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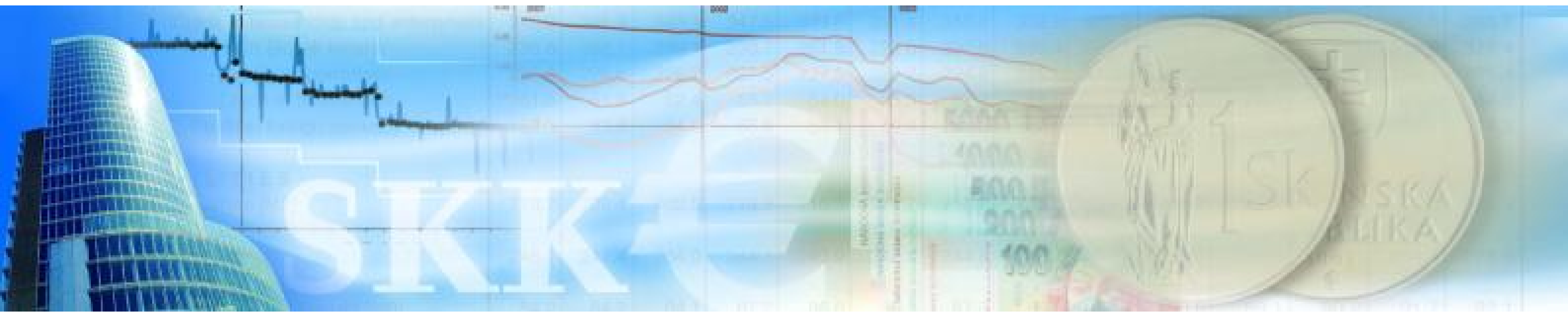
EUROSYSTÉM

Juraj Zeman, Matúš Senaj

DSGE MODEL – SLOVAKIA



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DSGE model - Slovakia

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Abstract

DSGE Slovakia is a medium size New Keynesian open economy model designed to simulate dynamic behavior of Slovak economy. It consists of about 50 equations and contains all important macroeconomic variables including real GDP and all its main components- consumption, investment, government expenditures, import and export then factors of production – labor, capital and oil and also consumer, producer, import and export price deflators, nominal interest rate and exchange rate.
Most parameters of the model are calibrated and remaining ones are estimated by various estimation technique.
Appropriateness of the model is judged by comparing statistics of simulated data with real ones, by analyzing impulse response functions and by reproducing historical time series.

Keywords: General equilibrium model, Slovakia
JEL classification: D58, E32

Reviewed by: Jean-Marc Natal (Swiss National Bank)
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1 Introduction

In this paper we present a DSGE model for the Slovak economy.

The key features of DSGE models are microeconomic foundations of their equations, rational expectations of all economic agents involved and a general equilibrium setting. These features ensure a theoretical cohesion of the model and make it suitable predominantly for qualitative analysis - studying different stages of business cycles, analyzing impacts of various policy changes as well as responses of variables to various structural shocks. The first simple versions of DSGE models, however, were trailing behind more empirically based models (e.g. VARs) in capturing empirical properties of real economy. In order to improve empirical tractability of DSGE models, simple versions were augmented by including more variables and by introducing various frictions. These enhanced DSGE models are comparable and in many instances even outperform their empirically based counterparts in empirics (Smets and Wouters, 2003) and can be used also for forecasting purposes.

Model presented in this paper is based on the work of Cuche-Curti, Dellas and Natal: DSGE model for Switzerland[1]. It is a medium size New Keynesian small open economy model designed to simulate dynamic behavior of Slovak economy. It consists of about 50 equations and contains all important macroeconomic variables including real GDP and all its main components- consumption, investment, government expenditures, import and export then factors of production – labor, capital and oil also consumer, producer, import and export price deflators, nominal interest rate and exchange rate.

The model displays sticky nominal prices and wages that adjust to staggered price/wage setting a la Calvo. In order to improve the persistence of inflation a partial indexation scheme for non-optimizers is introduced. The model also incorporates capital adjustment cost (paid for transforming investment into capital) which smoothes investment and external habit formation ("catching up with Jonses") that improves consumption dynamics.

Here we present first version of the model, the so called "baby model", which will be extended and improved in the near future.

The structure of the paper is as follows. Next section introduces main features of the model. Section 3 provides detailed description of the behavior of all agents in the modeled economy, such as firms, households, government and the central bank. The method of calibration of the parameters is described in section 4. Finally, section 5 presents the impulse response

[1] Authors thank to Jean-Marc Natal for his permission to use their model as a benchmark and for his invaluable help.

functions of the model. Particularly, we study four shocks: monetary policy loosening, expansionary fiscal policy, productivity shock and oil price shock.

2 Main features

The model has the following structure:

Production

There are two sectors of production – intermediate goods and final goods.

Inputs for intermediate goods are labor, capital and oil. Intermediate goods are tradable and can be used either domestically for producing final goods or can be exported abroad. Producers in this sector produce differentiated good. There is imperfect competition in this sector and hence producers have market power in setting price of goods used domestically (Kollmann, 2002).

Final goods are produced of intermediate goods either domestic or imported and of oil and are either consumed privately, publicly or invested. There is perfect competition in final good production sector. Final good is non tradable.

Household

There is a representative household who maximizes lifetime utility out of consumption and leisure. She makes two decisions: current consumption vs investment (that gives her higher consumption in future) and hours worked vs leisure. There is imperfect competition in the labor market that gives market power to workers in wage setting. In order to improve dynamics of the model, household sector is enhanced with the following amendments: habit formation in consumption (Fuhrer, 2000) which ensures that consumers smooth their consumption, fraction of consumers who do not borrow or save but instead spend all their current labor income (rule-of-thumb consumers, Gali et al, 2004) and capital adjustment costs that implies the cost of transforming investment into capital.

Trade

Only intermediate goods can be traded. Domestic firms export a fraction of intermediate goods abroad. Prices of exported intermediate goods can differ from prices of intermediate goods sold domestically (pricing to market structure – Bergin, Feenstra, 1999). Imported intermediate goods can not be consumed directly. Importing firms have market power in setting price of import. Hence exchange rate pass-through is incomplete and the law of one price does not necessarily hold in short term (Monacelli, 2005).

Financial market

Financial market is incomplete. In equilibrium, foreign investors do not hold domestic bonds. This means that the amount of domestic bonds equals zero at all times. Economies with incomplete insurance against idiosyncratic shocks have the potential to account for low correlation of consumption between domestic and foreign countries, the pattern that is observed in data (Backus et al, 1995). Domestic agents can insure against shocks by holding foreign assets. To avoid of excessive accumulation of net foreign assets in domestic economy in the model, their price increase with their level. The more is domestic country indebted (higher level of net foreign assets), the costlier for its citizens is to borrow further.

Monetary and fiscal policy

Monetary authority reacts to deviations of inflation, output and exchange rate from their steady state values by setting nominal interest rate (Taylor rule).

Fiscal authority keeps balanced budget each period.

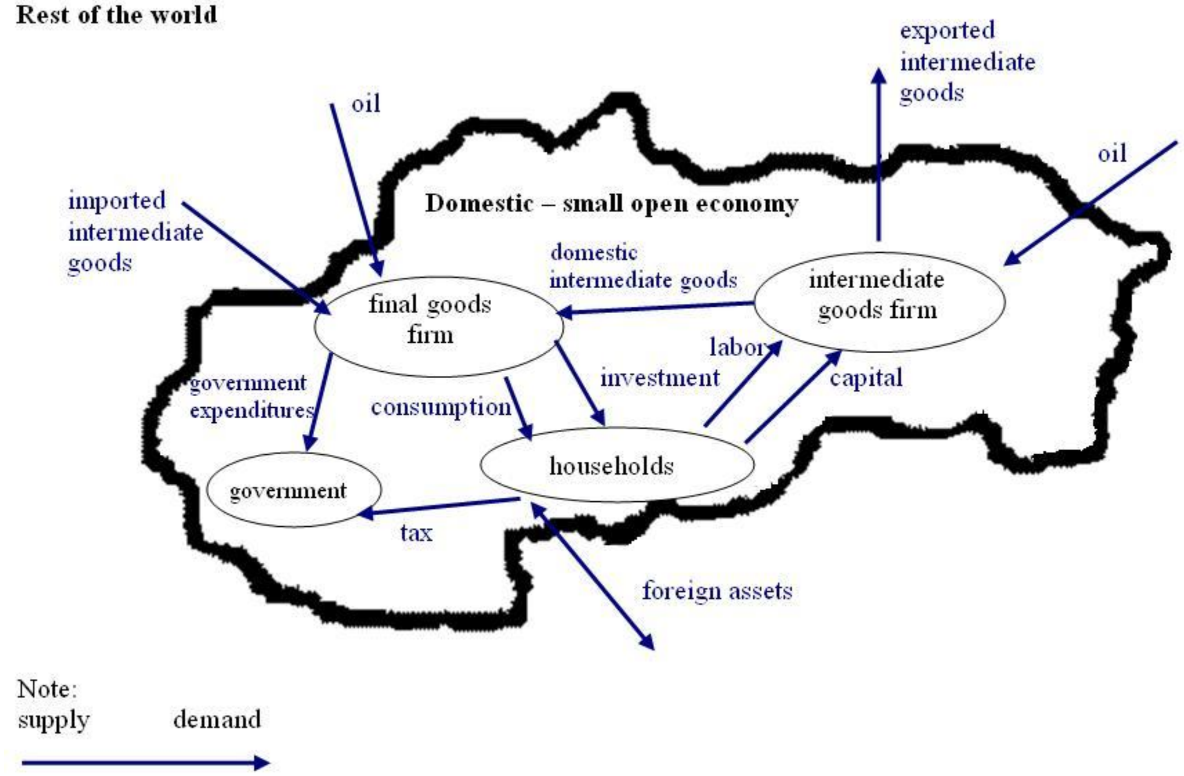
Price setting

There is staggered price setting á la Calvo for the prices of domestic and imported intermediate goods as well as for the price of labor (wages). Firms (workers) can not change their price unless they receive a random “price-change signal”. If it does not receive this signal the price is automatically adjusted according to certain indexation scheme.

