Analysis of Structural Differences and Asymmetry of Shocks Between the Czech Economy and the Euro Area[1]

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Abstract

The goal of this paper is to examine asymmetry of shocks and structural differences between the Czech economy and the euro area. For this purpose I use a New Keynesian DSGE model of two economies. Structural differences are examined using the posterior distributions of structural parameters. Results suggest that prices are more sticky in the Czech economy, especially in the non-tradable sector, while wages are more sticky in the euro area. It seems that the ECB smooths less the interest rate and reacts more to the development in output and inflation than the Czech National Bank. It also seems that labor supply in the Czech economy is more elastic than labor supply in the euro area. Asymmetry of shocks is examined using correlations between smoothed shocks obtained from the estimation. The most asymmetric shocks are shocks in government expenditures, labor supply shocks, and productivity shocks in the tradable sector, while the most symmetric shocks are consumption preference shocks, monetary policy shocks, and investment efficiency shocks.

Keywords

DSGE model, Bayesian estimation, structural differences, asymmetry of shocks, posterior distribution

JEL code

C51, C68, E32

INTRODUCTION, MOTIVATION

In 2004, the Czech economy joined the European Union, and by doing this, it committed itself to join the European Monetary Union in the future. Since then, attention of the academics and the public has been focused on evaluation whether the common monetary policy is optimal for the Czech economy or not, see Hurník, Tůma and Vávra (2010).

Asymmetric shocks and structural differences are regarded to be the main causes of a potential suboptimality of common monetary policy. Asymmetry of shocks is understood as differences in timing, magnitude or persistence of macroeconomic shocks among economies. Structural differences are, on the other hand, perceived as differences in propagation mechanisms of macroeconomic shocks.

[1] The first, six-page-long draft of this paper was presented at the MME 2013 Conference and under the title *Analysis of Structural Differences and Asymmetry of Shocks using Posterior Distributions* was published in the conference proceedings, see Slanicay (2013a).

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The reason why asymmetric shocks and structural differences can cause suboptimality of common monetary policy is as follows. Business cycle fluctuations of the main macroeconomic variables are driven by macroeconomic shocks. Asymmetric shocks and/or structural differences between economies cause differences in development of their macroeconomic variables over the business cycle. Optimal currency area theory (henceforth OCA), developed by Mundell (1961) and refined by Alesina and Barro (2002), states that one of the main factors influencing suitability of common currency for a given country is a synchronization of the business cycle with the rest of the union. This idea is pretty straightforward. Optimal monetary policy should react to the business cycle fluctuations in a way that promotes macroeconomic stability and development in the country. If the business cycle fluctuations differ across the monetary union countries, the applied common monetary policy is likely to be suboptimal for some countries. Therefore, an analysis of asymmetric shocks and structural differences, as sources of different business cycle behavior, plays an important role in evaluating costs and benefits of common currency.

The goal of this paper is to examine asymmetry of shocks and structural differences between the Czech economy and the euro area. For this purpose I use New Keynesian DSGE model of two economies which I estimate on the data of the Czech economy and the euro area, using Bayesian techniques. Structural differences are examined by comparison of the posterior distributions of structural parameters. Asymmetry of shocks is examined using correlations between smoothed shocks obtained from the model estimation.

The rest of this paper proceeds as follows. The next section provides a review of the related literature. The second section describes the employed model in a brief non-technical manner. The third section briefly discusses some issues related to the estimation of the model. The fourth section contains the analysis of structural differences based on comparison of posterior distributions. The fifth section deals with the analysis of asymmetry of shocks based on correlations between smoothed shocks obtained from the model estimation. Finally, the last section concludes.

1 LITERATURE REVIEW

Much economic research is focused on the issues of asymmetric shocks and structural differences between economies because of their important role in evaluating costs and benefits of common currency. Pauer (1996) provides a non-technical overview of a role of asymmetric shocks in a debate about costs and benefits of common currency.

Several authors try to determine to what extent are shocks in the EU asymmetric. Bayoumi and Eichengreen (1992) find that shocks are significantly more asymmetric across EU countries than across US regions, which may indicate that the EU will experience problems with operating a monetary union. On the other hand, Verhoef (2003) shows that symmetries of demand and supply shocks increase over time in the EMU.

Many authors examine the extent of homogeneity in the euro area. Basically, there are two prevalent approaches: (i) extract the cyclical component from the data using some filtration technique (Hodrick-Prescott filter, band-pass filter, etc.) or time series models and compute the correlations between the corresponding detrended time series; or (ii) use time series models (e.g. SVARs) to identify demand and supply shocks. An extensive survey of the old evidence can be found in Eickmeier (2006) or de Haan et al. (2008). A more recent evidence can be found in Giannone et al. (2010). They find that business cycle is highly synchronized in case of the so-called "core" countries of the euro area (Italy, Germany, France, Belgium, Austria, and the Netherlands) while the business cycle synchronization in the rest of the euro area is much lower. Gächter et al. (2012) examine the impact of the financial crisis on the business cycle synchronization in the euro area. Their results indicate a desynchronization of business cycles during the crisis period, both with respect to dispersion and to the correlation of business cycles.

There is also a growing literature on the business cycle synchronization between the euro area and the countries of Central and Eastern Europe (henceforth CEE). An extensive survey of the old evidence can be found in Fidrmuc and Korhonen (2006) who also offer a related meta-analysis. Benčík (2011) offers a more recent evidence on the BC synchronization between the euro area and the V4 countries. He finds that prior 2001 the business cycles of the V4 countries and the euro area were not synchronised, however, there seems to be convergence of business cycles as the synchronization increases between 2001 and 2007 when the V4 countries joined the EU and increases even further during the economic crisis of 2008–2009.

