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Labour Market in the Czech Republic: DSGE Approach

Martin Železník[1]

Abstract: This paper deals with the comparison of two versions of the DSGE model, supplemented with labour market frictions, based on different data used. One of the data sets has been pre-filtered with the HP filter (lambda set to 1) to get rid of any noise and the other with the original data series with measurement errors allowed. I compare the models with the following tools: parameters estimation, impulse response analysis, standard deviation and cross-correlations and recursive forecast. I also present the historical shock decomposition of the labour market variables to provide the explanation of the development in the Czech labour market, which is considered the most efficient labour market in Europe of the last couple of years with the lowest unemployment rate.

Key words: DSGE models, labour market, search and matching

JEL Classification: E32, E44, E58, J01

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Introduction

A good model can be devalued by the application of various transformations of the data, producing different results. Thus, I provide an analysis that presents the results using two different data sets in the estimation of the same model. The model is designed to describe the labour market in the Czech economy as it plays an important role in the functioning and understanding of the economy. This topic is of interest to the policy makers who can influence the labour market in the economy by setting law boundaries in which the agents, households, workers and firms exist. Policy makers should also understand the driving forces of the labour market in order to prevent the high volatility of the key labour market variables.

The aim of the paper is to compare the two versions of the model with a set of tools that can provide valuable information about the functioning of the model. Another, more empirical part of the paper is the identification of the main factors that can explain the

[1] National Bank of Slovakia, Economic and Monetary Analyses Department, Section of forecasting, Modelling and International Economy Analyses, Imricha Karvaša 1, 813 25 Bratislava, Slovak Republic, zeleznikmartin0@gmail.com.

development of the labour market in the Czech Republic especially in the last decade. I have used data from the 2000q1 − 2017q2 period.

To achieve the objective of the paper, the model approach is used. The dynamic stochastic general equilibrium (DSGE) models belong among the main tools of a macroeconomic modelling used in many central banks and institutions as policy advice. The basic version of this model without an elaborate labour market is used in the National Bank of Slovakia (Výškrabka, Tvrz and Železník (2018), to be published).

Model

Since we focus on the labour market development, a DSGE model with an elaborate labour market and search and matching frictions is used for the analysis. We use a model much like the one used by the Czech National Bank developed by Andrle et al. (2009) but supplemented with labour market as designed by Christoffel et al. (2009) and Trigari (2006). Similar work can be found in Tonner et al. (2015), where they use different versions of the possible incorporation of the labour market and test the model for a forecast. The structure of the model is quite standard; therefore, we only describe its most important features. The domestic economy has been modelled using the following representative economic agents: households, intermediate firms, importers, final goods producers, government and central bank.

Firms

The monopolistically competitive intermediate firms combine capital and labour to produce domestic intermediate goods similar to the ones described by Christoffel et al. (2008). Homogenous bundles of the intermediate goods together with homogenous bundles of imported goods are then used by the final goods producers. There are four different final production sectors that produce consumption goods, investment goods, government consumption goods and export goods. Each sector is comprised of infinite number of firms which combine domestic intermediate and imported goods to produce final goods similar to Gomes et al. (2010). Each firm produces distinct goods which allows them to charge a price that may differ from the prices charged by its competitors.

Nevertheless, firms are not allowed to re-optimize prices every period. They follow the Calvo (1983) pricing mechanism, where only a fraction of firms can re-optimize their prices in a given period. All of the remaining firms adjust their prices according to the past and steady-state inflation. Moreover, firms producing export goods set prices in foreign currency (local currency pricing), which prevents the immediate transmission of exchange rate movements to prices. Capital is a homogeneous production factor which is rented by the firms on a perfectly competitive market. On the other hand, there are infinitely many different types of labour and imported goods. All firms also pay taxes levied on their wage cost (social security).

Households

Households are Ricardian – they consume, own capital (invest), own firms, have access to financial markets (both domestic and international), supply labour and negotiate the price of their labour service. They also receive transfers from government and pay consumption (VAT), labour and dividend income taxes. The household members maximize the given expected lifetime utility similar to the one described by Christoffel et al. (2008).

Monetary authority

The monetary authority sets the nominal interest rates according to the modified Taylor (1993) rule:

$$\hat{R}_t^4 = \rho^R \hat{R}_{t-1}^4 + (1-\rho^R)\left(\phi^\pi\left(\pi_{t-1}^4 - \overline{\pi}_t^4\right) + \phi^C \widehat{C}_t + \phi^S \Delta\hat{S}_{t+1}\right) + \varepsilon_t^R.$$

Current value of nominal interest rate deviation from its steady state $\hat{R}_t^4$ depends on its previous value $\hat{R}_{t-1}^4$, on the deviation of previous inflation π_{t-1}^4 from its steady-state $\overline{\pi}_t^4$, on real consumption gap $\widehat{C}_t$ – which is here because the GDP variable does not exist in the model and consumption works as the approximation of GDP – and on deviation of expected nominal exchange rate $\Delta\hat{S}_{t+1}$. The parameter ρ^R represents the smoothing parameter, ϕ^πweight parameter of lagged inflation π_{t-1}^4 , ϕ^C weight on consumption gap, and ϕ^Sweight on expected nominal exchange rate. Deviations of interest rate from the interest rate rule are explained as monetary policy i.i.d. shock ε_t^R.

Fiscal authority

The government collects taxes (both distortionary and lump-sum) paid by households and firms. It unproductively consumes part of its income and pays the rest in a form of transfers to households. The difference between revenues and expenditures is financed by issuing bonds.

Financial markets

Financial markets are incomplete, which means that households are unable to perfectly insure against unexpected shocks. This structure leads to the UIP condition, which links together the domestic interest rates, foreign interest rates and expected changes in the exchange rate.

Foreign sector

The foreign sector is comprised of interest rates, prices and the demand for domestic export goods. This sector is exogenous, reflecting the negligible size of the domestic economy. Similarly to the Taylor rule, the foreign inflation $\pi_t^{IM*}$is defined as the deviation from its steady state. In this paper's set up, the foreign inflation is only influenced by the foreign monetary policy R_t^* that corresponds with the ECB. The foreign output Y_t^{IM*}, which determines the foreign demand for the domestic economy exports, is defined in similar fashion. The monetary policy in the foreign economy, in this case the Eurozone, is again defined via the Taylor rule, where the deviation of current nominal interest rate from its steady state R_t^* is influenced by foreign inflation π_t^{IM*} and foreign output Y_t^{IM*} with their representative weight parameters $\kappa^{R^*\pi^{IM*}}$ and $\kappa^{R^*Y^*}$. Each equation includes i.i.d. shocks and a straightforward explanation.

Labour Market

In this section the focus is on labour market, the main interest of the study. This model contains a labour market block with the search and matching frictions (S&M) and right-to-manage bargaining (RTM). Christoffel et al. (2009) and Trigari (2006) are the main consulted sources. In this alternative setup, an additional economic agent is introduced to the model - the employment agencies[2]. They act as the middleman between households that supply their labour and the intermediate firms which buy the labour as an input in their production. The labour agencies negotiate with the workers their wage and set the optimal amount of hours worked per employee according to the RTM concept. Under the RTM, the workers and the firms only negotiate the hourly wage rate and the firm then chooses the employment along the intensive margin[3]. This would imply a direct channel from the wages to inflation, so that the level of hourly wages and their stickiness play a direct role in inflation dynamics. This wage channel is in line with much of the New Keynesian modelling tradition, as seen in e.g. Christiano et al., (2005) and Smets and Wouters (2003). First, I build on Trigari's RTM framework to allow for a direct channel from wages to inflation. Second, once the firm and the worker meet, they bargain over the hourly wage rate, but in an infrequent way, where the staggering of the wage-setting process is modelled according to Calvo (1983).

I assume there is a continuum (normalized to one) of perfectly competitive employment agencies, each employing only one worker.

The production function of j-th employment agency is:

$$N_t^{OUT}(j) = z_{LM} N_t^{IN}(j)^{\alpha_{LM}},$$

where z_{LM} is a scale parameter and α_{LM} is elasticity of the production function. The employment agency pays workers for $N_t^{IN}(j)$ hours of work and sells $N_t^{OUT}(j)$ hours of work to the intermediate firms. Due to perfect competition and the homogeneity of workers, the aggregate production of employment agencies is:

$$N_t = \int_0^{n_t} N_t^{OUT}(j) \mathrm{d}j = n_t N_t(j), \forall j,$$

where n_t is the number of employed workers in the population. The employment evolves according to the following law of motion

$$n_t = (1 - \rho_{LM}) n_{t-1} + m_{t-1},$$

where ρ_{LM} is exogenous separation rate that determines how many job-worker pairs are destroyed each period, and m_{t-1} is the number of new matches formed in the previous period. Since the labour force[4] is normalized to one (the labour force is not modelled in this paper), the unemployment rate is expressed as $1-n_t$ at the beginning of the period. However, it is assumed that the workers that have lost employment start searching for a new job within that same period. Therefore, the pool of unemployed workers available for hire evolves according to

$$u_t = 1 - (1 - \rho_{LM}) n_t.$$

[2] In reality, one could link the theoretical concept of employment agencies to the human resources department of the intermediate firms

[3] Intensive margin represents the hours worked.

[4] Labour force is defined as a sum of employment and unemployment.

We assume that the search and matching process follow a standard matching function

$$m_t = \chi_t^{LM} u_t^{\nu_{LM}} v_t^{1-\nu_{LM}},$$

where χ_t^{LM} is matching efficiency shock, v_t is the number of vacant jobs and ν_{LM} is the elasticity of matching function w.r.t. unemployment. The matching efficiency shock develops according to

$$\chi_t^{LM} = \rho_\chi \chi_{t-1}^{LM} + (1-\rho_\chi)\chi_{SS}^{LM} + \varepsilon_t^\chi, \text{ where } \varepsilon_t^\chi \sim N(0,\sigma_\chi).$$

To be able to describe the behaviour of workers and employment agencies, we now need to define their respective value functions. The Bellman equation for employed workers $\mathcal{W}_t(j)$ that take part in wage bargaining captures the trade-off between labour income and disutility of work

$$\mathcal{W}_t(j) = (1-\tau_t^w)W_t^* N_t^{IN}(j) - \frac{\kappa^L N_t^{IN}(j)^{1+\psi}}{(1+\psi)\Lambda_t^I} + E_t\left\{\beta_{t,t+1}\left[(1-\rho_{LM})\left(\omega_w \mathcal{W}_{t+1}(j) + \left(1-\omega_w \mathcal{W}^*{}_{t+1}(j)\right)\right) + \rho_{LM}\mathcal{U}_{t+1}(j)\right]\right\},$$

where $\beta_{t,t+1} = \beta \frac{\Lambda_{t+1}^I}{\Lambda^I{}_t}$ is a stochastic discount factor, Λ_t^I is marginal utility, W_t^* is the newly bargained wage, τ_t^w is the income tax payed by the workers, ω_w is wage Calvo parameter and $\mathcal{U}_t(j)$ is the value function of unemployed workers. The value of a worker in employment $\mathcal{W}_t(j)$ depends on his wage income, which is determined by the product of nominal wage rate W_t^* and the hours worked $N_t^{IN}(j)$, which is then taxed. Second term in the first row represents the loss of utility from working. In the next period, an employee retains his job with the probability $(1-\rho_{LM})$. If he stays employed in t+1, with the probability ω_w he will not be able to re-negotiate the nominal wage. In this case the nominal wage is partially indexed to inflation and the employee's value to the family is $\mathcal{W}_{t+1}(j)$. If the employee manages to re-negotiate after all, it leads to the optimal re-negotiated wage in t+1 and his value to the family is $\mathcal{W}^*{}_{t+1}(j)$. With the probability ρ_{LM} he will be unemployed the next period. The value of an unemployed family member to the family is given by

$$\mathcal{U}_t(j) = b_t^{LM} + E_t\{\beta_{t,t+1}[s_t(1-\rho_{LM})(\omega_w \mathcal{W}_{t+1}(j) + (1-\omega_w)\mathcal{W}^*{}_{t+1}(j)) + (1-s_t(1-\rho_{LM}))\mathcal{U}_{t+1}(j)]\},$$

where $b_t^{LM} = \beta^b(1-\tau^w)\overline{WN}^{IN}$ are unemployment benefits that are given as β^b fraction of steady-state wage income and s_t is job-finding rate defined as m_t/u_t.