Exogenous shocks

There are several domestic and external shocks in the model. Domestic shocks are to productivity, fiscal expenditure and domestic interest rate. External shocks are to foreign output, foreign interest rate, foreign price level and to oil price.

Figure 1 scheme of the economy



Trends vs cycles

It is assumed that all real variables including output and its components are non-stationary processes with common stochastic trend. Hence all these variables are transformed to stationary ones by taking this stochastic trend away (de-trended) before they enter the model.

Price deflators are assumed to be non-stationary processes with common stochastic trend. Original non-stationary deflators are denoted by upper case letters (P_t) while their corresponding de-trended counterparts are denoted by lower case letters (p_t).

All other variables including interest rate and exchange rate are assumed to be stationary. A "hat" on a variable indicates the percentage deviation of that variable from its steady state value. In the case of net inflation and net interest rate, "hat" indicates difference of that variable from steady state value.

The final version of the model consists of a set of equations some of which are linearized by hand and remaining are left non-linear. The model is solved numerically using DYNARE software package[2] developed by Michel Juillard.

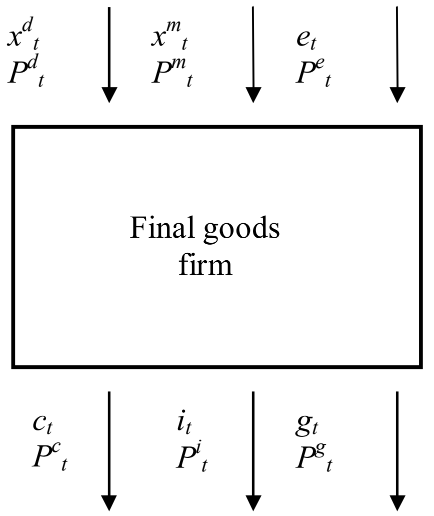
[2] DYNARE is downloadable at http://www.cepremap.cnrs.fr/juillard/mambo/index.php

3 The model

3.1 Final goods firms

Final goods firms operate in a perfectly competitive market and produce non-tradable goods from a bundle of domestic intermediate goods (x_t^d), a bundle of imported intermediate goods (x_t^m) and energy (e_t). Final goods are either consumed by domestic households (c_t) and government (g_t) or invested domestically (i_t).

Figure 2 final goods firm



These different types of final goods $l \in \{c, i, g\}$, whose demand is determined in a household sector, are produced with a technology represented by the production function

$$l_t = \left[\omega_{e,l}^{1-\rho_{e,l}} a(x_t^l)^{\rho_{e,l}} + (1-\omega_{e,l})^{1-\rho_{e,l}} (e_t^l)^{\rho_{e,l}}\right]^{1/\rho_{e,l}} \tag{3.1}$$

with

$$a(x_t^l) = \left[\omega_l^{1-\rho_l} (x_t^{d,l})^{\rho_l} + (1-\omega_l)^{1-\rho_l} (x_t^{m,l})^{\rho_l}\right]^{1/\rho_l} \tag{3.2}$$

Aggregator $a()$ combines domestic and imported intermediate goods with elasticity of substitution between them equal to $\left(1/1-\rho_l\right)$. ω_l is the share of domestic intermediate goods in the bundle. Then the bundle of intermediate goods is combined with energy and final goods are produced. The elasticity of substitution between intermediate goods and energy is $\left(1/1-\rho_{e,l}\right)$ and the share of energy is $(1-\omega_{e,l})$. Notice that elasticity of substitution between the bundle of intermediate goods and energy is in general different (much smaller, of course) from the elasticity of substitution between intermediate goods themselves.

Final goods firms optimize their production by minimizing their total cost. Given the price of domestic intermediate goods - P_t^d , the price of imported intermediate goods - P_t^m and the price of energy - P_t^e , they solve the following problem

$$\min TC_t = \min_{\{x_t^{d,l},x_t^{m,l},e_t^l\}} P_t^d x_t^{d,l} + P_t^m x_t^{m,l} + P_t^e e_t^l + \psi_t^l \Big\{ l_t - \\ -\left[\omega_{e,l}^{1-\rho_{e,l}} a(x_t^l)^{\rho_{e,l}} + (1-\omega_{e,l})^{1-\rho_{e,l}} (e_t^l)^{\rho_{e,l}}\right]^{1/\rho_{e,l}} \Big\}, \tag{3.3}$$

$l \in \{c,i,g\}$. ψ_t^l is a Lagrange multiplier that represents marginal cost.

Solution to this problem leads to following demand functions:

$$x_t^{d,l} = \left(\frac{P_t^d}{P_t^l}\right)^{\frac{1}{\rho_l-1}} \omega_l a(x_t^l)^{\frac{\rho_{e,l}-\rho_l}{1-\rho_l}} (\omega_{e,l} l_t)^{\frac{1-\rho_{e,l}}{1-\rho_l}} \tag{3.4}$$

$$x_t^{m,l} = \left(\frac{P_t^m}{P_t^l}\right)^{\frac{1}{\rho_l-1}} \omega_l a(x_t^l)^{\frac{\rho_{e,l}-\rho_l}{1-\rho_l}} (\omega_{e,l} l_t)^{\frac{1-\rho_{e,l}}{1-\rho_l}} \tag{3.5}$$

$$e_t^l = \left(\frac{P_t^e}{P_t^l}\right)^{\frac{1}{\rho_{e,l}-1}} (1-\omega_{e,l}) l_t \tag{3.6}$$

Value of $a(x_t^l)$ at the optimal quantities is

$$a(x_t^l) = \omega_{e,l} l_t \left[\omega_l \left(\frac{P_t^d}{P_t^l}\right)^{\frac{\rho_l}{\rho_l-1}} + (1-\omega_l)\left(\frac{P_t^m}{P_t^l}\right)^{\frac{\rho_l}{\rho_l-1}} \right]^{\frac{1-\rho_l}{\rho_l(1-\rho_{e,l})}} \tag{3.7}$$

By substituting these optimal quantities into total cost (TC_t) we can get the expressions for marginal costs ψ_t^l. Because final goods firms operate in a perfectly competitive market, marginal cost equals price level, $\psi_t^l = P_t^l$, $l \in \{c,i,g\}$.

$$P_t^l = \left\{ \omega_{e,l} \left[\omega_l \left(P_t^d\right)^{\frac{\rho_l}{\rho_l-1}} + (1-\omega_l\left(P_t^m\right)^{\frac{\rho_l}{\rho_l-1}} \right]^{\frac{\rho_{e,l}(1-\rho_l)}{\rho_l(1-\rho_{e,l})}} + (1-\omega_{e,l})\left(P_t^e\right)^{\frac{\rho_{e,l}}{\rho_{e,l}-1}} \right\}^{\frac{\rho_{e,l}-1}{\rho_{e,l}}} \tag{3.8}$$

Bundles $x_t^{d,l}$ and $x_t^{m,l}$ are CES aggregators of domestic and imported intermediate goods produced by *i* firms, $i \in [0,1]$

$$x_t^{d,l} = \left(\int_0^1 x_t^{d,l}(i)^{\theta_d} \, di \right)^{\frac{1}{\theta_d}} \quad and \quad x_t^{m,l} = \left(\int_0^1 x_t^{m,l}(i)^{\theta_m} \, di \right)^{\frac{1}{\theta m}} \qquad (3.9)\ (3.10)$$

$\frac{1}{1-\theta_d}$ $\left(\frac{1}{1-\theta_m} \right)$ is the elasticity of substitution between domestic (imported) intermediate goods.

The aggregator chooses the bundle of goods that minimizes the cost of producing a given quantity $x_t^{d,l}$, ($x_t^{m,l}$) taking the prices $P_t^d(i)$, ($P_t^m(i)$) as given. This leads to the following demand functions for goods *i*

$$x_t^{d,l}(i) = \left(\frac{P_t^d(i)}{P_t^d} \right)^{\frac{1}{\theta_d - 1}} x_t^{d,l} \quad and \quad x_t^{m,l}(i) = \left(\frac{P_t^m(i)}{P_t^m} \right)^{\frac{1}{\theta_m - 1}} x_t^{m,l} \qquad (3.11)\ (3.12)$$

where P_t^d and P_t^m are unit costs of the bundles $x_t^{d,l}$ and $x_t^{m,l}$ respectively, given by

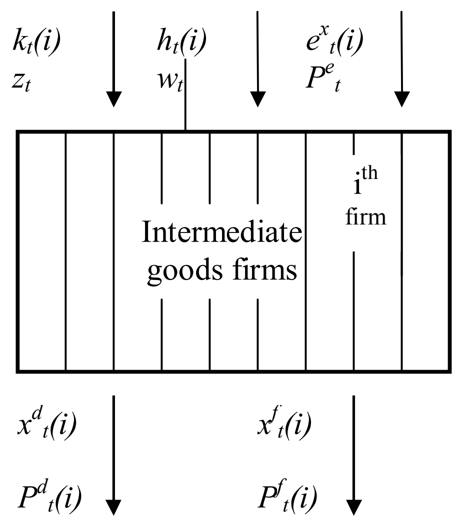
$$P_t^d = \left(\int_0^1 P_t^d(i)^{\frac{\theta_d}{\theta_d - 1}} \, di \right)^{\frac{\theta_d - 1}{\theta_d}} \quad and \quad P_t^m = \left(\int_0^1 P_t^m(i)^{\frac{\theta_m}{\theta_m - 1}} \, di \right)^{\frac{\theta m - 1}{\theta m}} \qquad (3.13)\ (3.14)$$

We can interpret P_t^d and P_t^m as the aggregate price indices.