Structural analysis of business cycle synchronization can be found in my previous paper, see Slanicay (2013b), where I examine such synchronization between the Czech economy and the euro area via fully-specified DSGE model. Using a two-country DSGE model I decompose the observed variables into the contributions of structural shocks and then consequently compute conditional correlations. I also examine how these correlations evolve over time. Similarly, Kolasa (2013) also reports conditional correlations between various business cycle components in the Euro Area and new member states of EU, as well as their evolution over time. The main difference is that he uses a business cycle accounting framework proposed by Chari et al. (2007) rather than a fully-specified DSGE model.

Using model comparison based on Bayes factor, several papers examine presence and relative importance of different sources of heterogeneity among economies. Jondeau and Sahuc (2007, p. 5) distinguish three main sources of heterogeneity: (i) structural heterogeneity which corresponds to differences in preferences, technology, etc.; (ii) policy heterogeneity which corresponds to differences in the conduct of economic policy; and (iii) stochastic heterogeneity which corresponds to differences in shocks hitting respective economies.[3] Jondeau and Sahuc (2007) examine sources of heterogeneity within the euro area and conclude that asymmetric shocks are the main sources of a different behavior of countries in the euro area, while structural differences play almost no role. Similar results are provided by Kolasa (2009) who investigates sources of heterogeneity between Poland and the euro area, and finds out that volatility and synchronization of shocks hitting both economies are the main sources of the heterogeneity between Poland and the euro area. Similarly, in Slanicay (2011) I examine sources of heterogeneity between the Czech economy and the euro area. I do not find substantial evidence in favor of heterogeneity in household preferences. I find slight differences in price and wage formation and substantial difference in interest rate smoothing. However, the main differences are in timing, persistence and volatility of structural shocks. Herber and Němec (2012) provide similar results. They find out that price and wage rigidities and the asymmetry of shocks are the main sources of heterogeneity between the Czech economy and the euro area. On the other hand, they find a strong evidence in favour of homogeneity in parameters describing preferences of households.

This paper has similar goal as the articles mentioned in the previous paragraph, i.e. to examine different sources of heterogeneous behavior between the Czech economy and the euro area. The main difference between this paper andthe existing literature lies in a different method employed. The articles mentioned above make use of the method based model comparison using Bayes factor while this article uses method based on comparison of posterior estimates. The idea which lies beneath the approach based on Bayes factor is following. Parameters can be modeled as common for both economies or as different for each economy. If a significant difference in the values of some parameters truly exists, then the models which allow for difference in these parameters should fit the data better than the models with common values of these parameters. I can compare the unrestricted variant of the model with the restricted variant where selected parameters are modeled as identical for both economies, and find which model fits the data better. If I find out that the unrestricted variant fits the data better, I can conclude that there

[3] Note, that both structural and policy heterogeneity influence propagation mechanisms of macroeconomic shocks among economies and thus can be included in the term "structural differences" while stochastic heterogeneity is an alternative label for asymmetric shocks.

is an evidence of structural difference in those parameters. The measure of how the model fits the data is a value of likelihood function and Bayes factor is simply the ratio of two likelihood values. It can be argued that likelihood function (and Bayes factor in turn) implicitly penalizes the richer structure of the model (i.e. the unrestricted variant) and thus potentially underestimates the significance of structural heterogeneity. The method based on comparison of posterior estimates examines structural differences per se and there should not be a bias of this kind.

2 MODEL

I use a New Keynesian DSGE model of two economies, originally presented in Kolasa (2009). I chose a two-country model because both economies are modeled in the same way there. This means that the log-linearized equations have the same structural form in both economies and the variables, parameters, and shocks have the same structural interpretation in both economies. This feature allows for consistent evaluation of structural differences between the Czech economy and the euro area.

Details about the derivation of the model can be found in the Appendix (available at the website of this journal, see the online version of the *Statistika: Statistics and Economy Journal* No. 1/2016 at: <*http://www.czso.cz/statistika_journal*>). In this section I limit my description of this model to a brief overview of its structure.

The model assumes that there are only two economies in the world: a domestic economy (represented by the Czech economy) and a foreign economy (represented by the euro area). The problematic fact that one economy is much smaller than the other is solved by parameter *n*, which governs the relative size of the two economies.

The next subsections offer a brief description of the domestic economy structure. The foreign economy has an identical structure. Parameters with an asterisk relate to the foreign economy.

2.1 Households

Households in a domestic economy are assumed to be homogenous and maximize its expected utility function:

$$U_t(j) = E_t \sum_{k=0}^{\infty} \beta^k \left[\frac{\varepsilon_{d,t+k}}{1-\sigma} (C_{t+k}(j) - H_{t+k})^{1-\sigma} - \frac{\varepsilon_{l,t+k}}{1+\phi} L_{t+k}(j)^{1+\phi} \right], \tag{1}$$

where E_t denotes expectations in the period t, β is a discount factor, σ is an inverse elasticity of intertemporal substitution in consumption, $H_t = hC_{t-1}$ is an external habit taken by the household as exogenous, h is a parameter of habit formation in consumption, C_t is a composite consumption index (to be defined later), ϕ is an inverse elasticity of labor supply, $\varepsilon_{d,t}$ is a preference shock in the period t, which influences intertemporal decisions about consumption and $\varepsilon_{l,t}$ is a labor supply shock in the period t.

