more information about what shocks drive the dynamics of a given variable. In particular, using a model that incorporates government and investment might result in a detailed description of effects that we summarize as the effects of demand shocks and technological shocks.

The knowledge of the relative importance of particular shocks, namely the distinction between foreign and domestic influences, is necessary for a conditional forecast using DSGE models. Using the information about the relevance of shocks to the domestic output, one can make a forecast based on expected paths of foreign GDP and exchange rate.

Bibliography

[1] Dědek O (2003): The Currency Shake-Up in 1997: A Case Study of the Czech Economy. In Griffith-Jones, S., Gottschalk, R., Cailloux, J.: International Capital Flows in Calm and Turbulent Times. Michigan, The University of Michigan Press, p. 231-266, ISBN 0-472-11309-7.

[2] Iskrev N (2010): Local identification in DSGE models. Journal of Monetary Economics., 57(2):189-202.

[3] Justiniano A, Preston B (2010): Monetary Policy and Uncertainty in an Empirical Small Open Economy Model. Journal of Applied Econometrics, 25(1):93-128.

[4] Monacelli T (2005): Monetary Policy in a Low Pass-through Environment. Journal of Money, Credit and Banking, 37:1047-1066.

[5] Remo A (2008): Monetary Policy and Stability of Czech Economy: Optimal Commitment Policy in NOEM DSGE Frame-work. CVKS MU, Brno, working paper no. 25/2008.

Figures and tables

Output per capita	Real GDP was seasonally adjusted by X12-ARIMA and divided by total population.
Real exchange rate	Nominal exchange rate was multiplied by ratio of seasonally adjusted HICP indices.
Inflation	HICP index was seasonally adjusted by X12-ARIMA, taking logs and first differences.
Quarterly HICP index	Quartely HICP indices were computed as averages of monthly indices.

Table 3: Preparation of the time series downloaded from Eurostat.

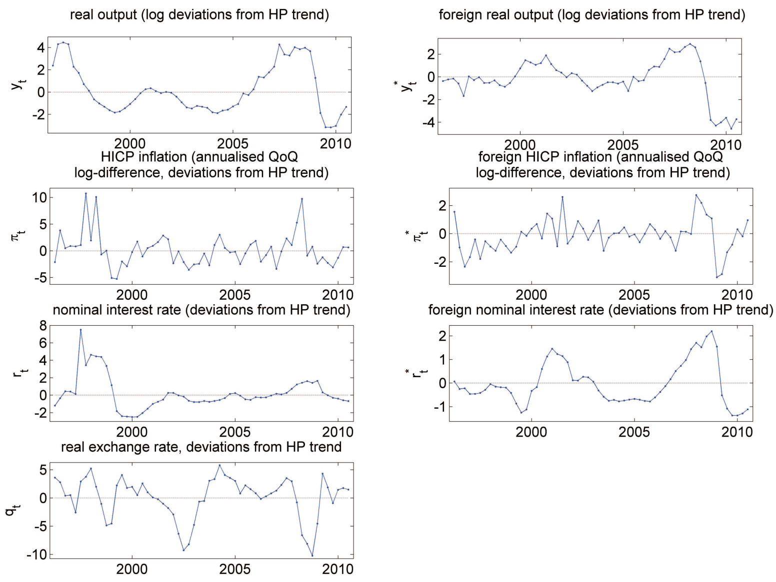

Figure 5: Data before estimation in percentage deviations from trend. All growth rates are annualized QoQ.

	ϵ_G	ϵ_A	ϵ_Q	ϵ_M	ϵ_A^*	ϵ_G^*	ϵ_M^*
Domestic consumption	84.06	2.03	7.93	2.80	0.01	3.15	0.01
Domestic interest rate	20.37	12.84	34.02	23.01	0.04	9.66	0.04
Domestic inflation	28.94	21.76	27.30	12.95	0.05	8.95	0.05
Domestic output gap	36.43	21.50	15.14	4.58	0.40	21.55	0.41
Terms of trade	56.96	26.19	7.23	3.17	0.32	5.88	0.25
Law of one price gap	2.13	1.01	70.99	20.51	1.09	2.56	1.71
Domestic marginal cost	51.38	34.88	6.25	1.63	0.01	5.84	0.01
Inflation in imports	6.75	3.33	51.33	29.30	0.67	7.99	0.63
Inflation in domestic goods	43.78	32.03	11.74	4.71	0.03	7.67	0.04
Real exchange rate	23.05	9.95	50.26	13.47	1.34	0.07	1.85

Table 4: Infinite horizon variance decomposition. Variances of endogenous variables are divided into percentage contributions of exogenous shocks. Rows sum to 100%.