3.2 Intermediate goods firms

Each domestic intermediate firm produces a differentiated good $x_t(i)$ with capital $k_t(i)$, labor $h_t(i)$ and energy $e_t^x(i)$ which is then used domestically - $x_t^d(i)$ for producing final goods or exported - $x_t^f(i)$, $x_t(i) = x_t^d(i) + x_t^f(i)$.

Figure 3 intermediate goods firm



Production function for intermediate good i is a CES function

$$x_t(i) = A_t \left\{ \alpha_c^{\frac{1}{\sigma_e}} \left[x_t^{k,l}(h_t(i), k_t(i)) \right]^{\frac{\sigma_e - 1}{\sigma_e}} + (1-\alpha_c)^{\frac{1}{\sigma_e}} \left(e_t^x(i) \right)^{\frac{\sigma_e - 1}{\sigma_e}} \right\}^{\frac{\sigma_e}{\sigma_e - 1}} \tag{3.15}$$

with

$$x_t^{k,l}(h_t(i), k_t(i)) = \left\{ \alpha_l^{\frac{1}{\sigma_{k,l}}} \left(h_t(i) \right)^{\frac{\sigma_{k,l}-1}{\sigma_{k,l}}} + (1-\alpha_l)^{\frac{1}{\sigma_{k,l}}} \left(k_t(i) \right)^{\frac{\sigma_{k,l}-1}{\sigma_{k,l}}} \right\}^{\frac{\sigma_{k,l}}{\sigma_{k,l}-1}}, \tag{3.16}$$

where A_t represents an exogenous stationary stochastic technological shock. $\sigma_{k,l}$ is elasticity of substitution between labor and capital and σ_e is elasticity of substitution between labor/capital and energy.

Each firm *i* tries to minimize total cost of producing $x_t(i)$ intermediate goods demanded by domestic and foreign final goods producers. Given wage rate w_t, rental rate of capital z_t and the price of energy P_t^e, firm *i* solves the following problem

$$\begin{aligned} \min TC_t(i) = \min_{\{h_t(i), k_t(i), e_t^x(i)\}} \; & w_t h_t(i) + z_t k_t(i) + P_t^e e_t^x(i) + \psi_t(i) \Bigg\{ x_t(i) - \\ & - A_t \left\{ \alpha_c^{\frac{1}{\sigma_e}} \left[x_t^{k,l}(h_t(i), k_t(i)) \right]^{\frac{\sigma_e - 1}{\sigma_e}} + (1-\alpha_c)^{\frac{1}{\sigma_e}} \left(e_t^x(i) \right)^{\frac{\sigma_e - 1}{\sigma_e}} \right\}^{\frac{\sigma_e}{\sigma_e - 1}} \Bigg\} \end{aligned} \tag{3.17}$$

where $\psi_t(i)$ is marginal cost of a firm i. The solution to this problem implies that all firms have identical real marginal cost ψ_t that does not depend on *i*

$$\psi_t = \frac{1}{A_t} \left\{ \alpha_c \left[\alpha_l w_t^{1-\sigma_{k,l}} + (1-\alpha_l) z_t^{1-\sigma_{k,l}} \right]^{\frac{\sigma_e - 1}{\sigma_{k,l}-1}} + (1-\alpha_c)(P_t^e)^{1-\sigma_e} \right\}^{\frac{1}{1-\sigma_e}} \tag{3.18}$$

Then index *i* can be dropped and we get aggregate demand for labor, capital and energy

$$h_t = \alpha_c \alpha_l \frac{x_t}{A_t} (\psi_t A_t)^{\sigma_e} w_t^{-\sigma_{k,l}} \left[\alpha_l w_t^{1-\sigma_{k,l}} + (1-\alpha_l) z_t^{1-\sigma_{k,l}} \right]^{\frac{\sigma_e - \sigma_{k,l}}{\sigma_{k,l}-1}} \tag{3.19}$$

$$k_t = \alpha_c (1-\alpha_l) \frac{x_t}{A_t} (\psi_t A_t)^{\sigma_e} z_t^{-\sigma_{k,l}} \left[\alpha_l w_t^{1-\sigma_{k,l}} + (1-\alpha_l) z_t^{1-\sigma_{k,l}} \right]^{\frac{\sigma_e - \sigma_{k,l}}{\sigma_{k,l}-1}} \tag{3.20}$$

$$e_t^x = (1-\alpha_c) \frac{x_t}{A_t} (\psi_t A_t)^{\sigma_e} (P_t^e)^{-\sigma_{k,l}} \tag{3.21}$$

Labor market consists of a continuum of monopolistically competitive households (Erceg et al, 1999) supplying differentiated services $h_t(j)$, $j \in [0,1]$ to the production sector. h_t index is defined as CES aggregator

$$h_t = \left(\int_0^1 h_t(j)^{\upsilon} dj \right)^{\frac{1}{\upsilon}} \tag{3.22}$$

where $(1/1-\upsilon)$ is the elasticity of substitution between labor types.

Households have market power in setting their wage rate $w_t(j)$. Firms choose the bundle of differentiated labor inputs in order to minimize their labor cost, given their labor needs h_t and wage rates $w_t(j)$. This leads to the following demand for labor j

$$h_t(j) = \left(\frac{w_t(j)}{w_t} \right)^{\frac{1}{\upsilon-1}} h_t \tag{3.23}$$

where w_t is a unit cost of the bundle h_t, given by

$$w_t = \left(\int_0^1 w_t(j)^{\frac{\upsilon}{\upsilon-1}} dj \right)^{\frac{\upsilon-1}{\upsilon}} \tag{3.24}$$

We can interpret w_t as the aggregate wage index.

3.3 Price setting in the intermediate goods sector

Because each firm produces differentiated products, they have market power in setting prices of their goods. They set prices of goods used domestically in domestic currency and prices of exported goods in foreign currency. We assume that these two prices are set independently of each other and are different in general. This price discrimination, termed "pricing to market", is justifiable for certain classes of goods, most notably for automobiles (Obstfeld and Rogoff , 1999) and electronic products that are typical export goods for Slovakia.

Each firm *i* tries to maximize its profit $\Pi_t(i) = \Pi_t^d(i) + \Pi_t^f(i)$.

Due to pricing to market assumption this maximization can be solved separately for goods used domestically and exported.

3.3.1 Domestic goods

By setting the price of intermediate goods used domestically $P_t^d(i)$, firm *i* solves

$$\max_{P_t^d(i)} \Pi_t^d(i) = \max_{P_t^d(i)} \left(\frac{P_t^d(i)}{P_t^C} - \psi_t \right) x_t^d(i), \tag{3.25}$$

where ψ_t is the real marginal cost and $P_t^d(i)/P_t^C$ is the real price of goods in terms of consumption units.

We use a standard assumption that firm set their prices in Calvo style (Calvo, 1983). Every period only $1-\tau_d, \tau_d \in [0,1]$ of domestic intermediate firms (selected randomly) can optimize the price of production. Firms that can not optimize adjust their price by indexing it, partially to previous period inflation and partially to steady state inflation. The indexing scheme is

$$P_{t+1}^d(i) = \left(1+\pi^C\right)^{1-\gamma}\left(1+\pi_t^C\right)^{\gamma} P_t^d(i) \tag{3.26}$$

A fraction γ of non-optimizing firm index its price to last period CPI inflation and the remaining $1-\gamma$ adjust to gross steady state inflation rate. The indexing scheme is introduced in order to account for more persistence in inflation dynamics observed in data.

Firm *i* sets its optimal price $P_t^d(i)$ keeping in mind that it may not be able to reoptimize in future. Thus the firm wants to select such price that maximizes the present value of all future expected profits achieved in periods when this price is just indexed but not reoptimized.

Substituting demand $x_t^d(i)$ into equation (profit), applying indexation scheme (3.26) and summing up over future periods we get

$$\max_{P_t^d(i)} \sum_{k=0}^{\infty} \tau^k E_t \rho_{t,t+k} \left(\left(\frac{\left(\tau\left(1+\pi^C\right)^{k(1-\gamma)}\left(\frac{P_{t+k-1}^C}{P_{t-1}^C}\right)^{\gamma}\left(P_t^d(i)\right)}{P_{t+k}^C} - \psi_{t+k} \right) \times \times \left(\frac{\left(\tau\left(1+\pi^C\right)^{k(1-\gamma)}\left(\frac{P_{t+k-1}^C}{P_{t-1}^C}\right)^{\gamma}\left(P_t^d(i)\right)}{P_{t+k}^d} \right)^{\frac{1}{\theta-1}} x_{t+k}^d \right) \tag{3.27}$$

where $\rho_{t,t+k}$ is a discount factor valuing $t+k$ payoffs at time *t*. Solution to the above problem leads to the following expression

$$P_t^d(i) = \frac{1}{\theta_d} \frac{\sum_{k=0}^{\infty} \left(\tau \left(1+\pi^C\right)^{\frac{1-\gamma}{\theta_d - 1}} \right)^k E_t \left(\rho_{t,t+k} x_{t+k}^d \left(\frac{P_{t+k-1}^C}{P_{t-1}^C} \right)^{\frac{\gamma}{\theta_d - 1}} \left(P_{t+k}^d\right)^{\frac{1}{1-\theta_d}} \psi_{t+k} \right)}{\sum_{k=0}^{\infty} \left(\tau \left(1+\pi^C\right)^{\frac{\theta_d (1-\gamma)}{\theta_d - 1}} \right)^k E_t \left(\rho_{t,t+k} x_{t+k}^d \left(\frac{P_{t+k-1}^C}{P_{t-1}^C} \right)^{\frac{\gamma\theta_d}{\theta_d - 1}} \left(P_{t+k}^d\right)^{\frac{1}{1-\theta_d}} \frac{1}{P_{t+k}^C} \right)} \tag{3.28}$$

According to the equation (3.28) firms set their optimal price as a markup over a weighted average of expected future marginal costs ψ_{t+k}.