Maximization of the utility function is subject to a set of flow budget constraints given by

$$\begin{aligned} &P_{C,t}C_t(j) + P_{I,t}I_t(j) + E_t\{\Upsilon_{t,t+1}B_{t+1}(j)\} = B_t(j) + W_t(j)L_t(j) \\ &+ R_{K,t}K_t(j) + \Pi_{H,t}(j) + \Pi_{N,t}(j) + T_t(j), \qquad \text{for} t = 0, 1, 2 \ldots, \end{aligned} \tag{2}$$

where $P_{C,t}$ denotes the price of the consumption C_t, $P_{I,t}$ is the price of investment goods I_t, B_{t+1} is the nominal payoff in period t+1 of the portfolio held at the end of period t, W_t is the nominal wage, $R_{K,t}$ denotes income of households achieved from renting capital K_t, $\Pi_{H,t}$ and $\Pi_{N,t}$ are dividends from tradable and non-tradable goods producers and T_t denotes lump sum government transfers net of lump sum taxes. $\Upsilon_{t,t+1}$ is the stochastic discount factor for nominal payoffs, such that $E_t\Upsilon_{t,t+1} = R_t^{-1}$, where R_t is the gross return on a riskless one-period bond.

Consumption index C_t consists of final tradable goods index $C_{T,t}$ and non-tradable goods index $C_{N,t}$ which are aggregated according to

$$C_t = \frac{C_{T,t}^{\gamma_c} C_{N,t}^{1-\gamma_c}}{\gamma_c^{\gamma_c}(1-\gamma_c)^{1-\gamma_c}}, \tag{3}$$

where γ_c denotes share of final tradable goods in consumption of households. Following Burstein et al. (2003) and Corsetti and Dedola (2005), it is assumed that consumption of a final tradable good requires ω units of distribution services $Y_{D,t}$, which implies

$$C_{T,t} = \min\{C_{R,t}; \omega^{-1}Y_{D,t}\}. \tag{4}$$

The consumption index of raw tradable goods is defined as

$$C_{R,t} = \frac{C_{H,t}^{\alpha} C_{F,t}^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}}, \tag{5}$$

where α denotes share of domestic goods in the domestic basket of tradable goods, $C_{H,t}$ is an index of home-made tradable goods and $C_{F,t}$ is an index of foreign-made tradable goods, both consumed in the domestic economy and defined as

$$C_{H,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\phi_H}} \int_0^n C_t(z_H)^{\frac{\phi_H-1}{\phi_H}} \mathrm{dz_H}\right]^{\frac{\phi_H}{\phi_H-1}}, \tag{6}$$

$$C_{F,t} = \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\phi_F}} \int_n^1 C_t(z_F)^{\frac{\phi_F-1}{\phi_F}} dz_F\right]^{\frac{\phi_F}{\phi_F-1}}, \tag{7}$$

where ϕ_H (ϕ_F) is an elasticity of substitution between domestic (foreign) tradable goods, consumed in the domestic economy. Analogously, the consumption index of non-tradable goods is defined as

$$C_{N,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\phi_N}} \int_0^n C_t(z_N)^{\frac{\phi_N-1}{\phi_N}} dz_N\right]^{\frac{\phi_N}{\phi_N-1}}, \tag{8}$$

where ϕ_N is an elasticity of substitution between domestic non-tradable goods.

Households use part of their income to accumulate capital K_t, assumed to be homogenous, which they rent to firms. Capital is accumulated according to the formula:

$$K_{t+1} = (1-\tau)K_t + \varepsilon_{i,t}\left(1 - S\left(\frac{I_t}{I_{t-1}}\right)\right)I_t, \tag{9}$$

where τ is a depreciation rate of capital and I_t denotes investment in the period t. Following Christiano et al. (2005), capital accumulation is subject to investment specific technological shock $\varepsilon_{i,t}$ and adjustment costs represented by function $S(\cdot)$. This function has to satisfy following properties $S(1) = S'(1) = 0$ and $S''(\cdot) = S''> 0$.

Homogenous investment goods are produced in the same way as the final consumption goods, which implies the following definitions:

$$I_t = \frac{I_{R,t}^{\gamma_i} I_{N,t}^{1-\gamma_i}}{\gamma_i^{\gamma_i}(1-\gamma_i)^{1-\gamma_i}}, \tag{10}$$

$$I_{R,t} = \frac{\mathrm{I}_{H,t}^{\alpha} I_{F,t}^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}}. \tag{11}$$

It is assumed that a composition of consumption and investment basket in a given economy can differ, i.e. parameters γ_c and γ_i can be different, and that composition of tradable baskets is identical, i.e. parameter α is the same for both tradable consumption goods and tradable investment goods in the given economy.

Each household is specialized in a different type of labor $L_t(j)$, which it supplies in a monopolistically competitive labor market. All supplied labor types are aggregated into homogenous labor input L_t according to the formula

$$L_t = \left[\left(\frac{1}{n}\right)^{\frac{1}{\phi_W}} \int_0^n L_t(j)^{\frac{\phi_W - 1}{\phi_W}} dj\right]^{\frac{\phi_W}{\phi_W - 1}}, \tag{12}$$

where ϕ_W is the elasticity of substitution between different labor types. A corresponding aggregate wage index is then defined as

$$W_t = \left[\frac{1}{n}\int_0^n W_t(j)^{1-\phi_W} dj\right]^{\frac{1}{1-\phi_W}}, \tag{13}$$

where $W_t(j)$ denotes a wage of the household j.

Following Erceg, Henderson and Levin (2000), a wage setting mechanism a-la Calvo is assumed. According to this set-up, every period only $1-\theta_W$ portion of households (randomly chosen) can reset their wages optimally, while the remaining portion of households θ_W remain their wages unchanged.