	Original data	Model
Domestic output gap	0.8805 0.7019	0.8540 0.6825
Foreign output gap	0.8278 0.6378	0.8518 0.6508
Domestic inflation	0.5359 0.4858	0.4382 0.1739
Foreign inflation	0.8236 0.6583	0.4982 0.2675
Domestic interest rate	0.8366 0.6876	0.7821 0.5871
Foreign interest rate	0.8708 0.6517	0.8200 0.6362
Real exchange rate	0.6931 0.3097	0.6405 0.4000

Table 5: Implied autocorrelation of 1st and 2nd order. Orders correspond to rows.

	lag/lead of output gap	-2	-1	0	1	2
Foreign output gap	Data	0.3546	0.5326	0.6713	0.6227	0.5307
	Model	0.3732	0.4610	0.5245	0.4320	0.3216
Domestic inflation	Data	0.4235	0.4080	0.5374	0.4716	0.4243
	Model	0.0932	0.2166	0.4719	0.3825	0.2942
Foreign inflation	Data	-0.2597	-0.1306	0.0654	0.1500	0.2355
	Model	-0.2848	-0.3156	-0.3333	-0.2954	-0.2567
Domestic interest rate	Data	0.5474	0.4558	0.3153	0.1479	0.0092
	Model	0.3440	0.3987	0.4359	0.3481	0.2685
Foreign interest rate	Data	0.5746	0.6614	0.6727	0.5247	0.3465
	Model	-0.0170	-0.0160	-0.0340	-0.0797	-0.1137
Real exchange rate	Data	-0.2610	-0.2708	-0.2097	-0.0476	0.0922
	Model	-0.1513	-0.1150	-0.0297	-0.0621	-0.0731

Table 6: Implied cross-correlation of Czech output gap with other time series.

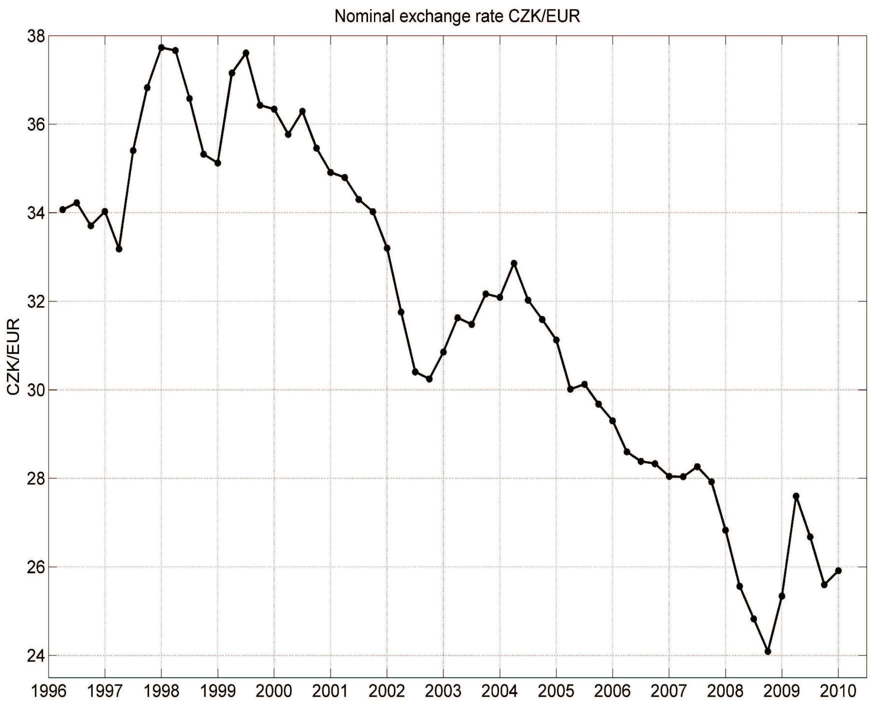

Figure 6: Nominal exchange rate CZK/EUR. Source: Czech National Bank.