Our main concern is the dynamics of aggregate price index P_t^d. Applying indexation scheme (3.26) to price index equation (3.13) gives

$$\left(P_t^d\right)^{\frac{\theta_d}{\theta_d - 1}} = (1-\tau) P_t^d(i)^{\frac{\theta_d}{\theta_d - 1}} + \tau \left(\left(1+\pi^C\right)^{1-\gamma} \left(1+\pi_{t-1}^C\right)^{\gamma} P_{t-1}^d \right)^{\frac{\theta_d}{\theta_d - 1}} \tag{3.29}$$

Log-linearizing equations (3.28) and (3.29) and combining them we can derive a New Keynesian Phillips curve for the domestic intermediate goods inflation

$$\hat{\pi}_t^d = \beta E_t \hat{\pi}_{t+1}^d + \gamma (\hat{\pi}_{t-1}^C - \beta \hat{\pi}_t^C) + \frac{(1-\tau_d)(1-\beta\tau_d)}{\tau_d} (\hat{\psi}_t - \hat{p}_t^d) \tag{3.30}$$

with

$$\hat{\pi}_t^d = \hat{p}_t^d - \hat{p}_{t-1}^d + \hat{\pi}_t^C \; , \tag{3.31}$$

where $p_t^d = \frac{P_t^d}{P_t^C}$, $\pi_t^C = \frac{P_t^C}{P_{t-1}^C} - 1$.

Current domestic intermediate goods inflation is a function of expected future domestic inflation, current and lagged CPI inflation and of real marginal cost in domestic intermediate goods.

3.3.2 Exported goods

Exporters set their price $P_t^f(i)$ in foreign currency to maximize their profit

$$\max_{P_t^f(i)} \Pi_t^f(i) = \max_{P_t^f(i)} \left(\frac{s_t P_t^f(i)}{P_t^C} - \psi_t \right) x_t^f(i) \tag{3.32}$$

where s_t is the nominal exchange rate expressed as a number of domestic currency for one unit of foreign currency $\left(SKK/€\right)$, $x_t^f(i)$ is foreign demand for domestic intermediate good i, which is a function of aggregate foreign demand given by

$$x_t^f = (1-\omega^*)\left(\frac{P_t^f}{P_t^*}\right)^{\frac{1}{\rho_f - 1}} y_t^* \tag{3.33}$$

where P_t^f is aggregate price index of export in foreign currency, P_t^* is foreign aggregate price index, y_t^* is foreign production of foreign non-tradable goods and $(1-\omega_t^*)$ is the share of domestic intermediate goods export in foreign final goods production.

Solving this problem, the same way we used in the previous section, leads to the dynamics of export prices inflation rate given by the following Phillips curve

$$\hat{\pi}_t^f = \beta E_t \hat{\pi}_{t+1}^f + \gamma_f (\hat{\pi}_{t-1}^* - \beta \hat{\pi}_t^*) + \frac{(1-\tau_f)(1-\beta\tau_f)}{\tau_f}(\hat{\psi}_t - r\hat{e}r_t - \hat{p}_t^f) \tag{3.34}$$

with

$$\hat{\pi}_t^f = \hat{p}_t^d - \hat{p}_{t-1}^f + \hat{\pi}_t^* \tag{3.35}$$

where $\hat{\pi}_t^f$ is the exported goods price inflation rate, $\hat{\pi}_t^*$ is the inflation rate in foreign economy and $r\hat{e}r_t$ is the percentage deviation from steady state of the real exchange rate defined by $rer_t = s_t P_t^* / P_t^C$.

3.3.3 Imported goods

Each importer imports a differentiated intermediate good i and sets its price[3] $P_t^m(i)$ above the price he paid for - $s_t P_t^*(i)$ in order to maximize

$$\max_{P_t^m(i)} \Pi_t^m(i) = \max_{P_t^m(i)} \left(\frac{P_t^m(i)}{P_t^C} - \frac{s_t P_t^*(i)}{P_t^C}_t \right) x_t^m(i) \tag{3.36}$$

The optimization leads to the following Phillips curve of import price inflation

$$\hat{\pi}_t^m = \beta E_t \hat{\pi}_{t+1}^m + \gamma_m (\hat{\pi}_{t-1}^C - \beta \hat{\pi}_t^C) + \frac{(1-\tau_m)(1-\beta\tau_m)}{\tau_m}(r\hat{e}r_t - \hat{p}_t^m) \tag{3.37}$$

Comparing equations (3.34) and (3.37) we see that real appreciation of domestic currency (a decrease of *rer*) increases inflation of exported goods and decreases inflation of imported goods.

Log-linearizing the final goods price equations (3.8), we obtain the final goods inflation equations

[3] Price setting is done in Calvo style.

$$\hat{\pi}_t^l = \omega_{e,l}(\omega_l \hat{\pi}_t^{d,l} + (1-\omega_l)\hat{\pi}_t^{m,l}) + (1-\omega_{e,l})\hat{\pi}_t^e \quad (3.38)$$

for $l \in \{c, i, g\}$.

3.4 Households

The economy is formed by a continuum of infinitely lived households. Similarly as Galí et al. (2004), Coenen and Straub (2005) and Cuche-Curti, Dellas, Natal (2007) we consider two types of households. The first type of household represents non-Ricardian consumers. They do not optimize their utility and thus consume their disposable income in the respective time period. The second type of households have access to capital markets, they accumulate capital and optimize their utility function subject to budget constraint and law of motion for capital.

Adding the non-Ricardian households improves the responses of the model to government expenditure shock. As Coenen and Straub (2005) showed the rise in government expenditures positively affects spending of non-Ricardian households. However such effect tends to be offset by a fall in Ricardian households' consumption.

In short, the overall real consumption of average household equals:

$$c_t = \lambda^T c_t^R + \left(1 - \lambda^T\right) c_t^O , \tag{3.39}$$

where c_t^R stands for consumption of rule of thumb consumers and c_t^O denotes consumption of optimizing consumers. Parameter λ^t represents the share of rule of thumb consumers.

3.4.1 Non – optimizing (rule of thumb) consumers

The consumers belonging to these households consume only current disposable income and do not own any assets. Such kinds of consumers follow a simple rule.

$$c_t^R = w_t h_t \tag{3.40}$$

Hours worked $\left(h_t\right)$ are chosen by firms and wages $\left(w_t\right)$ are set by optimizing households.

3.4.2 Optimizing – Ricardian consumers

Ricardian consumers maximize the utility function given by:

$$U_{j,0} = E_{j,0}\left[\sum_{t=0}^{\infty} \beta^t \left(\frac{\left(c_t^O(j) - hab * c_{t-1}^O\right)^{1-\sigma}}{1-\sigma} - \frac{\left(h_t\,(j)\right)^{1+\nu}}{1+\nu} \right)\right], \tag{3.41}$$

where $c_t^O\left(j\right)$ stands for real consumption of household *j*, while $h_t\left(j\right)$ represents the hours worked of the optimizing household j . Three parameters appear in the utility[4], β as a

[4] $0 < \beta < 1;\ \sigma, \nu > 0;\ \sigma \neq 1.$

subjective rate of discount, σ as an inverse of intertemporal elasicity of consumption and v is an inverse of elasticity of labor supply.

In order to replicate the hump-shaped response of consumption [5] to shocks, habit formation is embedded into the model by the term $hab * c_{t-1}^{O}$. We assume external habit formation also known as "catching up with Jonses" (Abel 1990), where consumers care about the difference between their actual consumption and lagged aggregate consumption. The parameter hab ($0 \leq hab \leq 1$) stands for the intensity of habit persistence.

The maximization of the utility function is subject to the following two sequences of constraints.

Let's start with a budget constraint. Each Ricardian household faces to the sequence of flow budget constraint.[6] At the beginning of the period t they earn labor income $(w_t h_t)$, they have yields from holding domestic and foreign riskless bonds purchased in period t and maturing in period t. And also the households benefit from renting their capital holdings (k_{t-1}) at the constant rental cost (z_t) and from ownership of the firms (div_t). The households pay lump-sum taxes(t_t). On the other hand the consumers can buy domestic (b_t) and foreign bonds f_t and also choose between consumption (c_t^O) and investment (i_t) during the period. The variable S_t denotes the exchange rate in terms of domestic currency per one unit of foreign currency.

$$b_t(j) + S_t f_t(j) + c_t^O(j) + i_t(j) - \frac{\varphi_k}{2}\left(\frac{k_t}{k_{t-1}} - 1\right)^2 k_{t-1} \leq \frac{\left(1+i_{t-1}^d\right)}{\left(1+\pi_t^c\right)} b_{t-1}(j) + \frac{\left(1+i_{t-1}^*\right)}{\left(1+\pi_t^c\right)} S_t f_{t-1} +$$
$$+ z_t k_{t-1}(j) + w_t(j) h_t(j) + div_t(j) - t_t(j) \tag{3.42}$$

We extended the model by embedding the capital adjustment costs. Their economic interpretation is that households must pay cost for transformation the investment into capital. This gives them an incentive to smooth investment. According to Ireland (2003), we assume adjustment cost given by:

$$\frac{\phi_k}{2}\left(\frac{k_t}{k_{t-1}} - 1\right)^2 k_{t-1} , \tag{3.43}$$

[5] This kind of response is hard to replicate in the absence of habit persistence (Grohé and Uribe, 2008).
[6] In real per-capita terms.

where φ_k [7] controls for the size of the capital adjustment cost.

And finally, the last constraint is capital accumulation. The stock of the capital grows according to the following law of motion:

$$k_t = (1-\delta)k_{t-1} + i_t \,. \tag{3.44}$$

Capital at time period *t* is equal to the capital from previous time period *t-1* adjusted by the amortization δ plus the amount of investment decided at time *t*.

Further, the decision problem was solved using the methods of dynamic programming. Particularly, the Bellman equation (Heer and Maussner, 2005) and the envelope theorem were used.