Therefore, both the employed and unemployed workers that find a new job have the same chance of being able to take part in wage negotiations the next period, which is defined as $1-\omega_w$. In such a case they will have the value function $\mathcal{W}^*{}_{t+1}$. Otherwise, they keep the average wage from the previous period and only index it to inflation. The value function in the next period is then $\mathcal{W}_{t+1}$. Full indexation to inflation is assumed.

The value functions of employed and unemployed worker can be added up to express the worker's surplus $\Delta_t^W(j) = \mathcal{W}_t(j) - \mathcal{U}_t(j)$, which denotes the family's surplus from an employed family member at wage $W_t(j)$ rather than having him unemployed:

$$\Delta_t^W(j) = (1-\tau_t^w)W_t^* N_t^{IN}(j) - b_{LM} - \frac{\kappa^L N_t^{IN}(j)^{1+\psi}}{(1+\psi)\Lambda_t^I} + E_t\{\beta_{t,t+1}(1-\rho_{LM})(1-s_t^{LM})[\omega_w \Delta_{t+1}^W(j) + (1-\omega_w)\Delta_{t+1}^{W*}(j)]\}.$$

Because there is a free entry in the vacancy posting market, firms are economically worthless in equilibrium if separated from a worker. The market value of a labour firm $J_t(j)$ matched to a worker who receives the nominal wage $W_t(j)$ is given by

$$J_t(j) = x_t z_{LM} N_t^{IN}(j)^{\alpha_{LM}} - (1+\tau_n)W_t^* N_t^{IN}(j) - fc_{LM} + (1-\rho_{LM})E_t\{\beta_{t,t+1}[\omega_w J_{t+1}(j) + (1-\omega_w)J_{t+1}^*(j)]\}'$$

where x_t is the competitive price the intermediate firms pay to the labour agencies for the supplied labour $N_t^{IN}(j)$, τ_n is labour tax payed by the employer, and fc_{LM} is the fixed cost[5] of production. The first row represents the real per-period profits of the firm when the nominal wage rate is $W_t(j)$. $N_t^{IN}(j)$ is the firm's labour input.

The value function of the employment agencies in the next period is either $J_{t+1}(j)$ with the probability ω_w or $J_{t+1}^*(j)$ with the probability$1-\omega_w$. In the first case, the average wage from the last period is only indexed to inflation, while in the other case the wage is re-negotiated to a new optimum.

Vacancy posting is a costly process in this model, just as it is in the reality. We can write down the value of vacancy opening to the firm as follows:

$$V_t(j) = -\frac{\kappa^V}{\Lambda_t^I} + E_t\{\beta_{t,t+1}[q_t(1-\rho_{LM})[\omega_w J_{t+1}(j) + (1-\omega_w)J_{t+1}^*(j)] + (1 - q_t)V_{t+1})]\}$$

where κ^V is the vacancy posting cost parameter and $q_t = m_t/v_t$ is the job-filling rate. The value of an open vacancy $V_t(j)$ depends negatively on fixed costs κ^V, expressed in terms of marginal utility, and positively on the value of the labour firm matched to the worker $J_{t+1}(j)$ with the probability q_t, as the firm only gains the value $J_{t+1}(j)$ if the vacancy is filled.

The free-entry condition implies that the firm would open new vacancies whenever $V_t(j) > 0$. Thus, in equilibrium $V_t = 0$, ∀t and the vacancy posting condition is

$$\frac{\kappa^V}{\Lambda_t^I} = E_t\{\beta_{t,t+1} q_t (1-\rho_{LM})[\omega_w J_{t+1}(j) + (1-\omega_w)J_{t+1}^*(j)]\}.$$

Under right-to-manage bargaining the labour agencies and workers first negotiate a real wage and then the labour agencies unilaterally choose the optimal number of hours worked according to their optimality condition, i.e. equating the return from marginal product of labour to the marginal cost, which is the wage plus the labour taxes that pay

[5] Job-related fixed costs are costs that are independent of the actual hours worked per employee, but not of the number of employees. In practice, such job-related fixed costs arise both on the labour and the capital side. On the labour side some employer benefits are not linked to the actual input of hours worked. An example of this can be a fixed entitlement of paid leave per quarter.

the firm: $x_t * MPL_t = W_t\,(1+\tau^N)$. MPL_t from production function of employment agencies is equal to $MPL_t = z_{LM}\alpha_{LM}N_t^{IN^{\alpha_{LM}-1}}$. This step is anticipated and internalized during the wage bargaining. Since both the labour agencies and the workers alike know how the change in wage will influence the choice of hours worked (let us denote this change by $dN_{W,t}$), they take this effect into account. $dN_{W,t}$ can be derived from production function of employment agencies.

Considering the RTM condition $x_t * MPL_t = W_t(1+\tau^N)$, the optimal wage W_t^* is negotiated via Nash bargaining, i.e. the total match surplus is divided between workers and employment agencies according to their negotiating power that is captured by the parameter η (negotiating power of workers). The wage negotiation can then be described as optimization problem of the following equation:

$$\max_{W_t^*}(\Delta_t^W)^\eta J_t^{1-\eta}.$$

This yields the following first-order condition:

$$\eta J_t \delta_t^W = (1-\eta)\Delta_t^W \delta_t^J$$

The average wage W_t evolves according to

$$W_t = \omega_w W_{t-1}\overline{\pi}^{(1-\gamma_w)}\pi_{t-1}^{\gamma_w} + (1-\omega_w)W^*$$

Balanced growth path

The model structure incorporates multiple stochastic trends that are used for stationarization of the input data within the model. This means that all the input time series are stationarized simultaneously while taking their mutual relationships as assumed by the DSGE model into account. As Andrle, M. (2009) argues, there is a need to investigate any trend behaviour in emerging countries because permanent shocks may potentially influence business cycle frequencies. He states: "The point is that the stationary DSGE model then may be unable to explain co-movements of filtered time series since it cannot explain the dynamics induced by permanent shocks in the de-trended variables." That is the reason why we employ the stochastic permanent trend shocks that can help investigate the data.

Next, we shall have a look at the individual sources of these permanent shocks. The real part of the growth at the BGP is driven by a set of nonstationary shocks:

• labour augmenting shock in the production process, ξ_t^A – the main driving force of growth, grows at the rate $g^{\xi A}$

• willingness to work shock, ξ_t^N – introduces non-stationarity to hours worked, grows at the rate $g^{\xi N}$

• investment specific shock, ξ_t^I – allows relative prices to trend in steady state, grows at the rate $g^{\xi I}$

• trade productivity shock, ξ_t^X – allows imports and exports to grow faster than output in a steady state, grows at the rate $g^{\xi X}$,

• exports quality shock, ξ_t^Q – allows for a higher growth rate of domestic exports relative to the foreign demand proxy in a steady state, grows at rate $g^{\xi Q}$.

Apart from these five real nonstationary shocks, there is also a nominal trend assumed in the model:

• consumer price index, P_t^C – grows at the BGP at the predetermined rate π^C .

Some details are shown in the section *Stationarization* of the appendix.

Trade openness

Further transformation of data is applied to trade variables – specifically exports, imports and world demand. Balanced growth path would indicate that nominal expenditure share of exports and imports in value added is constant. For treating the model trend behaviour consistently, we introduce an openness technology shock ξ^O_t to include the notion of the growing trend in nominal expenditure share of trade in value added. It is defined in measurement equations of these variables, which means that agents perceive trade variables as already deflated by the openness shock. Thus, the observed time series exhibit the following trend:

$$EX_t^{obs} = IM_t^{obs} = Y_t^{*obs} = g^{\xi A} g^{\xi N} g^{\xi I(\frac{1-\alpha}{\alpha})} g^{\xi X} g^{\xi O}$$

Data

Quarterly time series of 19 observables were used for the estimation. These data are consistent with ESA 2010 and cover the period between the first quarter of 2000 and the second quarter of 2017. Figures with the observed time series can be found in Figure 5 presented as quarter-on-quarter growths in percent except for interest rates that are in level and trade balance defined as net export on nominal GDP. I have used seasonally adjusted time series of real private consumption (C), gross fixed capital formation (I), government consumption (G), exports (goods and services) (EX), trade balance (goods and services) (TB), and their respective deflators – private consumption deflator (Pc), gross fixed capital formation deflator (Pi), government consumption deflator (Pg), export deflator (goods and services) (Px), import deflator (goods and services) (Pm); then also employment in hours worked (N), compensation per hour (W), unemployment rate (UR), nominal interest rate (R), nominal exchange rate[6] (S), and for the foreign environment foreign demand (WD), foreign interest rates (R*, EURIBOR), competitors' price on the import side (pf) and competitors' prices on the export side (pimf). The time series were obtained from the databases of Eurostat and Czech National Bank.

The data I have used are usually revised in time, which brings certain level of uncertainty. These revisions can be quite substantial. This is the motivation behind this paper: to investigate whether the different use of the data changes the results of the model. Thus, not only do I estimate the parameters of the model, but I also estimate the model with different data sets. First, I use the original data set, which allows the model to use the measurement errors to estimate and then filter out the part of the data that the model

[6] of CZK/EUR

finds uninformative. Secondly, I use a data set where any noise is removed before the data enter the model. The noise is removed using the Hodrick Prescott filter (HP) with λ set to 1[7], which means that the trend of the filtered variable stays very volatile, leaving us with data that are more stable in time, as shown in Figure 5 in the appendix. I do not remove the noise from the interest rates (home and foreign), unemployment rate or the nominal exchange rate. To the best of my knowledge, I have not seen this method in any of the literature before.

One reason to use the HP filter is that we do not want the model to replicate every bit of noise in the data. The advantage of this approach is that the identified shocks are more stable, which is preferable when using the model for forecasting. These models are usually used for medium term forecasting, which is supposed to predict the trends in the development of the economy. In the model with the original data, the shocks can differ from period to period quite significantly, which changes the view on, for example, the current state of the economy and the forecast, and the interpretation of the identified shocks is thus hard to disentangle. Another disadvantage of the usage of the original data with measurement errors is that the identified measurement errors can be deviated on one side, which can distort the information from the data. On the other hand, the disadvantage of the HP filtering of data can be that the important information for the estimation of the parameters can be lost, which could change the behaviour of the model.