2.2 Firms

There is a continuum of homogenous, monopolistic competitive firms in the tradable and non-tradable sectors of the domestic economy. The production functions of firms are represented by Cobb-Douglas functions, homogenous in labor and capital of degree one (i.e. with constant returns to scale):

$$\begin{aligned} Y_t(z_N) &= \varepsilon_{a^N,t} L_t(z_N)^{1-\eta} K_t(z_N)^{\eta}, \\ Y_t(z_H) &= \varepsilon_{a^H,t} L_t(z_H)^{1-\eta} K_t(z_H)^{\eta}, \end{aligned} \tag{14}$$

where η is the elasticity of output with respect to capital (common to both sectors, but potentially different in individual countries), and $\varepsilon_{a^H,t}$ ($\varepsilon_{a^N,t}$) is a productivity shock in the tradable (non-tradable) sector.

Firms set their prices in order to maximize their profits. It is assumed that firms face modified Calvo restriction on the frequency of price adjustment. According to this restriction, every period only $1-\theta$ portion of firms (randomly chosen) can reset their prices optimally, while θ portion of firms remain their prices unchanged.

It is assumed that prices are set in the producer's currency and that international law of one price holds for intermediate tradable goods. Thus, prices of domestic goods sold in the foreign economy and prices of foreign goods sold in the domestic economy are given by formulas:

$$P_t^*(z_H) = ER_t^{-1} P_t(z_H) \qquad P_t(z_F) = ER_t P_t^*(z_F), \tag{15}$$

where ER_t is the nominal exchange rate expressed as units of domestic currency per one unit of foreign currency.

2.3 International Risk Sharing

The assumption of complete financial markets implies that expected nominal returns on domestic and foreign bonds must be the same, which implies the following condition:

$$Q_t = \kappa \frac{\varepsilon_{d,t}^*}{\varepsilon_{d,t}} \frac{(C_t^* - h^* C_{t-1}^*)^{-\sigma^*}}{(C_t - hC_{t-1})^{-\sigma}}, \tag{16}$$

where κ is a constant depending on initial conditions and Q_t is a real exchange rate defined as

$$Q_t = \frac{ER_t P_{C,t}^*}{P_{C,t}}. \tag{17}$$

The real exchange rate can deviate from purchasing power parity because of changes in relative prices of tradable and non-tradable goods, changes in relative distribution costs and changes in terms of trade, as long as there is a difference between household preferences among countries, i.e. $\alpha \neq 1-\alpha^*$.

$$Q_t = S_t^{\alpha+\alpha^*-1} \frac{1+\omega^* D_t^*}{1+\omega D_t} \frac{X_t^{*1-\gamma_c^*}}{X_t^{1-\gamma_c}}, \tag{18}$$

where S_t are terms of trade defined as domestic import prices relative to domestic export prices[4]

$$S_t = \frac{ER_t P_{F,t}^*}{P_{H,t}}, \tag{19}$$

[4] The assumption of law of one price for tradable goods implies $S_t^* = S_t^{-1}$.

X_t and $X_t^*$are internal exchange rates defined as prices of non-tradable goods relative to prices of tradable goods

$$X_t = \frac{P_{N,t}}{P_{T,t}} \qquad X_t^* = \frac{P_{N,t}^*}{P_{T,t}^*} \tag{20}$$

and D_t and $D_t^*$are relative distribution costs, defined as prices of non-tradable goods relative to prices of raw tradable goods

$$D_t = \frac{P_{N,t}}{P_{R,t}} \qquad D_t^* = \frac{P_{N,t}^*}{P_{R,t}^*}. \tag{21}$$

2.4 Monetary and Fiscal Authorities

The behavior of central bank is described by a variant of Taylor rule:

$$R_t = R_{t-1}^{\rho}\left[E_t\left\{\left(\frac{Y_{t+1}}{\overline{Y}}\right)^{\varphi_y}\left(\frac{P_{C,t+1}}{(1+\overline{\pi})P_{C,t}}\right)^{\varphi_\pi}\right\}\right]^{1-\rho}\varepsilon_{m,t}, \tag{22}$$

where ρ is a parameter of interest rate smoothing, Y_t is a total output in the economy, $\overline{Y}$ denotes a steady state level of this output, $\overline{\pi}$ is a steady state level of inflation, ϕ_y is an elasticity of the interest rate to the output, ϕ_π is an elasticity of the interest rate to inflation and $\varepsilon_{m,t}$ is a monetary policy shock.

Fiscal policy is modeled in a very simple fashion. Government expenditures and transfers to households are fully financed by lump-sum taxes so that the state budget is balanced every period. Government expenditures consist only of non-tradable domestic goods and are modeled as a stochastic AR1 process $\varepsilon_{g,t}$. Given the assumptions about households, Ricardian equivalence holds in this model.