Thus we optimize the following Lagrange function for every time period with respect to $\{c_t, b_t, f_t, i_t, k_t, w_t\}$. Lagrange multipliers $\lambda_{1,t}$ and $\lambda_{2,t}$ are connected with budget constraint and capital accumulation equation.

$$\begin{aligned} L_t = Max&\left\{\frac{\left(c_t^O(j) - hab * c_{t-1}^O\right)^{1-\sigma}}{1-\sigma} - \frac{h_t(j)^{1+\nu}}{1+\nu}\right\} + \\ &+ \lambda_{1,t}\left\{\frac{\left(1+i_{t-1}^d\right)}{\left(1+\pi_t^c\right)} b_{t-1}(j) + \frac{\left(1+i_{t-1}^*\right)}{\left(1+\pi_t^c\right)} S_t f_{t-1}(j) + z_t k_{t-1}(j) + w_t(j) h_t(j) + div_t(j) - t_t(j) - \right. \\ &\left. - b_t(j) + S_t f_t(j) + c_t^O(j) + i_t(j) - \frac{\phi_k}{2}\left(\frac{k_t(j)}{k_{t-1}(j)} - 1\right)^2 k_{t-1}(j)\right\} + \\ &+ \lambda_{2,t}\left\{(1-\delta)k_{t-1}(j) + i_t(j) - k_t(j)\right\} \end{aligned} \tag{3.45}$$

The value function $V\left(k_{t-1}, b_{t-1}, f_{t-1}\right)$ solves the Bellman equation given by:

$$\begin{aligned} V(k_{t-1}, b_{t-1}, f_{t-1}) = Max&\left\{\frac{\left(c_t^O(j) - hab * c_{t-1}^O\right)^{1-\sigma}}{1-\sigma} - \frac{h_t(j)^{1+\nu}}{1+\nu} + \right. \\ &+ \lambda_{1,t}\left(\frac{\left(1+i_{t-1}^d\right)}{\left(1+\pi_t^c\right)} b_{t-1}(j) + \frac{\left(1+i_{t-1}^*\right)}{\left(1+\pi_t^c\right)} S_t f_{t-1}(j) + z_t k_{t-1}(j) + w_t(j) h_t(j) + div_t(j) - t_t(j) - \right. \\ &\left. - b_t(j) + S_t f_t(j) + c_t^O(j) + i_t(j) - \frac{\phi_k}{2}\left(\frac{k_t(j)}{k_{t-1}(j)} - 1\right)^2 k_{t-1}(j)\right) + \\ &\left. + \lambda_{2,t}\left\{(1-\delta)k_{t-1}(j) + i_t(j) - k_t(j)\right\} + \beta V\left(k_t, b_t, f_t\right) \right\} \end{aligned} \tag{3.46}$$

[7] $\phi_k \geq 0$

Consequently, the first order conditions associated with the Bellman equation were derived and the envelope theorem was used to eliminate the derivatives of the value function.

1. The first order conditions for consumption equals the Lagrange multiplier $\lambda_{1,t}$ to marginal utility of consumption:

$$\lambda_{1,t} = \left(c_t^O(j) - hab * c_{t-1}^O\right)^{-\sigma} \tag{3.47}$$

2. Optimal condition (FOC) for capital is as follows:

$$\lambda_{2,t} = \beta E_t\left[\frac{\phi_k}{2}\lambda_{1,t+1}\left(\frac{k_{t+1}^2}{k_t^2} - 1\right) + \lambda_{1,t+1}z_{t+1} + \lambda_{2,t+1}(1-\delta)\right] - \phi_k \lambda_{1,t}\left(\frac{k_t}{k_{t-1}} - 1\right) \tag{3.48}$$

3. FOC for investment states that both Lagrange multipliers are equal to each other.

$$\lambda_{1,t} = \lambda_{2,t} \tag{3.49}$$

4. Optimization with respect to domestic bond holdings leads to the following optimal condition.

$$\lambda_{1,t} = \beta\left(1 + i_t^d\right)E_t\left[\frac{\lambda_{1,t+1}}{1+\pi_{t+1}^c}\right] \tag{3.50}$$

5. Similarly to the previous equation (3.50), optimization with respect to holdings of foreign bonds gives next condition:

$$\lambda_{1,t}S_t = \beta\left(1 + i_t^f\right)E_t\left[\lambda_{1,t+1}\frac{S_{t+1}}{1+\pi_{t+1}^c}\right] \tag{3.51}$$

6. FOC for wages

In the spirit of Calvo (1983) we assume sticky wages. The wage setting mechanism is very similar to price setting introduced earlier. In every quarter, the household *j* is able to reset wage *w(j)* with probability $(1-\tau_w)$ and in doing so, the household maximize the utility function. The household which is not able to set optimal wage simply adjust their wage in line with the inflation. Real wages are indexed according to both steady state and past inflation (Cuche-Curti, Dellas and Natal, 2007) in the following way:

$$w_{t+l,t}(j) = \left(1+\pi^c\right)^{l(1-\gamma_w)}\left(\frac{P_{t+l-1}}{P_{t-1}}\right)^{\gamma_w}\frac{P_t}{P_{t+l}}w_{t,t}(j) \tag{3.52}$$

Those households, which are able to set optimal prices maximize the utility function with respect to $w_t(j)$. The first order condition implies the following optimal wage:

$$w_t(j)=\frac{\sum_{l=0}^{\infty}\sum_{l=0}^{\infty}\left(\beta\tau_w\right)^l E_t\left[U_{t+l,t}^h(j)\left(\frac{\left(1+\pi^c\right)^{l(1-\gamma_w)}P_tP_{t+l-1}{}^{\gamma_w}}{w_{t+l}P_{t+l}P_{t-1}{}^{\gamma_w}}\right)^{\frac{1}{\vartheta-1}}h_{t+l}\right]}{\sum_{l=0}^{\infty}\left(\beta\tau_w\right)^l E_t\left[\vartheta U_{t+l,t}^c(j)\left(1+\pi^c\right)^{l(1-\gamma_w)}\frac{P_t}{P_{t+l}}\left(\frac{P_{t+l-1}}{P_{t-1}}\right)^{\gamma_w}\left(\frac{\left(1+\pi^c\right)^{l(1-\gamma_w)}P_tP_{t+l-1}{}^{\gamma_w}}{w_{t+l}P_{t+l}P_{t-1}{}^{\gamma_w}}\right)^{\frac{1}{\vartheta-1}}h_{t+l}\right]} \tag{3.53}$$

Using the expression (3.24) the aggregate wage can be written.

$$w^{\frac{\vartheta}{\vartheta-1}}=\left(1-\tau_w\right)w_t(j)^{\frac{\vartheta}{\vartheta-1}}+\tau_w\left(\left(1+\pi^c\right)^{1-\gamma_w}\frac{P_t}{P_{t-1}}\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_w}w_{t-1}\right)^{\frac{\vartheta}{\vartheta-1}} \tag{3.54}$$

Then combining (3.53) and (3.54) and rewriting in terms of deviations from the steady state the New Keynesian Phillips curve for wages can be obtained. After simplification of the expression we get:

$$\begin{aligned}\hat{w}_t=&\frac{\beta}{1+\beta}E_t\left[\hat{w}_{t+1}\right]+\frac{1}{1+\beta}\hat{w}_{t-1}+\frac{\beta}{1+\beta}\left(E_t\left[\hat{\pi}_{t+1}^c\right]-\gamma_w\hat{\pi}_t^c\right)-\frac{1}{1+\beta}\left(\hat{\pi}_t^c-\gamma_w\hat{\pi}_{t-1}^c\right)+\\&+\frac{\left(1-\tau_w\beta\right)\left(1-\tau_w\right)}{\tau_w\left(1+\beta\right)\left(1+v\frac{1}{1-\vartheta}\right)}\left(v\hat{h}_t+\frac{\sigma}{1-hab}\left(\hat{c}_t^O-hab*\hat{c}_{t-1}^O\right)-\hat{w}_t\right)\end{aligned} \tag{3.55}$$

Current wage is a function of lagged and expected wage, lagged, current and expected domestic inflation, lagged and current consumption of optimizing households and hours worked.

3.5 Monetary policy

The aim of the central bank is to stabilize inflation, output of the economy and the exchange rate. Monetary policy follows modified Taylor rule.

The central bank adjusts the nominal interest rates according to deviations of the domestic inflation, output and exchange rate from their steady state levels. Lagged interest rate serves for interest rate smoothing. Parameter ρ stands for the degree of persistence in the interest rates. Monetary policy shock is represented by m_t.

$$\hat{i}_t^d=\rho\hat{i}_{t-1}^d+\left(1-\rho\right)\left(\phi_\pi\hat{\pi}_t^c+\phi_x\hat{x}_t+\phi_{der}d\hat{e}r_t\right)+m_t \tag{3.56}$$

3.6 Constraints

The following two equations close the model.

First, the model assumes that financial capital is not perfectly mobile. Thus the interest rate at which the households can borrow or lend foreign currency (i_t^f) equals to the interest rate in the foreign economy (i_t^*) adjusted by a decreasing function of the net foreign asset position (Kollmann, 2002). High indebtness of the domestic agents results in higher interest rates on additional loans.

$$\left(1+i_t^f\right)=\left(1+i_t^*\right)-\frac{\alpha}{\chi}\left(1+\pi^*\right)\left(\frac{S_t f_t}{rer_t}\right) \tag{3.57}$$

Parameter α is degree of capital mobility. The lower α the higher the capital mobility is. χ stands for steady state export in terms of foreign output.