Furthermore, I have transformed all data into quarter-on-quarter (qoq) growth rates, approximated by the first difference in their logarithm, except for the interest rates (both home and foreign) and unemployment rate that are used in levels. Trade balance is calculated as a ratio on nominal GDP.

In this paper, the appreciation of nominal exchange rate observed in the Czech Republic in the past is not modelled. The reason behind it is that the nominal exchange rate appreciated between 2000 and 2009, and since then the average nominal exchange rate has been rather stable. If we incorporated the nominal exchange rate appreciation in the BGP, it would create imbalances to identified shocks simply because the trend is not present in the data of the full sample. 'Imbalances' here mean that the identified shocks no longer are i.i.d. processes as they should be. On the other hand, if we do not include trend appreciation in the BGP, as in the case of this paper, usage of raw data of the exchange rate with the appreciation trend until 2009 would cause imbalances to shocks too. Therefore, I had decided to deal with this before the data entered the model. I applied the HP filter again, but in this case λ was set to 1600, a common value for quarterly data, and I removed the trend from the time series. Then, I used the transformation to quarter-on-quarter growths, which can be seen in Figure 4. As a result, the volatility of the exchange rate was preserved.

Calibration

In this chapter, I present the calibrated parameters important for setting the model to meet certain features of the economy observed in the data. The rest is estimated using

[7] The HP filter with lambda set to 1 is approximately equal to the Band Pass filter which retains the frequencies between [5,Inf].

Bayesian techniques, which allows us to specify some additional information about the estimation process such as the prior mean value of the estimated parameter with its standard deviation and prior distribution. The following table shows calibrated and fixed parameters in the model.

Table 1. Fixed parameters

Parameter	Name	Value
$g^{\xi A}$	Labour augmenting productivity	1.004
$g^{\xi I}$	Investment specific technology	1.002
$g^{\xi Q}$	Exports quality technology	1.007
$g^{\xi O}$	Openness shock	1.005
$g^{\xi X}$	Trade productivity shock	1.003
α	Output elasticity of labour	0.57
δ	Capital depreciation rate	0.015
α_C	Share of value added in final consumption	0.38
α_I	Share of value added in final investment	0.28
α_G	Share of value added in final gov. consumption	0.55
α_{EX}	Share of value added in final exports	0.20
$\sigma_{C,}$ $\sigma_{I,}$ $\sigma_{G,}$ σ_{EX}	Elasticity of substitution in final sectors	2
$\theta_{SS}{}^{C}$	Mark-up steady state in consumption sector	5
$\theta_{SS}{}^{I}$	Mark-up steady state in investment sector	5
$\theta_{SS}{}^{G}$	Mark-up steady state in gov. consump. Sector	5
$\theta_{SS}{}^{X}$	Mark-up steady state in export sector	6
$\theta_{SS}{}^{IM}$	Mark-up steady state in import sector	3
$\theta_{SS}{}^{W}$	Mark-up steady state in wages	5
$\theta_{SS}{}^{Ykl}$	Mark-up steady state in intermediate sector	5
R	Nominal domestic interest rate	3
R^*	Nominal foreign interest rate	3
α_{LM}	Elasticity of prod. func. of employment agency	0.99
B	Discount factor	0.9975
u_{LM}	Unemployment rate	6%
Ψ	Consumption habit formation	0.6
Φ	Elasticity of labour supply	1.1

Source: the author´s calculations.

The setting of parameters $\alpha_{C,}$ $\alpha_{I,}$ α_G and α_{EX} govern the import content of individual sectors in the economy, which leads to roughly matching great nominal ratios[8] of individual sectors in the Czech economy. The setting of growth of individual trend shocks matches the average growths of observed data. This setting can be seen in Table 6 of the appendix.

The output elasticity of labour α in the intermediate production function is set according to the data together with capital depreciation rate δ. The intertemporal elasticity of substitution between distinct bundles of domestic and imported goods in individual sectors, σ_C, σ_I, σ_G, and σ_{EX} are all set to 2 according to Christoffel (2008), giving the elasticity the value of 0.5.

Mark-up steady states, for example in the consumption sector $\theta_{SS}{}^{C}$, are set very close with the two exceptions. The value 5 represents 25% profit margin while we set the steady-state profit margin in the export sector $\theta_{SS}{}^{X}$ under 20% as it is considered to be operating in an environment with a higher level of competition as domestic exporters have to compete basically with the all countries in the world. On the other hand, the import sector usually has a higher profit margin $\theta_{SS}{}^{IM}$, in this case 50%. The discount factor is set to 0.9975, meaning the real interest rates are approximately 1% p.a. Lastly, the steady state of the unemployment is set according to the average rate between 2000 − 2017. There are other parameters in the labour market that help us to set the steady-state value of the unemployment, such as the job separation rate ρ_{LM} or the steady-state value of the matching efficiency shock. The rest parameters represent the dynamic properties of the model, so they are going to be estimated.

Empirical Results

This section is a crucial part of the paper. Firstly, the results of the estimation are presented. The second tool used to check how the model fits is based on the comparison of the standard deviations of the model variables with the data. Secondly, the impulse response function is applied to check the dynamics of the model. Another very practical tool here is a recursive forecast that decides whether the model is suitable for forecasting. And finally, the shock decomposition of the selected variables is shown to examine the reasons behind the development of the data. All of the computations were carried out in MATLAB (version 7.14, release (R2012a)). The IRIS toolbox (version 20140909) was used for the Bayesian estimation of the model.

Estimation of parameters

In Table 2 are presented the results of the estimation based on the HP filtered data. In this table, the parameters are divided into groups. The 'LM' group includes parameters linked to the labour market; the 'foreign' group comprises of parameters used in foreign economy equations and in the far-right column there are the standard deviations of the representative shocks. The 'markups' group includes the AR parameters of the shock processes in individual sectors. The next group, 'trends', covers AR parameters con-

[8] Great nominal ratio – for example the share of nominal private consumption on GDP

nected to trend shocks. The 'MP' group are the monetary policy parameters; for example, ϕ^{π} is the reaction of monetary policy interest rates to the change in inflation. The following groups of parameters are linked with the price setting in individual sectors of the economy. On the left there are 'Calvo' parameters that show the price rigidities, and on the right is the 'Index' group with γ parameters that express the weight of the indexation of prices to the inflation of the previous period and to the steady state inflation π^{C}. The group of shocks labelled 'other' captures the estimates of the rest of the parameters. In the third column marked 'prior' are shown the priors for the estimation together with the setting of the standard deviation; the fifth column includes the estimated values of parameters; and the sixth column indicates the high posterior density interval, which shows the width of the interval where the estimates lie.

First, we shall focus on labour market parameters. An interesting parameter is the bargaining power in negotiation process over wage η. The estimate is rather small and implies that the negotiating power of workers is small, which contradicts the study by Pápai (2017), where he estimates the negotiating power of firms to be 0.385. Whereas Němec (2013) and Železník (2012) conclude that almost all from the production surplus get the firm, implying that workers have only a very small negotiating power.

The next parameter is ρ_{χ}, the AR parameter of the match efficiency shock. Its estimated value is 0.732, resulting in a quite persistent development of the shock (can be seen in Figure 9). This result is in line with the data as the matching efficiency copies the evolution of the unemployment rate. When the unemployment rate is on decrease, the matching efficiency is increasing, and the other way round. Therefore, since the unemployment rate is a quite persistent process, the matching efficiency is too. Parameter ν_{LM} represents the matching elasticity in the matching function with respect to the job seekers. Its estimated value 0.219 means that a successful match is more dependent on the amount of vacancies. Thus, in case of a vacancy, there is a quite high probability of filling it.

An interesting result is the markup persistence parameter in the import sector $\rho^{\theta^{IM}}$, indicating a very high persistence estimate of 0.985. The estimates based on the original data (Table 5 in the appendix) produce different results. For the import sector, the value is 0.305, which would not be that surprising for the original data as the import deflator is very volatile and this markup shock catches most of its volatility.

In this part, the monetary policy parameters shall be discussed. The interest rate smoothing parameter ρ^{R} is estimated close to its prior 0.883 with the usual high value. The next three parameters represent the responsiveness of the monetary policy to the domestic inflation ϕ^{π}, output (consumption) ϕ^{C}, and the exchange rate ϕ^{S}. The weight on inflation in the Taylor rule ϕ^{π} is close to its prior 1.679 and is in line with the condition stressed by Taylor: that a change in inflation should induce a bigger change in the nominal interest rate. Also, this estimate has been calculated in papers as well, e. g. Pápai (2017). The other two parameters are usually small, and, in this case, they are very close to zero. In the estimation using the original data, the results are almost the same. The only difference is the responsiveness of the monetary policy to change in inflation ϕ^{π}, which is a little bit higher with the estimated value of 2.091.

Another unit of estimated parameters concerns the price rigidities in individual sectors. An interesting result is that we can see a lower estimate in the export sector ω^{EX}, which is in line with our assumption that export sector is very competitive and its firms have to very quickly react on demand and on their competitors in home and foreign economies. Similar results are produced when using the original data, as seen in Table 5. Of course, the estimates are lower when using the original data as the data are more volatile.

Table 2. Priors vs estimated parameters (HP)