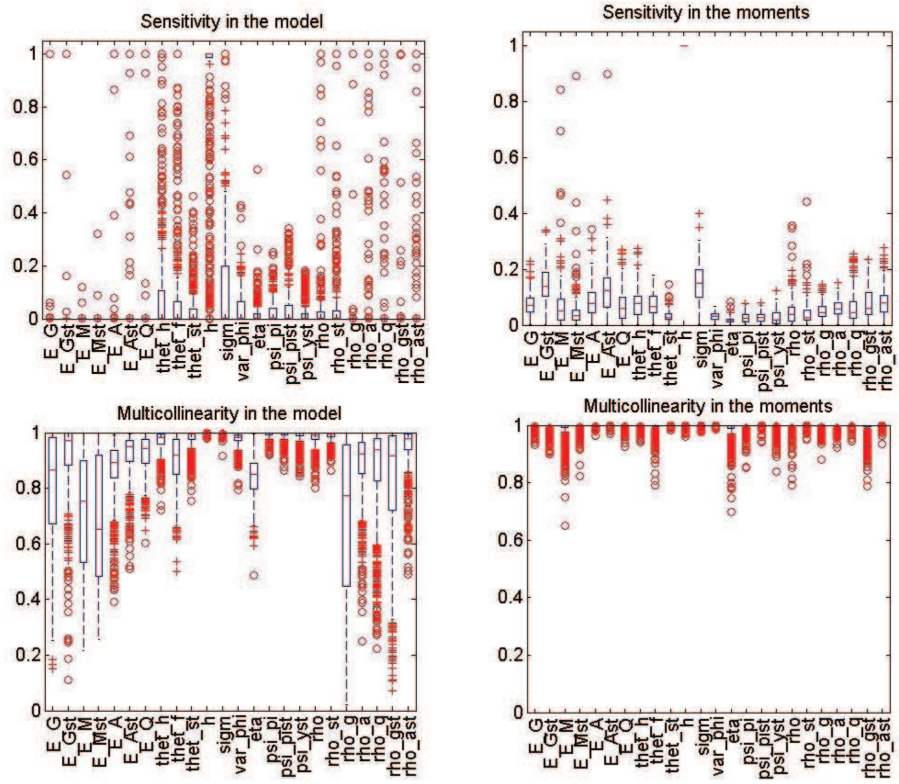

Figure 7: Results from identification analysis. The left column concerns identifiability given the model structure, the right column concerns identifiability from data. Box plots show values of collinearity coefficients obtained in Monte Carlo sampling, red circles indicate outliers. Values close to one indicate potential identification issues.