Second, balance of payment equilibrium, which states that sum of current account and capital account equals to zero. Such equilibrium can be rewritten as follows:

$$0=\frac{\Delta_t}{1+\pi_t^c}x_t^f p_t^* p_t^{f*}-\frac{\Delta_t}{1+\pi_t^c}x_t^m p_t^*-\frac{\Delta_t}{1+\pi_t^c}p_t^e e_t-\left(S_t f_t-\frac{\Delta_t}{1+\pi_t^c}\left(1+i_{t-1}^f\right)S_t f_{t-1}\right) \tag{3.58}$$

3.7 Exogenous variables

The model features 7 exogenous variables. Majority of them describe economic development in the foreign/external economy. Particularly, foreign interest rate, inflation, output and crude oil price are given. The rest of the variables assumed as exogenous belong to domestic sector. Here, the productivity and monetary shocks are embedded. And finally, government expenditure is also assumed to be exogenous. Deviations from the steady state of exogenous variables follow stationary autoregressive process. The following equations - from (3.59) to (3.65) – describe the behavior of the exogenous variables. The variables $\left(ei^*, e\pi^*, ey^*, ea, em, ep, eg\right)$ stand for the shocks

$$\hat{i}_t^* = \rho_1^i \hat{i}_{t-1}^* + ei^* \tag{3.59}$$

$$\hat{\pi}_t^* = \rho_1^\pi \hat{\pi}_{t-1}^* + e\pi^* \tag{3.60}$$

$$\hat{y}_t^* = \rho_1^y \hat{y}_{t-1}^* + ey^* \tag{3.61}$$

$$\hat{a}_t = \rho_1^a \hat{a}_{t-1} + ea \tag{3.62}$$

$$\hat{m}_t = em \tag{3.63}$$

$$\hat{p}_t^e = \rho_1^p \hat{p}_{t-1}^e + ep \tag{3.64}$$

$$\hat{g}_t = \rho_1^g \hat{g}_{t-1} + eg \tag{3.65}$$

4 Calibration of the parameters

The whole set of the parameters of the presented model can be divided into four groups according to the technique of calibration. The final list of the parameters and their values can be found in the appendix 1.

First part consists of those parameters which we took as given. Some of them are borrowed from the literature. For instance, the time discount (β) is set to 0.99 (Hansen, 1985), depreciation rate 0.015 (Beneš, et. al., 2005). According to Chang and Kim (2005) typical value of Frisch elasticity is less than 0.5. We assume that Frisch elasticity equals to 0.4 thus ν equals to 2.5. Parameters determining the behavior of the central bank were set according Taylor's suggestion. Persistence parameter is set to 0.8. The parameter determining the response of the central bank to deviations of inflation (ϕ_π) is 1.5. Since we deal with quarterly model ϕ_x equals to 0.5/4 as suggested by Galí (2008). Similarly the parameter determining reaction to fluctuations in exchange rate is set to 0.125.[8]

On the other hand some of the parameters were set as an expert judgment based mainly on the actual Slovak data. To the second group belongs for instance share of rule of thumb consumers (0.5). According to the statistical survey conducted in Slovakia, one half of the households do not save money and they spend all what they earned. We assume that wages are optimized once a year and prices are optimized more frequently. The average duration of the price contract is 3.3 quarters.

Third part is formed by the estimated parameters. In order to replicate the behavior of the exogenous variables we estimated the AR(1) processes. Thus we can obtain the coefficients of equations describing the exogenous variables and also the majority of the standard deviations of the shocks. Here the OLS estimation method is employed.

[8] Since the estimated parameters of the Taylor rule were insignificant due to short time period, we prefer standard parameters for Taylor rule borrowed from the literature.

Finally, four selected parameters were calibrated according to standard deviations of the selected variables. Here we deal with habit formation parameter *hab*, two elasticities (ρ_c and ρ_f) and the size of capital adjustment cost (φ_k). Our aim was to match standard deviations of the simulated and empirical time series and the emphasis was put also on the shape of impulse-response functions. Standard deviations and relative standard deviations are presented in Table 1 and 2, where we compare empirical time series with the time series obtained using the model.

In October 1998 National Bank of Slovakia changed exchange rate regime and adopted exchange rate floating. On the other hand, in 2008, final steps regarding the eurozone entry was done and the conversion rate of Slovak koruna was set. Therefore, we use empirical data that covers stable time period 1999-2007. For the comparison we used Quarterly HP filtered time series.

Table 1 Standard deviation

	empirical	model
output	0.015	0.011
consumption	0.016	0.010
export	0.041	0.012
import	0.037	0.032
investment	0.083	0.086
domestic interest rate	0.014	0.004
ex. rate changes	0.020	0.019
inflation	0.013	0.004

Source: Author's calculation

Table 2 Standard deviation relative to GDP

	empirical	model
output	1	1
consumption	1.06	0.91
export	2.77	1.14
import	2.54	2.95
investment	5.64	7.92
domestic interest rate	0.93	0.35
ex. rate changes	1.35	1.74
inflation	0.90	0.40

Source: Author's calculation

5 IR functions

This section presents impulse response functions of the selected variables. We focus on four types of shocks, such as loosening of the monetary policy, expansionary fiscal policy, positive productivity shock and the oil price shock. All shocks which hit the economy are temporary. Presented figures show percentage deviations of the variables from their steady state level.

5.1 Monetary policy shock

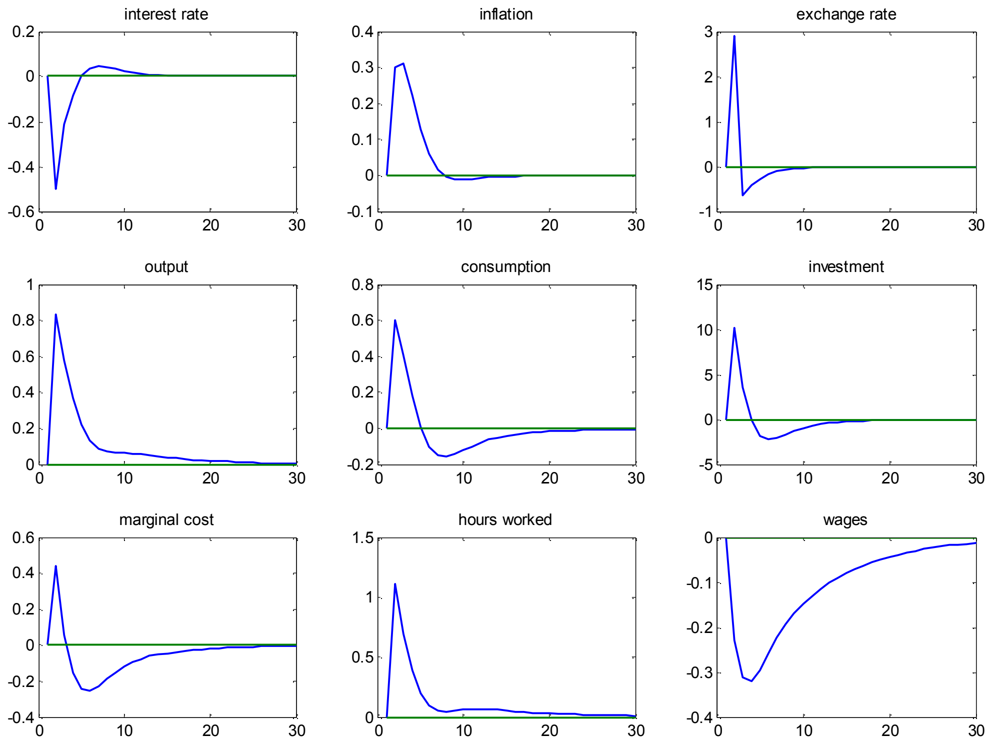
In figure 4 we see response of the economy to expansionary monetary policy namely to unexpected reduction of short term interest rate. Consumption, investment and output all expand. There are two channels through which this is happening.

Exchange rate channel – lower interest rate through UIP causes depreciation of nominal exchange rate, and due to price rigidity this leads to depreciation of real exchange rate. Import becomes more expansive relative to domestically produced goods which encourages export and discourages imports hence net export increases.

Interest rate channel – lower interest rate boosts investment and consumption thus output. As a consequence of higher economic activity hours worked, thus employment expands.

Higher output caused by higher demand leads to marginal cost increase and this together with depreciated currency push inflation up.

Figure 4 monetary policy loosening (50 b.p.)



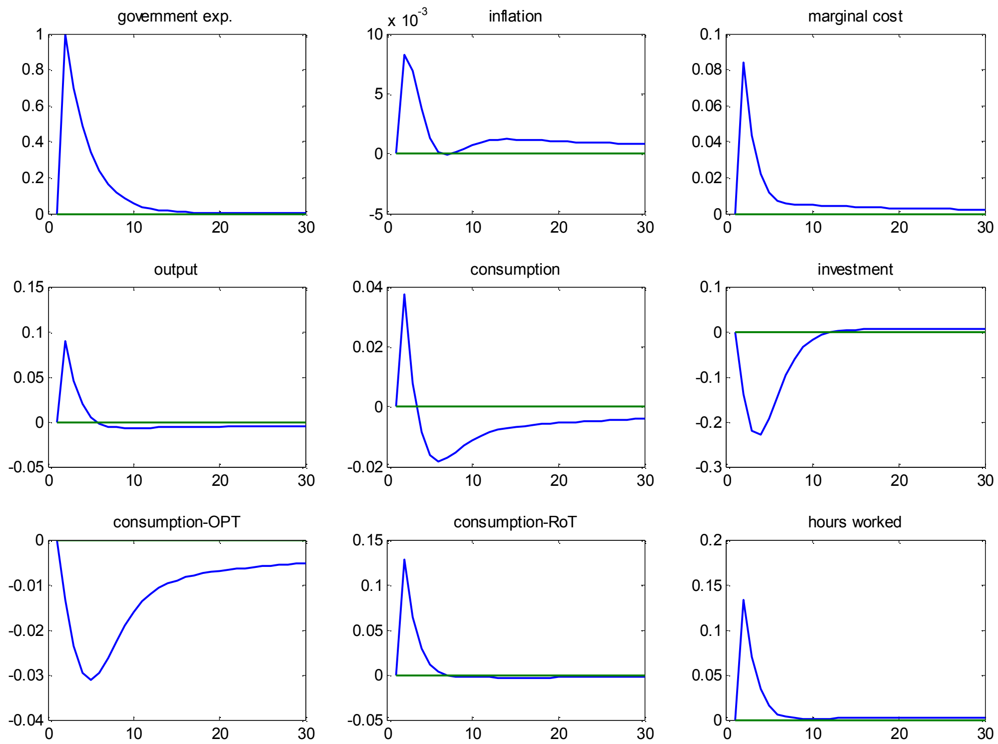
Source: authors' calculation

5.2 Expansionary fiscal shock

Figure 5 shows the impact of expansionary fiscal shock. Higher government expenditure boosts output but the impact is quite small. A 1 percent increase in public expenditures leads to 0.1% increase in output. Consumption of rule of thumb consumers increases, while consumption of optimizing consumers decreases as their disposable income goes down. They have to pay higher taxes to balance government budget (RoT consumers do not pay any taxes). Overall consumption expands while investment is crowded out by government expenditures. Expansionary fiscal policies lead to higher employment (hours worked).