params	dist.	prior	std	estimated	(90% HPDI)	params	dist.	prior	std	estimated	(90% HPDI)
LM						Std					
ρ_X	β	0.5	0.2	0.732	(0.553- 0.948)	σ_X^{LM}	IG	0.1	2	0.019	(0.011-0.027)
v_{LM}	β	0.5	0.2	0.219	(0.078- 0.353)	$\sigma^{\xi RP}$	IG	0.1	2	0.006	(0.004-0.008)
η	β	0.5	0.2	0.11	(0.001- 0.386)	$\sigma^{\xi govy}$	IG	0.1	2	0.002	(0.002-0.002)
Foreign						Std					
$\rho^{\pi IM*}$	β	0.5	0.2	0.658	(0.572- 0.749)	$\sigma^{\pi IM*}$	IG	0.01	2	0.003	(0.002-0.003)
ρ^{Y*}	β	0.5	0.2	0.743	(0.433- 0.986)	σ^{Y*}	IG	0.01	2	0.01	(0.005-0.015)
$\rho^{\pi EX*}$	β	0.5	0.2	0.939	(0.902- 0.978)	$\sigma^{\pi EX*}$	IG	0.01	2	0.001	(0.001-0.001)
ρ^{R*}	β	0.75	0.1	0.909	(0.890- 0.929)	σ^{R*}	IG	0.01	2	0.001	(0.000-0.001)
Markups						Std					
$\rho^{\theta Ykl}$	β	0.25	0.1	0.22	(0.081- 0.355)	$\sigma^{\theta Ykl}$	IG	0.8	2	0.213	(0.119-0.306)
$\rho^{\theta C}$	β	0.25	0.1	0.387	(0.211- 0.573)	$\sigma^{\theta C}$	IG	0.8	2	0.109	(0.069-0.146)
$\rho^{\theta I}$	β	0.25	0.1	0.256	(0.104- 0.401)	$\sigma^{\theta I}$	IG	0.8	2	0.127	(0.078-0.177)
$\rho^{\theta G}$	β	0.25	0.1	0.447	(0.298- 0.585)	$\sigma^{\theta G}$	IG	0.8	2	0.302	(0.199-0.409)
$\rho^{\theta EX}$	β	0.25	0.1	0.263	(0.097- 0.424)	$\sigma^{\theta EX}$	IG	0.8	2	0.333	(0.206-0.475)
$\rho^{\theta IM}$	β	0.5	0.2	0.985	(0.979- 0.990)	$\sigma^{\theta IM}$	IG	0.8	2	0.065	(0.053-0.076)
Trends						Std					
$\rho^{\xi I}$	β	0.25	0.1	0.238	(0.088- 0.386)	$\sigma^{\xi I}$	IG	0.01	2	0.003	(0.001-0.004)
$\rho^{\xi X}$	β	0.25	0.1	0.341	(0.158- 0.525)	$\sigma^{\xi X}$	IG	0.01	2	0.004	(0.003-0.005)
$\rho^{\xi Q}$	β	0.25	0.1	0.174	(0.070- 0.277)	$\sigma^{\xi Q}$	IG	0.01	2	0.011	(0.009-0.013)
$\rho^{\xi A}$	β	0.25	0.1	0.505	(0.316- 0.702)	$\sigma^{\xi A}$	IG	0.01	2	0.004	(0.002-0.005)
$\rho^{\xi O}$	β	0.25	0.1	0.631	(0.513- 0.754)	$\sigma^{\xi O}$	IG	0.01	2	0.007	(0.005-0.008)
MP						MP					
ρ^{R}	β	0.75	0.1	0.883	(0.850- 0.917)	$\kappa^{R*\pi IM*}$	N	1.2	0.2	1.028	(0.809-1.262)
φ^{π}	N	1.8	0.2	1.679	(1.400- 1.976)	κ^{R*Y*}	N	0.1	0.1	0.189	(0.068-0.313)
φ^{C}	N	0.1	0.1	-0.009	(-0.015--0.005)	φ^{S}	N	0.1	0.1	-0.013	(-0.115-0.104)
Calvo						Index					
ω^{W}	β	0.5	0.1	0.407	(0.145-0.562)	γ^{W}	β	0.5	0.1	0.558	(0.385-0.714)
ω^{Ykl}	β	0.5	0.1	0.422	(0.288-0.555)	γ^{Ykl}	β	0.5	0.1	0.467	(0.296-0.625)
ω^{C}	β	0.5	0.1	0.794	(0.727-0.854)	γ^{C}	β	0.5	0.1	0.694	(0.576-0.814)

ω^{I}	β	0.5	0.1	0.562	(0.471-0.666)	γ^{I}	β	0.5	0.1	0.549	(0.408-0.694)
ω^{G}	β	0.5	0.1	0.915	(0.891-0.940)	γ^{G}	β	0.5	0.1	0.599	(0.472-0.737)
ω^{EX}	β	0.5	0.1	0.215	(0.117-0.297)	γ^{EX}	β	0.5	0.1	0.363	(0.216-0.508)
ω^{IM}	β	0.5	0.1	0.669	(0.573-0.756)	γ^{IM}	β	0.5	0.1	0.611	(0.482-0.746)
Other						Std					
$\rho^{\theta TFP}$	β	0.75	0.1	0.894	(0.829- 0.946)	$\sigma^{\theta TFP}$	IG	0.1	2	0.004	(0.003-0.005)
$\rho^{\xi C}$	β	0.75	0.1	0.893	(0.831- 0.956)	$\sigma^{\xi C}$	IG	0.1	2	0.051	(0.036-0.068)
$\rho^{\xi RP}$	β	0.75	0.1	0.58	(0.451- 0.712)	$\sigma^{\xi RP}$	IG	0.1	2	0.003	(0.002-0.005)
$\rho^{\xi RP*}$	β	0.75	0.1	0.519	(0.416- 0.625)	$\sigma^{\xi RP*}$	IG	0.1	2	0.005	(0.003-0.006)

Source: the author´s own calculations.

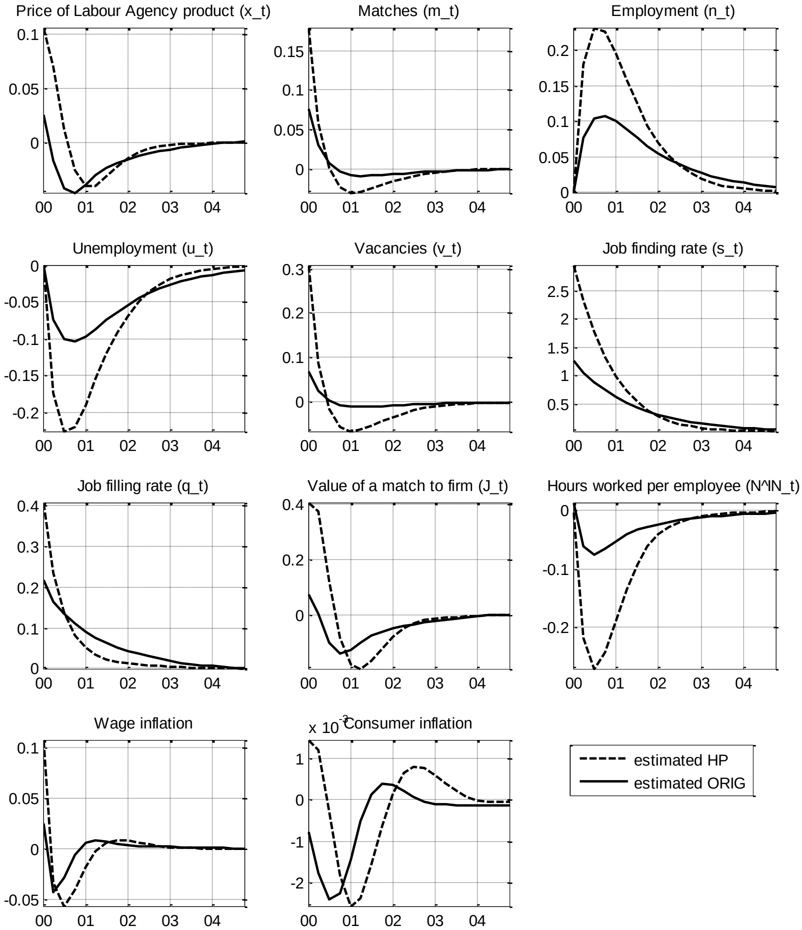
Impulse response analysis

This section deals with the impulse response functions to matching efficiency shock (Figure 1) and to domestic monetary policy shock (see in Figure 10 in the appendix). Variables are depicted as percentage points deviations from their respective steady states. On the x-axis 20 quarters are shown, that is 5 years. The black dashed line represents the estimated version of HP data and the black filled line the estimated version of original data.

A positive shock increases the efficiency of the matching process that pairs the unemployed persons with vacancies by increasing the number of matches created (m_t). Thus, the employment rate (n_t) rises and unemployment (u_t) decreases. By a definition, the job filling rate (q_t) and job finding rate (s_t) increase. The value of the firm (J_t) increases at first, which induces an increase in vacancies (v_t) in the short term, and then both variables decrease. The negotiating process then results in higher wages, which results in a higher price for the product of the labour agency (x_t) and in lowering the hours worked per employee (N_t^{IN}) – because the labour agency can, by the right-to-manage approach, dictate the number of hours worked.

A shock in monetary policy means that the central bank raises the interest rates 1 percentage point above its steady state. The foreign variables do not react to our domestic shock as the Czech economy is small and does not have much influence on the foreign economy. The variables linked to the labour market are the ones that should interest us the most. We can see that the response to monetary policy shock is different in this case. The unemployment (u_t) increases with a higher impact in the model estimated with the HP data and with a smaller impact in the model estimated with the original data. Same applies for the employment (n_t), only with a negative effect; therefore, the matches of workers with vacancies drop. The job-filling rate (q_t) increases as the match rate decreases lower than the vacancy rate. The job-finding rate (s_t) decreases as the matches decline and unemployment rises. Since this shock is contractionary to the economy, total number of hours worked and the hours worked per employee decreases together with wage inflation and consumer price inflation.

Figure 1. IRF: Matching efficiency shock (HP vs ORIG, deviation from ss, qoq, in pp)



Source: the author´s own calculations.

Simulated Moments

In this section, a different tool is used to analyse the results of the models. Comparing the model-implied standard deviations and correlations with the observed data shows us how the model can fit the data. In Table 3 we can see the standard deviations of the key macroeconomic variables with their 90 % HPDI intervals for the two estimated models. In Table 4 the cross-correlations are presented.

Looking at labour market variables, specifically wage inflation standard deviation (W), we can see that the version estimated using the HP data performs well, 1.01 vs 0.87 in the data. The next model is less successful, 1.06 in the model vs 1.69 in the data. Hours worked (HW, in equations N_t^{OUT}) are less volatile in the HP-filtered data and a model that uses this data is not able to fit this low volatility. However, looking at the model estimated with the original data (the column 'Std (orig model)'), the model is very successful as opposed to the original data and implies almost the same standard deviation as in the data: 1.41 in the model and 1.43 in the data. Employment of persons (E) brings quite the opposite result. The less volatile data, estimated with the HP data model, fits this standard deviation very well: 0.64 in the model versus 0.48 in the data. The second model has a twice as high standard deviation. A great interest here is the unemployment rate (UR, in the model u_t), where both models fit the data on a satisfactory level.

Table 3. Standard deviations: data vs. model

vars	Std (orig data)	Std (orig model)	(90% HPDI)	Std (HP data)	Std (HP model)	(90% HPDI)
C	0.72	0.61	(0.55-0.66)	0.46	2.13	(1.93-2.31)
Pc	0.58	0.33	(0.29-0.36)	0.37	0.20	(0.32-0.41)
W	1.69	1.06	(1.00-1.16)	0.87	1.01	(0.95-1.04)
HW	1.43	1.41	(1.35-1.46)	0.51	1.64	(1.41-1.67)
E	0.49	0.95	(0.87-0.99)	0.48	0.64	(0.59-0.69)
UR	1.64	1.81	(1.23-2.29)	1.64	1.21	(0.89-1.21)

Source: the author's own calculations.

The following table presents the cross-correlations of the variables. The results are quite reasonable – for example, the correlation of unemployment (UR) with wages (W) is 0.22 in the data and 0.12 in the model. Correlations of the vacancies are less satisfactory: for example, for the unemployment rate the correlation is -0.96 in the data, but in the model it is only -0.04. The correlations of the labour market variables with real part of the economy, in this case with consumption, are good. The results of the original version of the model are shown in the appendix in Table 7.