2.5 Market Clearing Conditions

The model is closed by satisfying the market clearing conditions. Goods market clearing requires that output of each firm producing non-tradable goods is either consumed by households in the domestic economy, spent on investment, used for distribution services or purchased by the government. Similarly, output of firms producing tradable goods is either consumed or invested in the domestic or foreign economy. Formally:

$$Y_{N,t} = C_{N,t} + I_{N,t} + Y_{D,t} + G_t, \tag{23}$$

$$Y_{H,t} = C_{H,t} + C_{H,t}^* + I_{H,t} + I_{H,t}^*. \tag{24}$$

The total output in the economy is given by the sum of output in tradable and non-tradable sectors:

$$Y_t = Y_{N,t} + Y_{H,t}. \tag{25}$$

Finally, market clearing conditions for factor markets requires

$$L_t = \int_0^n L_t(z_N)dz_N + \int_0^n L_t(z_H)dz_H \tag{26}$$

$$K_t = \int_0^n K_t(z_N)dz_N + \int_0^n K_t(z_H)dz_H. \tag{27}$$

2.6 Exogenous Shocks

Business cycle behavior of the model is driven by seven structural shocks in each economy: productivity shocks in tradable sector ($\varepsilon_{a_{H},t}$ and $\varepsilon^*_{a_{F},t}$), productivity shocks in non-tradable sector ($\varepsilon_{a_{N},t}$ and $\varepsilon^*_{a_{N},t}$), labor supply shocks ($\varepsilon_{l,t}$ and $\varepsilon^*_{l,t}$), investment efficiency shocks ($\varepsilon_{i,t}$ and $\varepsilon^*_{i,t}$), consumption preference shocks ($\varepsilon_{d,t}$ and $\varepsilon^*_{d,t}$), government spending shocks ($\varepsilon_{g,t}$ and $\varepsilon^*_{g,t}$) and monetary policy shocks ($\varepsilon_{m,t}$ and $\varepsilon^*_{m,t}$).

Except for monetary policy shocks which are represented by IID processes, all other shocks are represented by AR1 processes in the log-linearised version of the model. I allow for correlations between innovations of corresponding shocks in both economies.

3 ESTIMATION

3.1 Data

For the estimation of the model I used the quarterly data of the Czech economy and the euro area-17 economy from the 1st quarter of 2000 to the 1st quarter of 2014. The data series were downloaded from the Eurostat web database. I used the following 14 time series (seven for each economy): real GDP, consumption, investment, the HICP, the real wage, the short-term interest rate, and the internal exchange rate (defined as prices of non-tradable goods relative to prices of tradable goods). Except for nominal interest rates, all the observed variables are seasonally adjusted and expressed as demeaned 100*log differences. Nominal interest rates are demeaned and expressed as quarterly rates in percent.[5]

The model is estimated with Random Walk Chain Metropolis-Hastings algorithm, using Dynare toolbox for Matlab, version 4.2.4.[6] I generated two independent chains, each with 2 000 000 draws. From each chain I used only 25% of last draws in order to get rid of the influence of different initial values of the parameters in each chain. Average acceptance rate in each chain is about 29%, which is in line with the informal recommendation about ideal acceptance rate, see for example Koop (2003).

3.2 Calibration

Because of a large number of parameters and a short length of the data sample employed, I decided to calibrate a few parameters. I calibrated those parameters for which I have a good prior information from the data, and those parameters which are known to be weakly identifiable in DSGE models. This mixed approach is quite common in the literature and leads to a better identifiability of non-calibrated parameters, see Canova (2007).

The parameter n governing the relative size of both economies is calibrated to be 0.0138, according to the ratio of nominal GDP levels, averaged over the examined period. The share of tradable goods in consumption in the Czech economy γ_c (in the Euro Area 17γ^*_c) is calibrated to be 0.5384 (0.4953). These values correspond to the complements of the average shares of services and energy goods in the HICP baskets in the examined period. Parameters γ_i and γ^*_i, which denote the share of tradable

5 More details about the data and their visual representation can be found in the Appendix (available at the website of the *Statistika: Statistics and Economy Journal* in the online version of the No. 1/2016 at: <*http://www.czso.cz/statistika_journal*>).

6 More details about Dynare toolbox as well as the Dynare code of the model can be found in the Appendix (see online version of the No. 1/2016 of the *Statistika: Statistics and Economy Journal* at: <*http://www.czso.cz/statistika_journal*>).

7 The portion of discarded draws was set according to Markov Chain Monte Carlo convergence diagnostics which can be found in the Appendix (see online version of the No. 1/2016 of the *Statistika: Statistics and Economy Journal* at: <*http://www.czso.cz/statistika_journal*>).

investment goods, are set equal to 0.5006 and 0.4257, according to the average shares of investment expenditures other than construction works and cultivated assets in the examined period. The shares of domestic tradable goods α and α^* are set equal to 0.28 and 0.989, following Musil (2009).

The discount factors β and β^* are calibrated to be 0.9975, which implies an annual steady state real interest rate of . This value roughly corresponds to the long term mean of annual real interest rates in both economies. Quarterly depreciation rates τ and τ^* are calibrated to be 0.025, which implies an annual depreciation rate of 10%. Distribution costs ω and ω^* are calibrated to zero which implies no share of distribution services in the tradable goods. Elasticities of output with respect to capital η and η^* are calibrated at 0.4160 and 0.3618, which corresponds to the complement to the average shares of labor on the GDP in the given economy in the period 2000–2010.[8] Elasticities of substitution among labor types ϕ_W and ϕ^*_W, which are known to be badly identifiable, are set equal to 3 following Smets and Wouters (2003). This value implies a wage mark-up of 50%. Following Slanicay and Vašíček (2011), Čapek (2010) and Matheson (2010), who argue that incorporating price (wage) indexation into the Calvo price (wage) setting mechanism deteriorates the empirical fit of DSGE models, I decided to set indexation parameters δ_H, δ^*_F, δ_N, δ^*_N, δ_W and δ^*_W equal to 0. It implies that the estimated variant of the model employs the original Calvo price (wage) setting mechanism, see Calvo (1983).