As in the case of monetary loosening, higher output caused by higher demand leads to marginal cost increase and this together with depreciated currency lifts inflation.

Figure 5 expansionary fiscal policy (1 %)

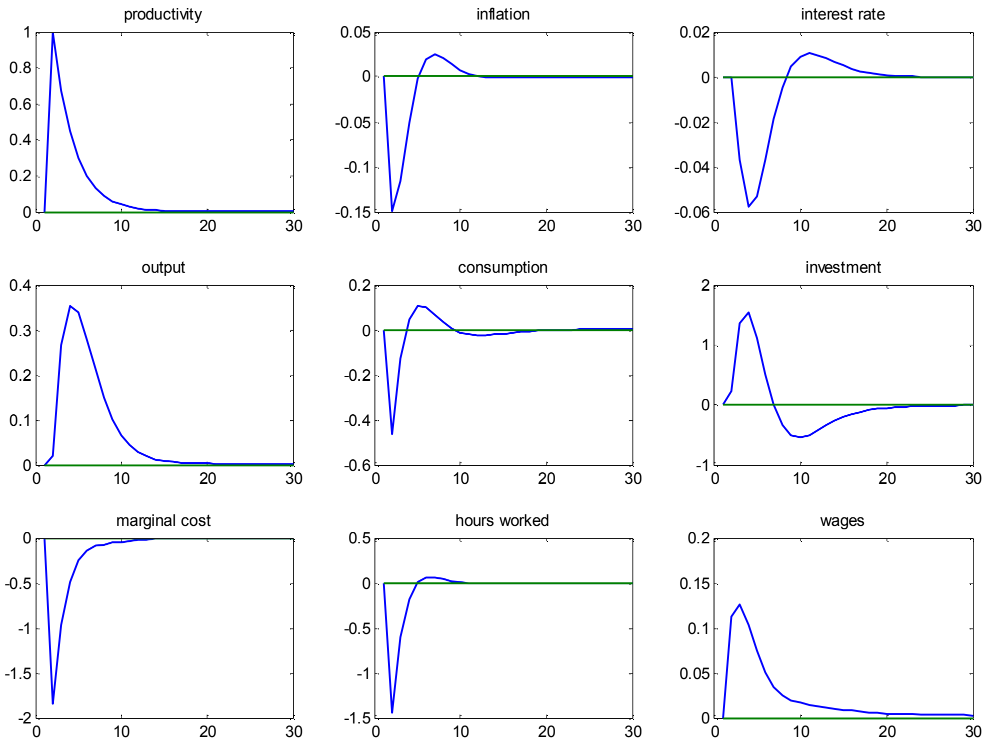


Source: authors' calculation

5.3 Productivity shock

Figure 6 shows the impact of a positive supply shocks, namely the unexpected rise of productivity. Output and investment both rise. Despite the fact that wages and the price of capital both increase, marginal cost goes down as higher productivity outweighs those increases. Lower marginal cost leads to lower inflation.

Figure 6 increase in productivity (1 %)

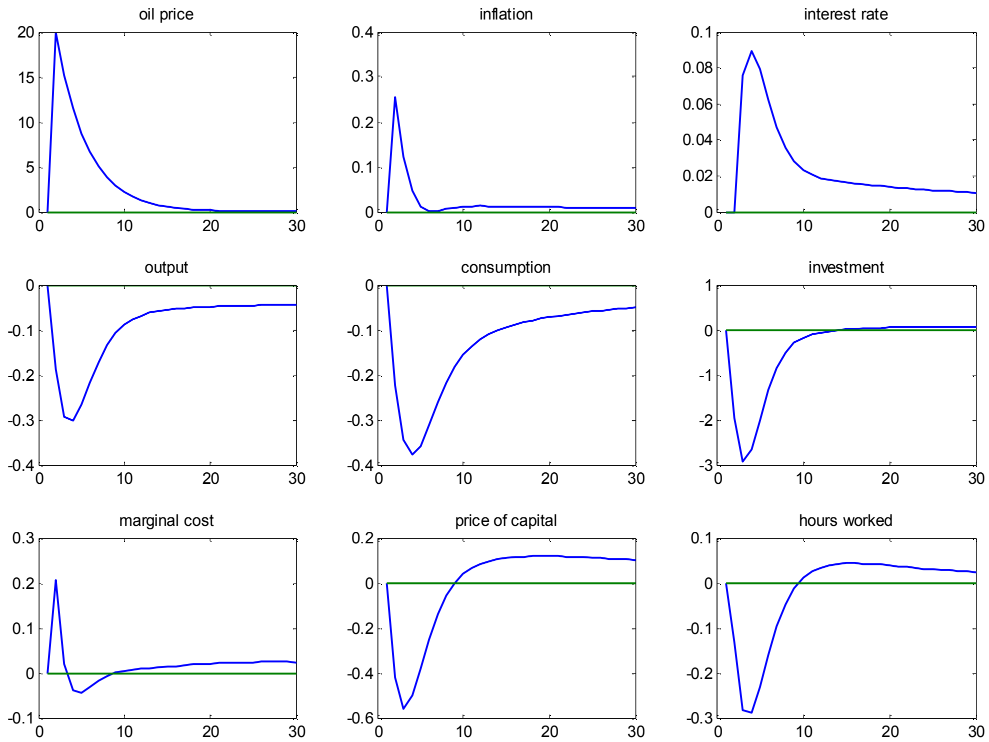


Source: authors' calculation

5.4 Oil price shock

In figure 7 there is an impact of negative supply shock – an increase of price of oil. The response of the economy is almost a mirror image of the situation caused by positive supply shock. Output, consumption and investment go down. This leads to lower cost of capital and lower wages. However decrease of these two components of marginal cost is surpassed by the increase of oil price and marginal cost actually rises. Higher marginal cost drives inflation up.

Figure 7 increase in oil price by 20 %



Source: authors' calculation

6 Simulations of the selected variables

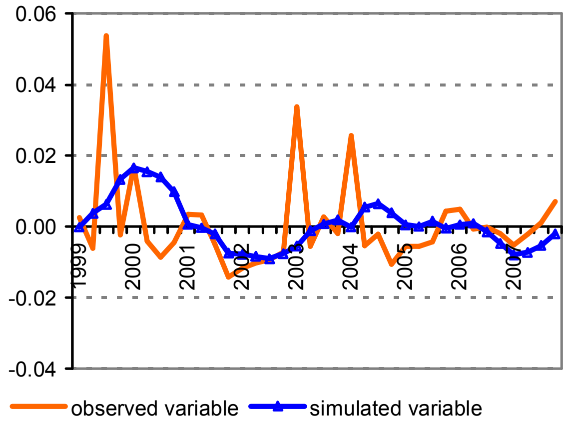
As a third method to evaluate the fit of the model we choose a comparison of the observed time series with the model ex post forecasts. In the next three figures the observed (HP filtered time series) and simulated variables (dynamic forecast of the model with known exogenous variables[9]) are presented. It is worth noting that such an evaluation is difficult due to several structural changes in the Slovak economy in the last two decades.

In general, the fit of the presented baseline model is satisfying but further work is needed to improve the forecasting power of the DSGE model for Slovakia. First figure shows the development of the CPI inflation. Two outliers in the observed data accompanied with changes in the tax system (1st quarter 2003 and 2004) can be identified here. Next figure presents the evolution of the interest rates. These two time series are comparable only after the year 2000 because Slovak interest rates recorded exceptional behavior (the interest rates were higher than 15 % p.a.) before that year. The last figure compares observed and simulated gross domestic product.

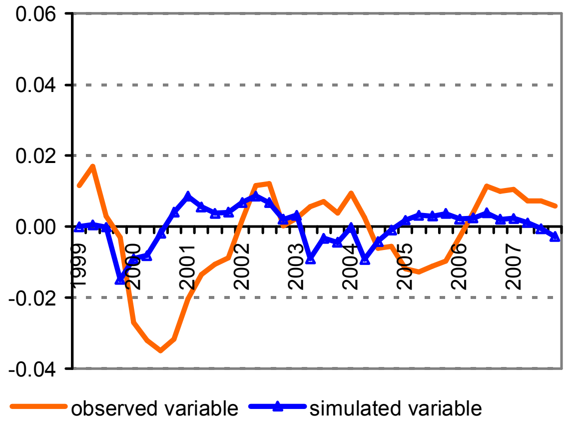
[9] Productiviti is proxied by Solow residual from production function.