Table 4. Cross-correlations: data vs. model (HP)

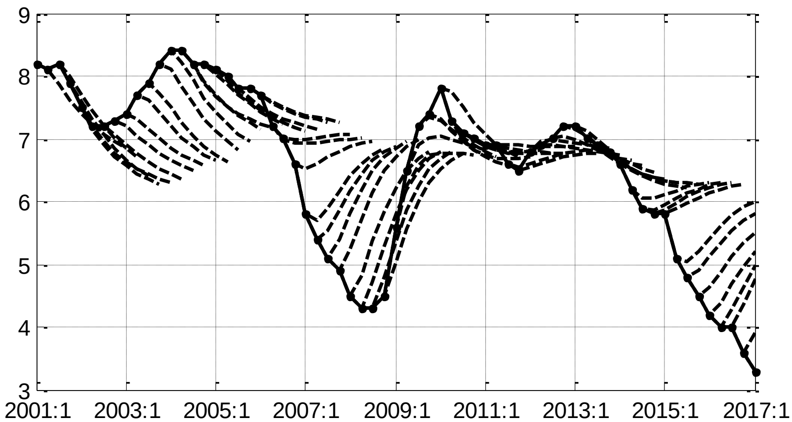
DATA	C	Pc	W	HW	UR	V	MODEL	C	Pc	W	HW	UR	V
C	1.00	0.06	0.56	0.29	-0.10	0.69	C	1.00	0.27	0.28	0.61	-0.05	0.32
Pc	0.06	1.00	0.46	-0.10	-0.05	0.42	Pc	0.27	1.00	0.20	0.00	0.04	-0.19
W	0.56	0.46	1.00	-0.38	0.22	0.40	W	0.28	0.20	1.00	0.31	0.12	0.09
HW	0.29	-0.10	-0.38	1.00	-0.27	0.47	HW	0.61	0.00	0.31	1.00	-0.06	0.22
UR	-0.10	-0.05	0.22	-0.27	1.00	-0.96	UR	-0.05	0.04	0.12	-0.06	1.00	-0.04
V	0.69	0.42	0.40	0.47	-0.96	1.00	V	0.32	-0.19	0.09	0.22	-0.04	1.00

Source: the author's own calculations.

Recursive Forecasts

Figure 2 shows the recursive forecast for every quarter of the examined period. The forecast covers 8 quarters as these kinds of models are usually used for medium-term forecasting, which in many central banks is 2 years. The model tends to come back to its steady state as all shocks are on this trajectory during the unconditional forecast. 'Unconditional forecast' means that in any forecast for any period we do not impose any values to innovations of shocks on the forecast horizon, and just let them follow their respective shock processes instead. The steady state value for the Czech Republic is set close to its historical average of 6%. For the 2010-2014 period, when the unemployment rate was around its steady state value, the model predicts the unemployment rate well; but from 2014 on, when the unemployment rate in the Czech Republic began to fall and widely opened the unemployment rate gap, the model fails to predict this development.

Figure 2. Recursive forecast: unemployment rate (unconditional, HP model)



Source: the author's own calculations.

In the appendix, I have enclosed the unconditional recursive forecast for consumer price inflation for both versions of the model. In Figure 7 and Figure 8 we can see that the model did not predict the inflation drop during the crises, but performs well after the crisis during the years 2010-2012. It did not capture the drop in inflation at the end of 2012, but from then on the model seems to predict adequately.

Historical shock decomposition

In this part, I have applied the shock decomposition to identify the shocks behind the evolution of the examined variables. The outcome is presented in groups of shocks to make the results more transparent. I have divided the shocks into the following categories: technology shocks (trend shocks that mainly govern the labour productivity), demand shocks (shocks that capture preferences in individual sectors of the model), foreign shocks (shocks regarding a foreign environment), markups (shocks that are linked to profit margins in individual sectors), and, finally, labour market group (match efficiency shocks).

One of the key macroeconomic variables linked to labour market is wage (in our case, compensation per hour). Figure 3 presents the results. We can see that the growth of wages is mainly influenced by the technology group that includes shocks regarding the labour productivity: the growth was high before the crisis and fell down in 2009 and so it also stayed (under its steady state growth) until 2016 when it started to pull the wage growth up again. There are some periods when it has produced a positive effect on wages, for example 2011 or 2016.

Another interesting effect can be found in domestic demand shocks (horizontal line bars), which include the domestic monetary policy shock. There is a positive effect of the monetary policy in the second half of 2012, where the Czech National Bank lowered the interest rates from 1.21 in 2012q2 to 0.87 in 2012q3 and to 0.5 in 2012q4. From then on, the interest rates very slowly decreased to 0.29 at the end of 2015 with no effect on wages.

Following the interest rates as a standard monetary policy tool, the Czech National Bank decided to implement a non-standard measure of fixing the exchange rate of CZK/EUR. This policy took place in November 2013 and the analysis shows a positive impact of this policy on wages in the 2013q4 and 2014q1. This effect is hidden in the foreign group of shocks (forward slash bars) thanks to the UIP shock that captures the exchange rate movements.

In the first half of 2017, we can again see a positive effect of monetary policy that stems from the setting of interest rates. In the last quarter, 2017q2, the positive effect on wages (in demand bars) is of one third due to the loose monetary policy. The Czech National Bank must have registered the same effect as they started to increase the interest rates in 2017q3. The same effects can be observed in the Czech domestic inflation.

The next variable to discuss is the hours worked presented in the Figure 11. The effect of technology shocks in this variable is mainly driven by the temporary TFP shock together with the willingness to work shock. Before the crisis hit the economy, the total factor productivity was quite high between 2007 - 2009. After the crisis, the technology shocks development was very volatile, but most of the time it shows a negative impact on the growth of hours worked, just as at the end of the observed period. On the other hand, the foreign environment influences the hours worked positively after the crisis, which is mainly assigned to the foreign demand shock as it takes place at the end of the 2017q2. In the group of demand shocks can be again seen the effect of domestic monetary policy at the end of 2012, but it is slightly negated by the domestic preference shocks. In the first half of 2017, there is, again, a positive effect of monetary policy together with preference shock raising the demand, which increases the hours worked needed. Markups have a very volatile influence on the hours worked, whereas the labour market shock has a surprisingly small influence. It exhibits a negative influence after the crisis, but from 2014 on it started to affect the growth of hours worked in a positive manner.

Lastly, the unemployment rate variable. The results are shown in Figure 12, where we can see that the main effect comes from the labour market shock. Before the crisis, the labour market shock together with a high demand for employment caused the fall of the unemployment rate. Right after the crisis, in 2009, the effect of labour market shock changed dramatically and stands behind the rise of the unemployment rate. From 2011 on, the technology group of shocks shows a positive effect on the decrease in the unemployment rate; mainly the productivity shock that grew slowly under its steady state level, which was slowing down the increase of the productivity, and thus more employment was needed. The foreign shocks exhibit the opposite effect. This is mainly driven by the development of the foreign interest rates. The ECBs interest rates are lower almost the whole time after the crisis, which produces a contractionary effect on the Czech economy. Therefore, it increases the unemployment rate. The demand shocks have only a small influence after the crisis, but at the end of the period they show a positive effect on the decrease in unemployment. The effects on the unemployment rate in these kinds of models can vary quite significantly. A good example of the different model approaches to the labour market and how they can affect the progress of the unemployment rate can be found in Tonner et al. (2015).

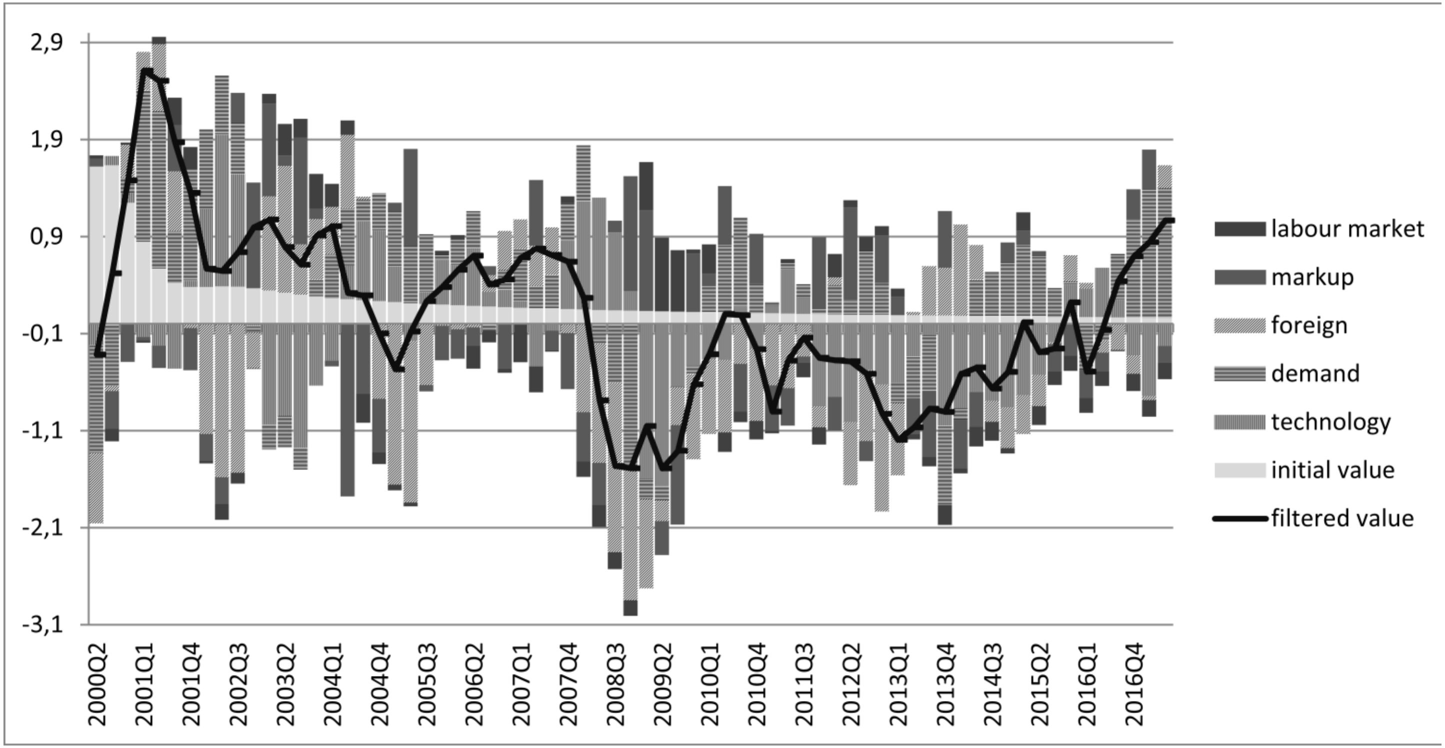
Conclusion

In this paper, I have applied the DSGE model to a small open economy of the Czech Republic with search and matching frictions in the labour market. Firstly, I have calibrated the model to match the average growth in the individual sectors according to the data using various permanent shocks, which allowed for modelling of the BGP with different steady-state growths in the individual sectors of the economy examined in the model. Secondly, I have adjusted the import content of the individual sectors to match the data.

Two sets of data have been used for the estimation. The first set consists of data filtered with the Hodrick-Prescott filter with a very volatile trend (lambda set to 1) to get rid of any noise that could influence the estimation, while the second set contains the original data. For both versions of the model the Random Walk Metropolis-Hastings algorithm has been used. The posterior means of the model parameters, which represent the structure of the economies, have been compared. The estimated parameters in both versions are quite similar with some expected differences, for example in the price rigidities or in the persistence of the markup shocks, which in both cases stems from the differences in the data used. The more volatile the data used, the less persistent markup shocks and the less rigid prices are produced.

The results of the labour market parameters' estimation are quite similar for the two versions of the model. The negotiation power of workers is lower than the power of firms, which is a likely situation for the Czech economy. It could be interesting to estimate this parameter in a few years to see whether this result changes. The reason behind the change in the negotiation power can come from the fact that the Czech labour market nowadays lacks the available work force as the unemployment rate is the lowest in the whole of European Union and firms here have to fight over job candidates – and a possible tool to do that is to offer them higher wages.