Steady state shares of consumption, investment and government spending in the total output correspond to their average shares in the GDP in the examined period. Namely, $\frac{\overline{C}}{\overline{Y}} = 0.4929$, $\frac{\overline{I}}{\overline{Y}} = 0.2590$, $\frac{\overline{C^*}}{\overline{Y^*}} = 0.5681$ and $\frac{\overline{I^*}}{\overline{Y^*}} = 0.1999$. Other steady state shares are calculated consistently with the derivation of the model (analogously for the foreign economy):

$$\frac{\overline{G}}{\overline{Y}} = 1 - \frac{\overline{C}}{\overline{Y}} - \frac{\overline{I}}{\overline{Y}}, \tag{28}$$

$$\frac{\overline{Y_N}}{\overline{Y}} = \frac{1 + \omega - \gamma_c}{1 + \omega}\frac{\overline{C}}{\overline{Y}} + (1 - \gamma_i)\frac{\overline{I}}{\overline{Y}} + \frac{\overline{G}}{\overline{Y}}, \tag{29}$$

$$\frac{\overline{Y_H}}{\overline{Y}} = 1 - \frac{\overline{Y_N}}{\overline{Y}}. \tag{30}$$

3.3 Prior Setting

Remaining parameters are estimated. For parameters whose natural domain is the interval between 0 and 1, I chose Beta distribution of priors. For structural parameters whose natural domain is the set of non-negative real numbers, I chose Gamma distribution of priors, except for the parameters of adjustment costs S^*, S^{**}. For those I chose Normal distribution of priors. For parameters representing standard deviations of shocks, whose natural domain is the set of non-negative real numbers, I chose Inverse Gamma distribution of priors. For parameters representing spillovers of the foreign shocks, whose natural domain are real numbers, I chose Normal distribution of priors.

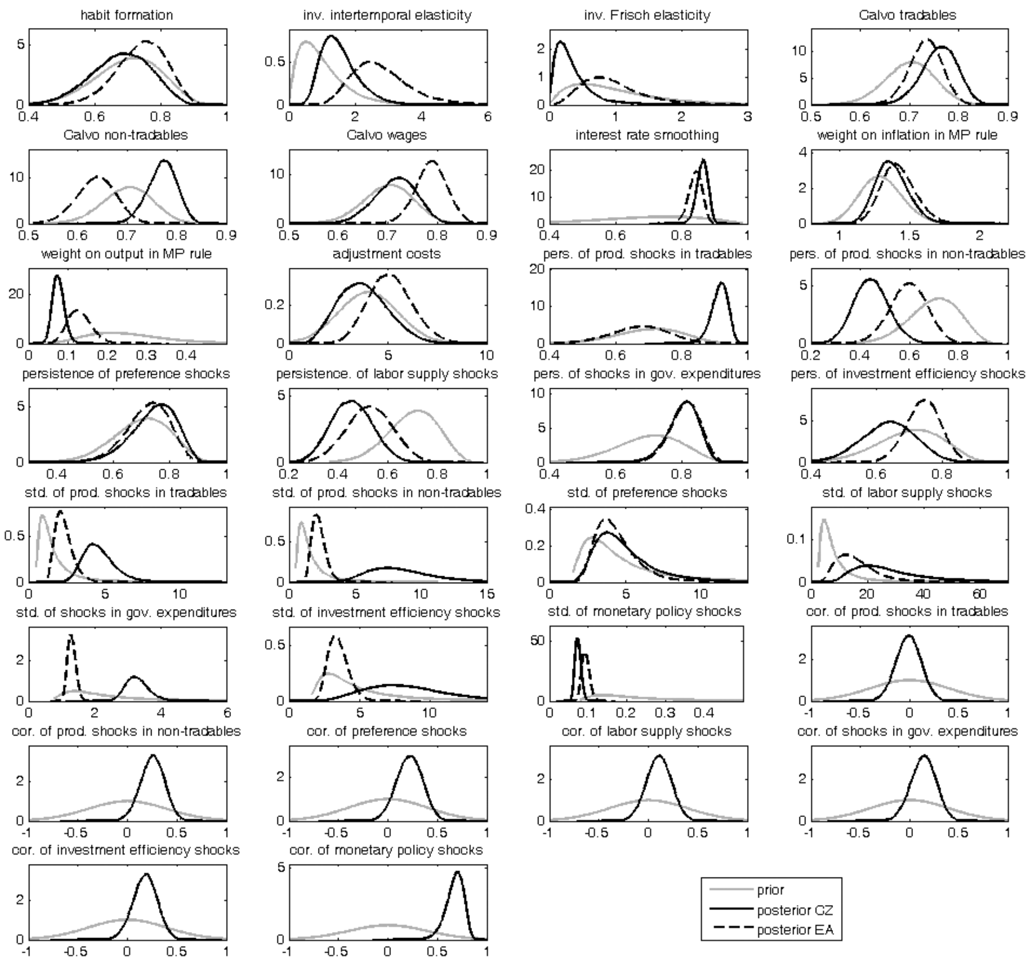
Prior means for Calvo parameters of price and wage stickiness θ_H, θ^*_F, θ_N, θ^*_N, θ_W and θ^*_W are set to be 0.7 which implies the average price (wage) duration of 10 months. Priors for parameters in the Taylor rule are set consistently with Taylor (1999). Inverse elasticities of intertemporal substitution σ and σ^* and inverse Frisch elasticities of labor supply ϕ ϕ^* are estimated with relatively loose priors with prior means set to be 1.0, following Galí (2008), and prior std. deviations equal to 0.7, which are values commonly

[8] See: <*http://stats.oecd.org*>.

found in the business cycle literature. Parameters of habit formation h and h^* are estimated with prior means set to be and prior std. deviations equal to , as in Smets and Wouters (2003). Priors for capital adjustment costs S^* and S^{**} are taken from Kolasa (2009). Priors for shocks are taken from Herber and Němec (2012).