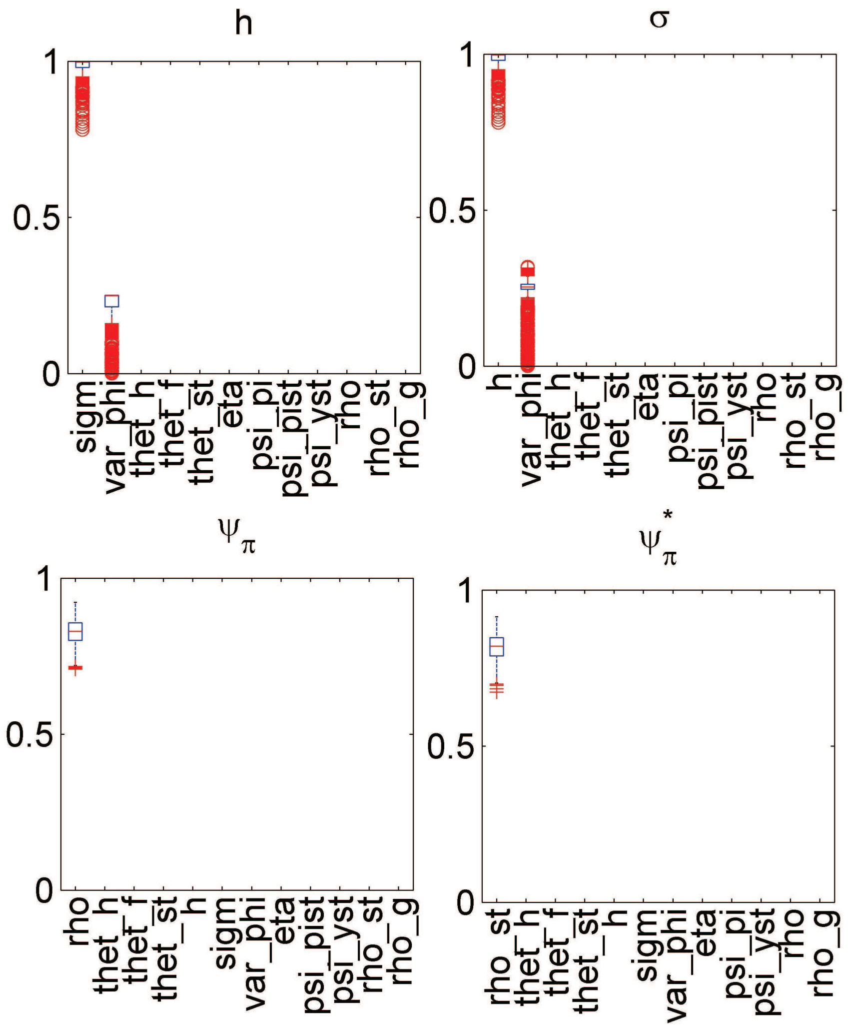

Figure 8: Partial correlations between parameters. Box plots show values of collinearity coefficients obtained in Monte Carlo sampling, red circles indicate outliers. Values close to 1 indicate potential identification issues.

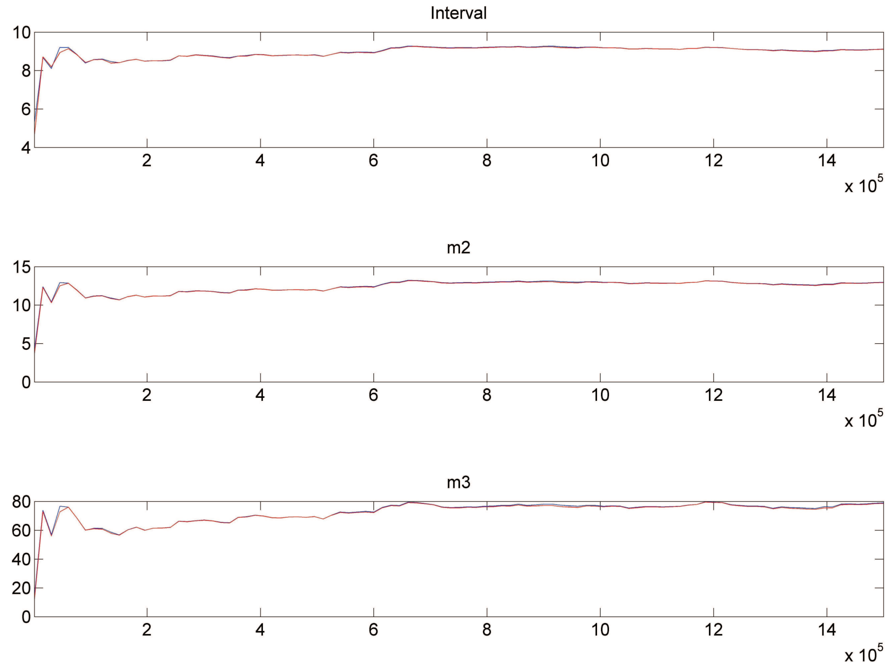

Figure 9: Brooks-Gelman convergence diagnostics. Both runs of Metropolis Hastings algorithm converge and are stable over the last 40% of samples that we use for computing the estimates of parameters.