Figure 3. Shock decomposition, wages (qoq, deviation from the steady state, in p.p., HP model)



Source: the author's own calculations.

As a next step, we have compared the reactions of the two versions of the model to the same shocks using the impulse response functions to see any differences between the different sets of data used for the estimation. It turns out that the reactions of the prices are quite similar, but the main differences are in the reaction of the real part of the economy, where the model estimated using the HP-filtered data suggests that the real variables would react more on the monetary policy shock. The same result can be observed concerning the labour market variables, where the unemployment rate reacts at least twice as strongly in the model using the HP data than in the model using the original data.

Another tool to check how the model fits the data has been the comparison of the standard deviations and cross-correlations of variables that are produces by the two versions of the model and data. Both models fit the respective data quite well, with some room for improvement.

The main tool for the investigation of the development of the labour market variables has been the historical shock decomposition, showing us that the wage inflation is mainly driven by the labour productivity (long term or temporary, technology shocks) with significant effects of domestic demand shocks. In the demand shocks group, an inflationary effect of the domestic monetary policy has been revealed, resulting from the setting of the interest rates. Moreover, in the foreign group of shocks, a positive (inflationary) effect of the non-standard monetary policy measure has been found as the Czech National Bank fixed the CZK/EUR exchange rate in 2013 on a higher depreciated level than would be set on the market. At the end of the observed period, inflationary pressures coming from the interest rate setting has been uncovered, suggesting that the monetary policy started being expansionary in the 2017.

The decomposition of hours worked has shown that they are mainly influenced by quite volatile temporary shocks. The analysis has revealed that the foreign environment influenced the hours worked positively after the crisis. A positive effect of domestic monetary policy has been found in the increase of hours worked in 2012 as well as at the end of the observed period, in 2017q2.

The decomposition of unemployment rate has revealed a major influence of the labour market shocks explaining most of the unemployment rate volatility. In addition, it turns out that the slow increase of labour productivity after the crisis led to a lower unemployment rate with the opposite effect of the foreign environment.

Considering the results obtained using different techniques to compare the usefulness of the different versions of the model for forecasting and the identification of the development of the labour market variables, I prefer the model with the HP-filtered data as the original data are very volatile for the Czech Republic (the same for the identified shocks), and it is hard to disentangle the relevant information for policy makers. The estimation results and the behaviour of the economy based on the IRFs have not proven the big difference between the two versions. The fit of the two versions of the model is quite satisfactory too. Therefore, it can be concluded that for forecasting and policy analysis, the HP-filtered version is indeed more suitable.

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Appendix

Stationarization

To present how permanent shocks influence the behaviour of the economy, this paper expresses the notion that there is a common real trend growth in all production sectors, and that is the combination of shocks:

$$g^{Ykl} = g^{A} g^{\xi^{N}} \left(g^{\xi^{I}}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}$$

which is also the real growth of the intermediate sector. The growth of the final production sectors in the economy should also be established. The consumption sector Y_t^C exhibits the same growth as the domestic intermediate production. However, the investment sector Y_t^I is enriched with another trend shock ξ_t^I which allows the real investment in a steady state grow faster than the consumption sector. The same investment specific trend shock is responsible for the different growth of inflation in the investment sector π_t^I which is lower in the data than in the consumption sector. The growth of inflation in the consumption sector π_t^C is defined through the parameter π^C that captures the steady-state growth of inflation according to BGP. Thus, the inflation in the investment sector is defined as

$$\pi^{I} = \frac{\pi^{C}}{g^{\xi^{I}}}$$

Another example of how the model has been constructed is the definition and stationarization of the growth of real consumption through a combination of real shocks:

$$dCI_t = \frac{CI_t}{CI_{t-1}} g^{\xi A} g^{\xi N} g^{\xi I\left(\frac{1-\alpha}{\alpha}\right)}$$

The rest of the variables are stationarized in accordance with their respective trends. The setting of the growths of individual trend shocks in a steady state is defined in the calibration section.

Figure 4. Exchange rate CZK/EUR (original vs HP-filtered, qoq)

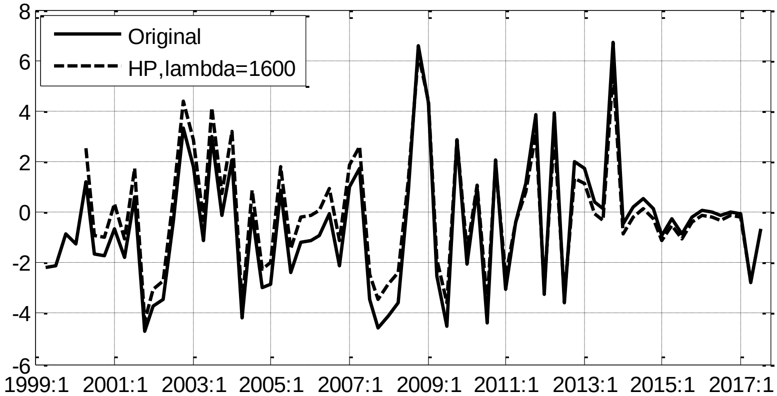


Figure 5. Observed data, original vs HP-filtered (quarter-on-quarter growths)

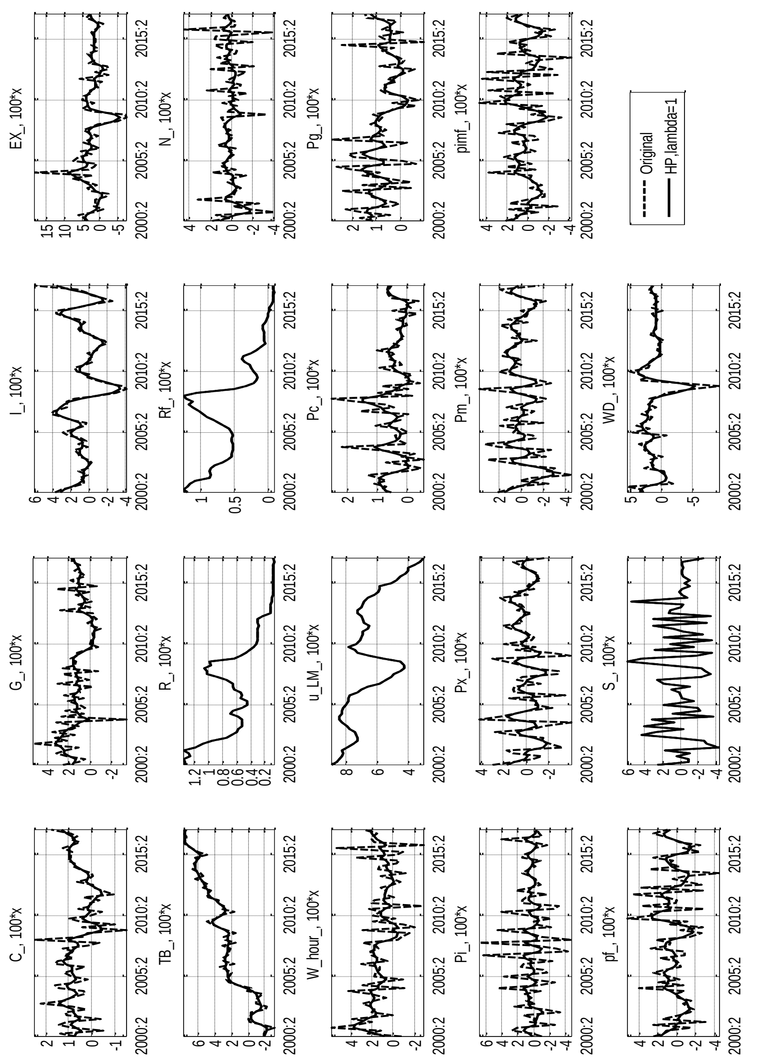


Figure 6. RF: Unemployment rate (unconditional, ORIG model)

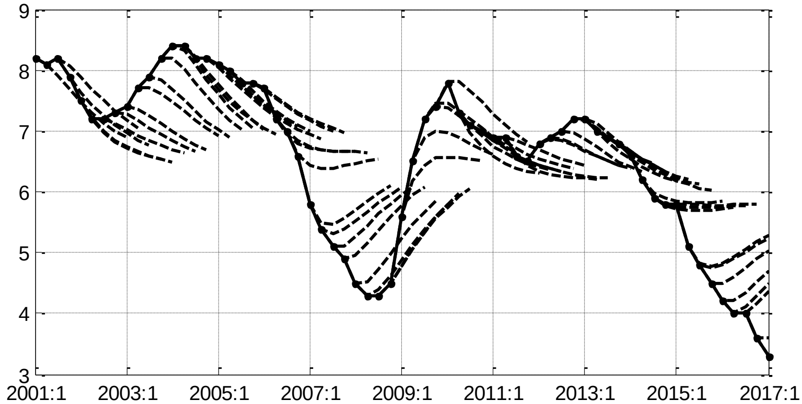


Figure 7. RF: Private consumption deflator (unconditional, qoq, HP model)

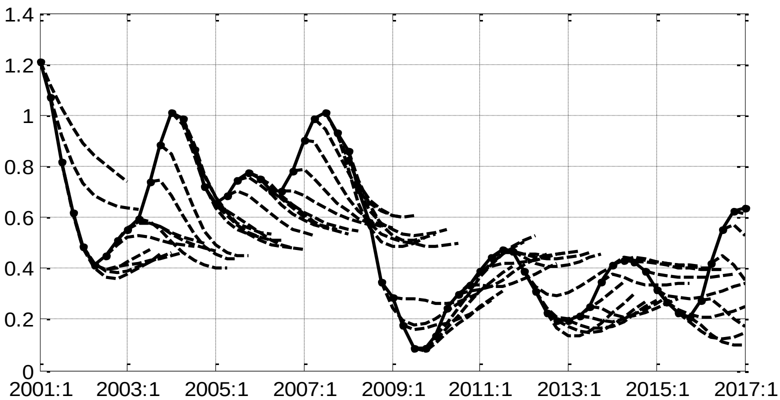


Figure 8. RF: Private consumption deflator (unconditional, qoq, ORIG model)

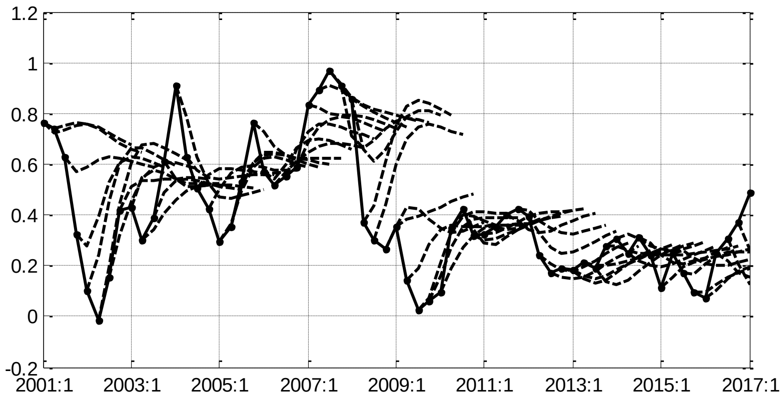


Figure 9. Kalman smoother, match efficiency shock, χ_t^{LM} (HP model)