Figure 1 depicts the prior and posterior distributions of the estimated parameters so the readers get some idea on how well are the parameters identified in the data. We can see that there is a substantial, though not perfect, overlap of prior and posterior distributions which may suggest either that prior distributions are well chosen or that there is not enough information about the parameters in the data. In most cases, however, posterior distributions are either not overlapping so heavily with prior distributions or are more tight than prior distributions which suggest that the data bear some information regarding the estimated parameters.

Figure 1 Priors and Posteriors



Source: Own construction

4 ANALYSIS OF STRUCTURAL PARAMETERS

Structural differences manifest themselves as significant differences in values of some parameters. As the estimates of parameters are given by their posterior distributions, see Figure 1, it seems therefore intuitive to compare posterior distributions of corresponding parameters in both economies and evaluate how much they overlap.[9]

There are many ways how to evaluate the overlap of posterior distributions. I use the following five criteria.[10] The benchmark criterion is the overlapping area of normalized posterior densities, henceforth denoted as *area*. The obtained number must lie between zero and one, where zero means that densities do not have single common point while unity means identical densities. The next four criteria use credible intervals in various specifications. The criterion *s_2S* is based on two-sided probability band and measures the lowest level of significance at which two-sided probability bands do not overlap. Similarly, the criterion *s_HPD* denotes the lowest level of significance at which the highest posterior density intervals do not overlap. The last two criteria are based on point estimates. The criterion *s_med* denotes the lowest level of significance at which posterior median is out of two-sided probability bands, while the criterion *s_mod* denotes the lowest level of significance at which posterior mode is out of HPD interval bands.[11] The possible values of all five criteria range from zero to one, where zero represents absolute asymmetry in the parameter values while unity represents absolute symmetry in the parameter values.

The reason for multiple criteria is the following: the benchmark criterion *area* may in certain circumstances deliver a strange result. It may happen that calculated *area* of two posterior distributions can be very low although their central tendencies (represented for example by posterior mean) are the same. It is the case when the main difference between two posterior distributions lies in different identifiability of these two parameters and, therefore, in different uncertainty connected with posterior estimates.

Table 1 displays calculated criteria of the overlap of posterior distributions, ordered from the lowest *area* to the highest. The biggest difference lies in the degree of price stickiness in the non-tradable sector, with *area* = 0.05. It seems that domestic prices of non-tradable goods are much more sticky than foreign prices of non-tradable goods. Point estimates[12] imply that the average duration of domestic prices of non-tradable goods is about 13 months, while the average duration of foreign prices of non-tradable goods is only 8.2 months.

The second biggest difference is in the way how central banks react to the development of output, with *area* = 0.22. It seems that unlike the Czech National Bank (henceforth CNB), the ECB reacts more to the development of output. Point estimates imply that one percent deviation of output from the steady state (trend) brings about change in the interest rate of 0.041% in the Czech economy, and 0.081% in the euro area.

The third biggest difference is in the degree of wage stickiness, with area = 0.32. Results suggest that wages in the Czech economy are less sticky than wages in the euro area. Point estimates imply that the average duration of wage is 10.5 months in the Czech economy, and 14.1 months in the euro area.

There is also a big difference in the inverse Frisch elasticity of labor supply, with *area* = 0.35. It seems that labor supply in the Czech economy is more elastic than labor supply in the euro area. Point estimates imply that the 1% increase of the real wage induces 2.9% increase of the labor

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9 This type od analysis can be also used for identification of structural changes in an economy, see Čapek (2016) who applies this approach on the Czech economy data.

10 Formal definition od these criteria can be found in the Appendix (see online version of the No. 1/2016 of the *Statistika: Statistics and Economy Journal* at: *http://www.czso.cz/statistika_journal*).

11 Note that both criteria *s_med* and *s_mod* deliver two values – one for a domestic parameter and one for a foreign parameter.

12 Point estimates are represented by the estimated posterior mean.

Table 1 Overlap of Posterior Distributions

structural parameters	*area*	*s_2S*	*s_HPD*	*s_med*	*s_mod*
price stickiness of non-tradables	0.05	0.06	0.06	0.01 0.01	0.01 0.01
weight on output in MP rule	0.22	0.23	0.25	0.01 0.05	0.01 0.05
wage stickiness	0.32	0.33	0.36	0.06 0.04	0.07 0.05
inverse elasticity of labor supply	0.35	0.36	0.35	0.11 0.07	0.09 0.06
inverse elasticity of intertemporal subs.	0.36	0.37	0.37	0.08 0.07	0.08 0.06
adjustment costs	0.55	0.57	0.54	0.29 0.19	0.24 0.18
interest rate smoothing	0.58	0.57	0.59	0.26 0.28	0.23 0.30
price stickiness of tradables	0.67	0.68	0.65	0.46 0.36	0.46 0.32
habit formation in consumption	0.71	0.71	0.70	0.48 0.44	0.53 0.36
weight on inflation in MP rule	0.84	0.84	0.82	0.70 0.69	0.65 0.67

Source: Own calculation

supplied in the Czech economy, while in the euro area the 1% increase of the real wage induces only 1% increase of the labor supplied.[13]

There is also a difference related to the inverse elasticity of intertemporal substitution, with *area* = 0.36. It suggests that domestic households are less willing to smooth consumption over the time then their foreign counterparts.

The overlapping *area* of remaining parameters is higher than 0.5, which suggests that differences in these parameters are less significant. However, there are still some interesting differences which are worth interpreting. It seems that domestic prices in the tradable sector are more sticky than foreign prices in the tradable sector. Point estimates imply that the average duration of prices in the tradable sector is 12.5 months in the Czech economy, and 11.2 months in the euro area.