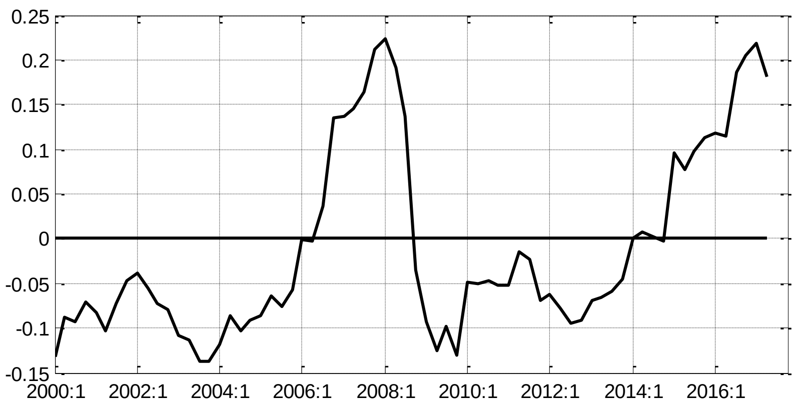


Figure 10. IRF: Monetary policy shock (HP vs ORIG, deviation from ss, qoq, in pp)

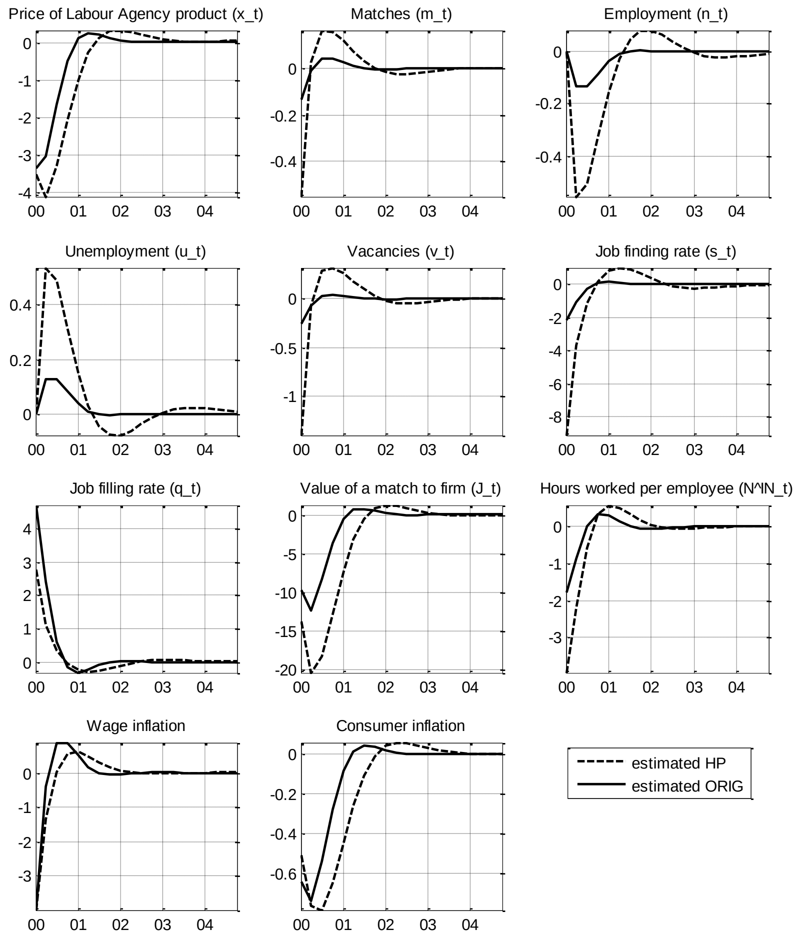


Table 5. Priors vs estimated parameters (ORIG)

params	dist.	prior	std	estimated	(90% HPDI)	params	dist.	prior	std	estimated	(90% HPDI)
LM						Std					
ρ_X	β	0.5	0.2	0.835	(0.679-0.989)	σ_X^{LM}	IG	0.1	2	0.019	(0.015-0.024)
v	β	0.5	0.2	0.391	(0.062-0.894)	$\sigma^{\xi Iprem}$	IG	0.1	2	0.004	(0.003-0.006)
η	β	0.5	0.2	0.183	(0.025-0.419)	$\sigma^{\xi govy}$	IG	0.1	2	0.002	(0.002-0.003)
Foreign						Std					
$\rho^{\pi IM*}$	β	0.5	0.2	0.081	(0.013-0.143)	$\sigma^{\pi IM*}$	IG	0.01	2	0.009	(0.007-0.010)
ρ^{Y*}	β	0.5	0.2	0.541	(0.225-0.864)	σ^{Y*}	IG	0.01	2	0.002	(0.001-0.002)
$\rho^{\pi EX*}$	β	0.5	0.2	0.868	(0.789-0.951)	$\sigma^{\pi EX*}$	IG	0.01	2	0.003	(0.001-0.004)
ρ^{R*}	β	0.75	0.1	0.957	(0.939-0.976)	σ^{R*}	IG	0.01	2	0.001	(0.000-0.001)
Markups						Std					
$\rho^{\theta Ykl}$	β	0.25	0.1	0.209	(0.067-0.341)	$\sigma^{\theta Ykl}$	IG	0.8	2	0.193	(0.100-0.286)
$\rho^{\theta C}$	β	0.25	0.1	0.192	(0.063-0.317)	$\sigma^{\theta C}$	IG	0.8	2	0.163	(0.089-0.235)
$\rho^{\theta I}$	β	0.25	0.1	0.123	(0.037-0.205)	$\sigma^{\theta I}$	IG	0.8	2	0.331	(0.252-0.429)
$\rho^{\theta G}$	β	0.25	0.1	0.211	(0.069-0.343)	$\sigma^{\theta G}$	IG	0.8	2	0.164	(0.092-0.233)
$\rho^{\theta EX}$	β	0.25	0.1	0.270	(0.104-0.433)	$\sigma^{\theta EX}$	IG	0.8	2	0.347	(0.244-0.450)
$\rho^{\theta IM}$	β	0.5	0.2	0.305	(0.075-0.510)	$\sigma^{\theta IM}$	IG	0.8	2	0.065	(0.048-0.082)
Trends						Std					
$\rho^{\xi I}$	β	0.25	0.1	0.221	(0.073-0.367)	$\sigma^{\xi I}$	IG	0.01	2	0.003	(0.001-0.004)
$\rho^{\xi X}$	β	0.25	0.1	0.253	(0.093-0.400)	$\sigma^{\xi X}$	IG	0.01	2	0.003	(0.002-0.005)
$\rho^{\xi Q}$	β	0.25	0.1	0.255	(0.102-0.403)	$\sigma^{\xi Q}$	IG	0.01	2	0.006	(0.004-0.009)
$\rho^{\xi A}$	β	0.25	0.1	0.257	(0.096-0.412)	$\sigma^{\xi A}$	IG	0.01	2	0.006	(0.004-0.008)
$\rho^{\xi O}$	β	0.25	0.1	0.346	(0.161-0.525)	$\sigma^{\xi O}$	IG	0.01	2	0.007	(0.004-0.009)
MP						MP					
ρ^{R}	β	0.75	0.1	0.856	(0.805-0.909)	$\kappa^{R*\pi IM*}$	N	1.2	0.2	0.765	(0.428-1.115)
φ^{P}	N	1.8	0.2	2.091	(1.824-2.353)	κ^{R*Y*}	N	0.1	0.1	0.180	(0.034-0.325)
φ^{Y}	N	0.1	0.1	0.020	(0.002-0.039)	φ^{S}	N	0.1	0.1	0.003	(-0.107-0.104)
Calvo						Index					
ω^{W}	β	0.5	0.1	0.364	(0.202-0.556)	γ^{W}	β	0.5	0.1	0.589	(0.427-0.758)
ω^{Ykl}	β	0.5	0.1	0.477	(0.298-0.653)	γ^{Ykl}	β	0.5	0.1	0.443	(0.285-0.609)
ω^{C}	β	0.5	0.1	0.707	(0.582-0.835)	γ^{C}	β	0.5	0.1	0.452	(0.295-0.612)
ω^{I}	β	0.5	0.1	0.230	(0.126-0.314)	γ^{I}	β	0.5	0.1	0.439	(0.274-0.599)
ω^{G}	β	0.5	0.1	0.562	(0.405-0.727)	γ^{G}	β	0.5	0.1	0.485	(0.318-0.644)
ω^{EX}	β	0.5	0.1	0.228	(0.141-0.312)	γ^{EX}	β	0.5	0.1	0.416	(0.253-0.573)
ω^{IM}	β	0.5	0.1	0.293	(0.189-0.398)	γ^{IM}	β	0.5	0.1	0.447	(0.283-0.608)
Other						Std					
$\rho^{\theta TFP}$	β	0.75	0.1	0.864	(0.767-0.964)	$\sigma^{\theta TFP}$	IG	0.1	2	0.004	(0.003-0.005)
$\rho^{\xi C}$	β	0.75	0.1	0.697	(0.513-0.892)	$\sigma^{\xi C}$	IG	0.1	2	0.024	(0.010-0.040)
$\rho^{\xi RP}$	β	0.75	0.1	0.452	(0.321-0.587)	$\sigma^{\xi RP}$	IG	0.1	2	0.007	(0.005-0.010)

Table 6. Calibrated great ratios

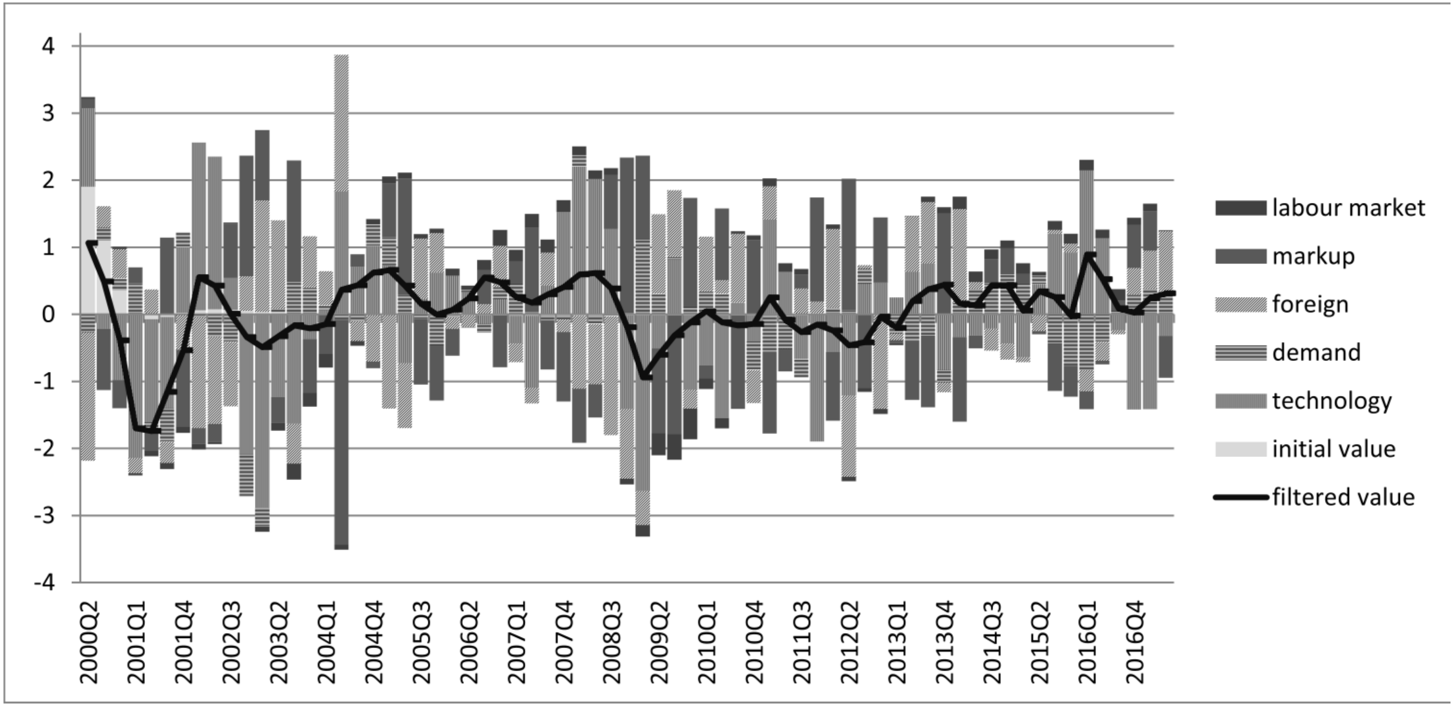
Variable	Data-CZ	Model-CZ
Real growth		
Consumption	0.60	0.65
Gov. Consumption	0.38	0.65
Investment	0.73	0.85
Export	2.07	1.46
Import	1.93	1.46
Price growth		
Gov. cons. Deflator	0.70	0.50
Consumption deflator	0.42	0.50
Investment deflator	0.20	0.30
Export deflator	-0.01	0.20
Import deflator	-0.07	0.20
Compensation per employee	1.10	1.10
Nom. Expenditure Share		
Gov. Consumption (NES)	0.20	0.20
Consumption (NES)	0.49	0.54
Investment (NES)	0.28	0.23
Export (NES)	0.65	0.60
Import (NES)	0.62	0.58
Import Content Share		
Consumption (NIC)	0.33	0.31
Gov. Consumption (NIC)	0.20	0.19
Investment (NIC)	0.40	0.40
Export (NIC)	0.44	0.50

Source: own calculations.

Table 7. Cross-correlations: data vs. model (ORIG)

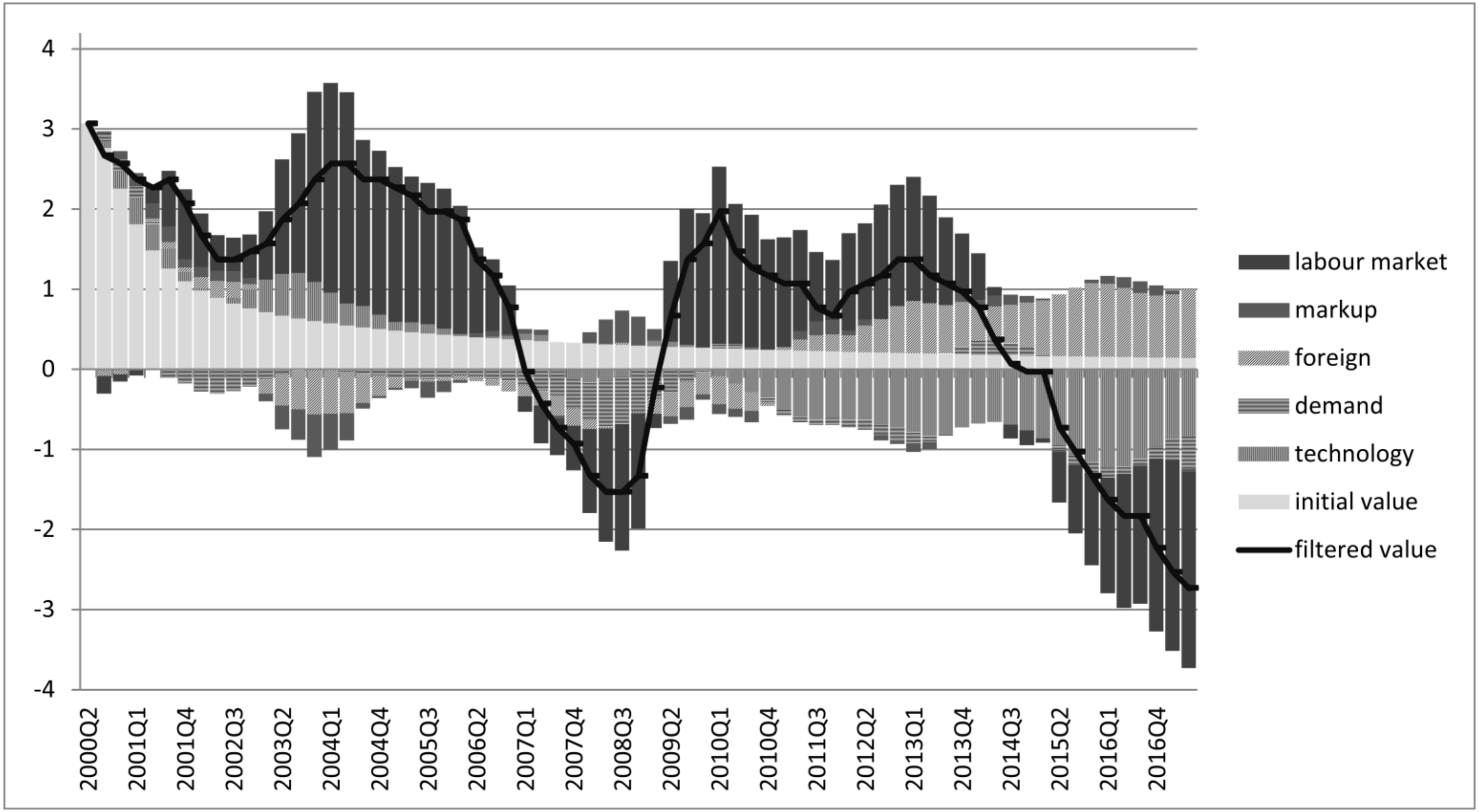
DATA	C	Pc	W	HW	U	V	**MODEL**	C	Pc	W	HW	U	V
C	1.00	-0.33	0.12	0.12	-0.11	0.50	C	1.00	0.08	0.23	0.15	0.06	-0.07
Pc	-0.33	1.00	0.39	-0.21	-0.01	0.28	Pc	0.08	1.00	0.23	0.08	0.18	-0.39
W	0.12	0.39	1.00	-0.77	0.11	0.15	W	0.23	0.23	1.00	0.20	0.07	-0.05
HW	0.12	-0.21	-0.77	1.00	-0.11	0.14	HW	0.15	0.08	0.20	1.00	-0.04	0.03
UR	-0.11	-0.01	0.11	-0.11	1.00	-0.96	UR	0.06	0.18	0.07	-0.04	1.00	-0.16
V	0.50	0.28	0.15	0.14	-0.96	1.00	V	-0.07	-0.39	-0.05	0.03	-0.16	1.00

Figure 11. Shock decomposition, hours worked (qoq, deviation from the steady state, in p.p., HP model)



Source: the author's own calculations.

Figure 12. Shock Decomposition, Unemployment Rate (level, deviation from steady state, in p.p., HP model)



Source: the author's own calculations.

Table 8. Parameter legend

Param	Description	Param	Description
ρ_X	AR parameter of matching efficiency shock	σ_X^{LM}	std of matching efficiency shock
v_{LM}	elasticity of matching function wrt unemployment	$\sigma^{\xi Iprem}$	std of investment demand shock
η	bargaining power of workers	$\sigma^{\xi govy}$	std of government shock
Foreign		Std	
$\rho^{\pi IM*}$	AR parameter of foreign competitors prices on the export side	$\sigma^{\pi IM*}$	std of foreign competitors prices on the export side shock
ρ^{Y*}	AR parameter of foreign demand	σ^{Y*}	std of foreign demand shock
$\rho^{\pi EX*}$	AR parameter of foreign competitors prices on the import side	$\sigma^{\pi EX*}$	std of foreign competitors prices on the import side shock
ρ^{R*}	AR parameter of foreign Taylor Rule	σ^{R*}	std of foreign monetary policy shock
Markups		Std	
$\rho^{\theta YkI}$	AR parameter of intermediate good sector markup shock	$\sigma^{\theta YkI}$	std of intermediate good sector markup shock
$\rho^{\theta C}$	AR parameter of final good consumption sector markup shock	$\sigma^{\theta C}$	std of final good consumption sector markup shock
$\rho^{\theta I}$	AR parameter of final good investment sector markup shock	$\sigma^{\theta I}$	std of final good investment sector markup shock
$\rho^{\theta G}$	AR parameter of final good government sector markup shock	$\sigma^{\theta G}$	std of final good government sector markup shock
$\rho^{\theta EX}$	AR parameter of final good export sector markup shock	$\sigma^{\theta EX}$	std of final good export sector markup shock
$\rho^{\theta IM}$	AR parameter of final good import sector markup shock	$\sigma^{\theta IM}$	std of final good import sector markup shock
Trends		Std	
$\rho^{\xi I}$	AR parameter of investment specific shock	$\sigma^{\xi I}$	std of investment specific shock
$\rho^{\xi X}$	AR parameter of export specific shock	$\sigma^{\xi X}$	std of export specific shock
$\rho^{\xi Q}$	AR parameter of quality shock	$\sigma^{\xi Q}$	std of quality specific shock
$\rho^{\xi A}$	AR parameter of labour augmented shock	$\sigma^{\xi A}$	std of labour augmented shock
$\rho^{\xi O}$	AR parameter of opennes shock	$\sigma^{\xi O}$	std of opennes shock
MP		MP	
ρ^{R}	AR parameter in domestic Taylor Rule	$\kappa^{R*\pi IM*}$	weight of foreign inflation in foreign Taylor Rule
φ^{π}	weight of lagged inflation in domestic Taylor Rule	κ^{R*Y*}	weight of foreign output in foreign Taylor Rule
φ^{C}	weight of consumption gap in domestic Taylor Rule	φ^{S}	weight of exchange rate in domestic Taylor Rule
Calvo		Index	
ω^{W}	Calvo parameter in wages	γ^{W}	Indexation parameter in wages

ω^{Ykl}	Calvo parameter in intermediate good sector	γ^{Ykl}	Indexation parameter in intermediate good sector
ω^{C}	Calvo parameter in final good consumption sector	γ^{C}	Indexation parameter in final good consumption sector
ω^{I}	Calvo parameter in final good investment sector	γ^{I}	Indexation parameter in final good investment sector
ω^{G}	Calvo parameter in final good government sector	γ^{G}	Indexation parameter in final good government sector
ω^{EX}	Calvo parameter in final good export sector	γ^{EX}	Indexation parameter in final good export sector
ω^{IM}	Calvo parameter in final good import sector	γ^{IM}	Indexation parameter in final good import sector
Other		Std	
$\rho^{\theta TFP}$	AR parameter in total factor productivity shock	$\sigma^{\theta TFP}$	std of total factor productivity shock
$\rho^{\xi C}$	AR parameter in consumption preference shock	$\sigma^{\xi C}$	std of consumption preference shock
$\rho^{\xi RP}$	AR parameter in domestic risk premium shock	$\sigma^{\xi RP}$	std of domestic risk premium shock