Other structural differences are related to the parameters in the monetary policy rule, namely the degree of interest rate smoothing and the way how central banks react to the development of inflation. It seems that the ECB smooths its interest rate less than the CNB does and that the ECB reacts more to the development of inflation than the CNB does. Point estimates imply that one percent deviation of inflation from the steady state (trend) induce a change in the interest rate of 0.75% in the Czech economy and 0.9% in the euro area.

5 ANALYSIS OF ASYMMETRY OF SHOCKS

Except for monetary policy shocks, the shocks in the Czech economy are more volatile than the same kind of shocks in the euro area, see Figure 1. Volatility of monetary policy shocks is little bit larger in the euro area than in the Czech economy, nevertheless, the differences in the estimated posterior means are almost negligible.

[13] One need to be very careful with the interpretation of the results for the elasticity of labor supply. Firstly, it is well-known fact that estimates of the elasticity of labor supply obtained from macro data are usually much higher than estimates based on micro data, for a discussion of this topic see Chetty et al. (2011), Peterman (2012) or Reichling and Whalen (2012). Secondly, as the posterior distributions of the other structural parameters are more or less centred, it does not matter whether we choose as the point estimate the posterior mean, posterior mode or posterior median. However, in the case of the inverse Frisch elasticity of labor supply the posterior distributions are highly skewed, see Figure 1, which imply a very different values for the posterior mean, posterior mode and posterior median. In particular, posterior mean is higher than posterior median which is higher than posterior mode. Nevertheless, the result that labor supply in the Czech economy is more elastic than labor supply in the euro area seems to be robust among these different point estimates.

As regards the correlations between corresponding shocks in both economies, for obvious reasons it can not be analysed via the method based on the overlap of posterior distributions. Therefore, I decided to analyse these correlations via their point estimates obtained from smoothed realisations of the shocks. Table 1 displays correlations between corresponding innovations in the shocks and, except for the monetary policy shocks which are modeled as IID processes, correlations between the corresponding whole shocks represented by AR1 processes.

Table 2 Estimated Correlations between Shocks

structural shocks	correlation (p value)	
	innovation	**AR1**
consumption preference shocks	0.22 (0.10)	0.82 (0.00)
monetary policy shocks	0.66 (0.00)	n.a.
shocks in investment efficiency	0.20 (0.14)	0.64 (0.00)
productivity shocks in non-tradables	0.30 (0.03)	0.57 (0.00)
productivity shocks in tradables	–0.04 (0.79)	0.35 (0.01)
labor supply shocks	0.15 (0.29)	0.33 (0.01)
shocks in government expenditures	0.16 (0.23)	–0.18 (0.18)

Source: Own calculation

If we are interested in the asymmetry of shocks actually hitting the economies, then we should pay more attention to the correlations between the corresponding whole shocks, presented in the last column of the Table 1.[14] We can see that the whole shocks are much more correlated than the corresponding innovations, thus suggesting that shocks are less asymmetric than what would the correlations between innovations imply.

The most correlated shocks are (ordered from the highest correlation to the lowest) consumption preference shocks (cor = 0.82), monetary policy shocks (cor = 0.66), investment efficiency shocks (cor = 0.64), and productivity shocks in the non-tradable sector (cor = 0.57). Correlations of these shocks are quite high, all of them are statistically significant on the significance level $\alpha = 0.01$. We can say that these shocks are quite symmetric between the Czech economy and the euro area. On the other hand, the shocks with the lowest correlations are (ordered from the lowest correlation to the highest) shocks in government expenditures (cor = –0.18), labor supply shocks (cor = 0.33), and productivity shocks in the tradable sector (cor = 0.35). These shocks can be regarded as asymmetric between the Czech economy and the euro area.

CONCLUSION

In this paper I examined asymmetry of shocks and structural differences between the Czech economy and the euro area. For this purpose I used New Keynesian DSGE model of two economies, originally presented in Kolasa (2009). The model is estimated on the data of the Czech economy and the euro area, using Bayesian techniques.

Structural differences are examined via the overlap of posterior distributions of structural parameters. Results suggest that prices in the Czech economy are more sticky than prices in the euro area,

[14] In Kolasa (2009), which is the reference paper for the model employed in this paper, the asymmetry of shocks is analysed using correlations between corresponding innovations in the shocks. From my point of view, these results might be misleading because these correlations are only between innovations and not between shocks actually hitting the economies. I view the results based on the correlations between the whole shocks (in most cases represented by AR1 process) as more meaningful.

especially in the non-tradable sector, while wages are more sticky in the euro area than in the Czech economy. It seems that the ECB smooths less the interest rate and reacts more to the development in output and inflation than the CNB. It also seems that labor supply in the Czech economy is more elastic than labor supply in the euro area. Results also suggest that Czech households are less willing to smooth consumption over the time then their foreign counterparts.

Asymmetry of shocks is examined using correlations between smoothed shocks obtained from the model estimation. Except for monetary policy shocks, the shocks in the Czech economy are more volatile than the same kind of shocks in the euro area. The most asymmetric shocks are shocks in government expenditures, labor supply shocks, and productivity shocks in the tradable sector, while the most symmetric shocks are consumption preference shocks, monetary policy shocks, and investment efficiency shocks. Productivity shocks in the non-tradable sector can be regarded as moderately symmetric.

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APPENDIX

See the separate PDF file in online version of the *Statistika: Statistics and Economy Journal* No. 1/2016 at: <*http://www.czso.cz/statistika_journal*>.