Figure 8 comparison of simulated and observed variables

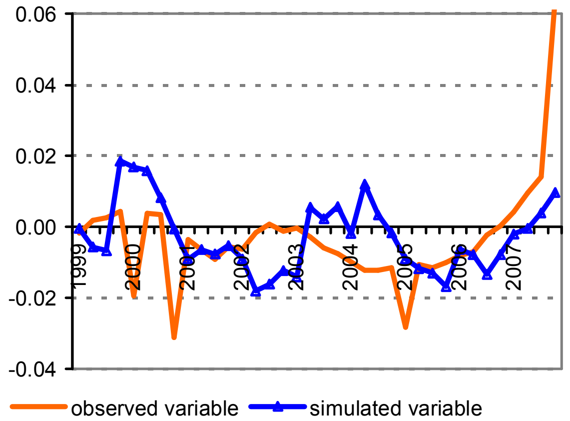
CPI inflation



Domestic interest rate



Gross domestic product



Source: authors' calculation

7 Conclusion

We have constructed a medium-size DSGE model of small open economy that contains all important macroeconomic variables. It incorporates both nominal frictions (price and wage stickiness) and real frictions (capital adjustment cost and habit formation) which improve dynamic behavior of model variables. Parameters of the model have been calibrated using combination of several techniques. One group of parameters has been borrowed from existing literature while others have been set according to actual Slovak data either as an expert judgment or as values matching certain observable statistics. Parameters of exogenous processes have been estimated.

Appropriateness of the model has been judged by three different ways, comparing statistical characteristics (second moments) of simulated data with empirical ones, replicating historical data and finally analyzing impulse response functions.

Responses of macroeconomics variables to exogenous shocks in most cases coincided with what one would expect real variables would respond, especially qualitatively. The magnitude of these responses of some variables, of real exchange rate in particular, is too large. Hence the economy overreacts to the monetary shock. The authors want to improve these shortcomings by including more adjustments or modifying the existing ones. Further research will involve a modification of UIP, investment adjustment cost and variable capital utilization.

Concerning setting up parameter values, authors would like to select a group of parameters that would be estimated using Bayesian estimation techniques.

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9 Appendix

9.1 List of parameters

Parameter	Description	Value (Implied elasticity)	Source
Households			
β	Time discount	0.99	Hansen, 1985
δ	Depreciation rate	0.015	Beneš, et. al., 2005
λ^t	Share of rule of thumb consumers.	0.5	Gfk Slovakia Survey
hab	Habit formation	0.6	Calibrated
σ	Inverse elasticity of intertemporal consumption	1.1 (0.91)	
ν	Inverse elasticity of intertemporal labor supply	2.5 (0.4)	Chang and Kim, 2005
ϑ	1-inverse elasticity of wage substitution between different labor types	0.8 (5)	Cuche-Curti. et.al,2007
theta,	1-inverse elasticity of subst. Individual goods domestic	0.7 (3.3)	
thetam	1-inverse elasticity of subst. Individual goods imported	0.7 (3.3)	
thetaf,	1-inverse elasticity of subst. Individual goods exported	0.9 (10)	
Final goods			
ρ_c	1-inverse of elasticity of subst. Domestic vs. import	-4.9	Calibrated
ρ_{ec}	1-inverse of elasticity of subst. Dom/import vs. energy	-10 (0.09)	Cuche-Curti. et.al,2007
ρ_i	1-inverse of elasticity of subst. Domestic vs. import	0.01 (1.01)	Cuche-Curti. et.al,2007
ρ_{ei}	1-inverse of elasticity of subst. Dom/import vs. energy	-10 (0.09)	Cuche-Curti. et.al,2007
ρ_g	1-inverse of elasticity of subst. Domestic vs. import	0.01 (1.01)	Cuche-Curti. et.al,2007
ρ_{eg}	1-inverse of elasticity of subst. Dom/import vs. energy	-10 (0.09)	Cuche-Curti. et.al,2007
ρ_f	1-inverse of elasticity of subst. Export vs. foreign	-0.3	Calibrated
ω_c	Share of domestic intermed. good vs. imported	0.60	Expert judgment
ω_i	Share of domestic intermed. good vs. imported	0.20	Expert judgment
ω_g	Share of domestic intermed. good vs. imported	0.60	Expert judgment
ω_{ec}	Share of domestic/imported vs. energy	0.99	Expert judgment
ω_{ei}	Share of domestic/imported vs. energy	0.99	Expert judgment
ω_{eg}	Share of domestic/imported vs. energy	0.99	Expert judgment
Intermediate goods			
α_c	Share of labor/capital vs. energy	0.98	

α_l	Share of labor vs. capital	0.5	Expert judgment
σ_{kl}	Elasticity of subst. Capital vs. labor	0.9999 (0.9999)	
σ_e	Elasticity of subst. Cap/labor vs. energy	0.15 (0.15)	
Philips curves			
γ_d,	Price indexation	0.6	
γ_m	Price indexation	0.6	
γ_f	Price indexation	0.6	
γ_w	Wage indexation	0.6	
τ_d	Probability of no price change	0.7	
τ_m	Probability of no price change	0.7	
τ_f	Probability of no price change	0.7	
τ_w	Probability of no wage change	0.75	
Taylor rule			
ρ	Autoregression coefficient of interest rate	0.8	Galí (2008)
ϕ_π	Weight of inflation gap	1.5	Galí (2008)
ϕ_x	Weight of output gap	0.125	Galí (2008)
ϕ_{der}	Weight of output gap	0.125	
Constraints			
φ_k	Size of the capital adjustment cost	8	Calibrated
phi	Size of foreign economy relative to domestic	60	Expert judgment
α	Degree of capital mobility	0.0019	Kollmann, 2002
χ	Steady state domestic export in terms of foreign output	0.005695	Expert judgment
Exogenous processes			
ρ_1^i	Foreign interest rate	0.92	Estimated - OLS
ρ_1^π,	Foreign inflation	-0.22	Estimated - OLS
ρ_1^y	Foreign output	0.87	Estimated - OLS
ρ_1^a	Productivity	0.33	Estimated - OLS
ρ_1^p	Price of energy	0.76	Estimated - OLS
ρ_1^g	Government expenditures	0.7	Estimated - OLS
σ^{i*}	Foreign interest rate	0.0006	Estimated - OLS
$\sigma^{\pi*}$	Foreign inflation	0.002	Estimated - OLS
σ^{y*}	Foreign output	0.003	Estimated - OLS
σ^a	Productivity	0.010	Estimated - OLS
σ^m	Monetary policy shock	0.003	Estimated - OLS
σ^{pe}	Price of energy	0.130	Estimated - OLS
σ^g	Government expenditures	0.022	Estimated - OLS

9.2 IR functions (DSGE vs. QPM)

In order to compare the impulse response functions of our baseline DSGE model with Quarterly Projection Model developed by our colleagues Gavura and Reľovský (2005) from the monetary policy department we present three types of shocks (e.g. monetary policy loosening, expansionary fiscal policy and permanent oil price shock. Quarterly projection model is a small open economy "gap model" focused on the transmission mechanism of the Slovak economy. It includes forward looking agents and active monetary policy. [10] It is worth noting that following comparisons serve only for illustrations because these models are based on different foundations.

Here we present three types of impulse response functions. First refers to QPM model, second belongs to baseline DSGE model and third combines DSGE model with Taylor rule parameters borrowed from QPM model. Thus the Taylor rules are as follows:

1. Orange dashed line – Quarterly Projection Model.

$$i_t^d = 0.7\, i_{t-1}^d + (1-0.7)\left(i_t^* + 2.25\left(\pi_{t+4}^c - \pi_{t+4}^*\right) + 0.75\hat{x}_t\right) + m_t ,$$

where i_t^* stands for policy neutral level of the interest rate and.

2. Blue solid line – baseline DSGE model with standard Taylor rule (page 23).

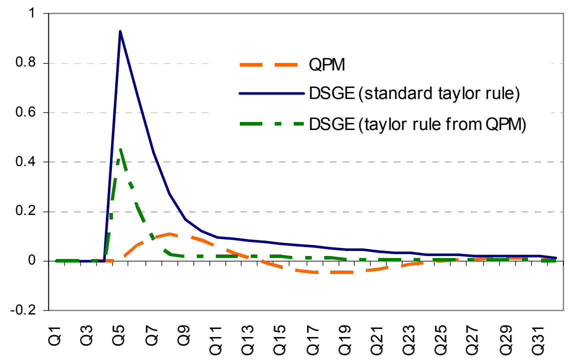
$$\hat{i}_t^d = 0.8\,\hat{i}_{t-1}^d + (1-0.8)\left(1.5\hat{\pi}_t^c + 0.125\hat{x}_t + 0.125 d\hat{e}r\right) + m_t$$

3. Green semi-dashed line – DSGE model with Taylor rule parameters similar as in QPM.

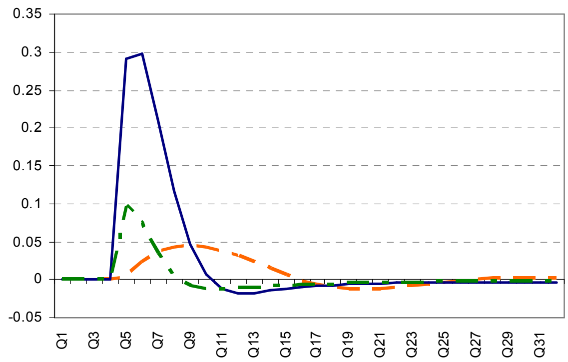
$$\hat{i}_t^d = 0.7\,\hat{i}_{t-1}^d + (1-0.7)\left(2.25\hat{\pi}_t^c + 0.75\hat{x}_t\right) + m_t$$

Monetary policy loosening (50 b.p.)

Output



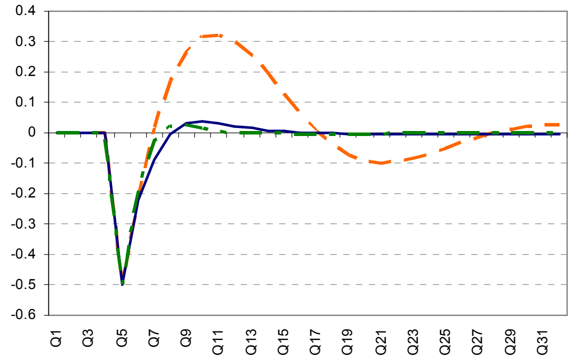
CPI inflation

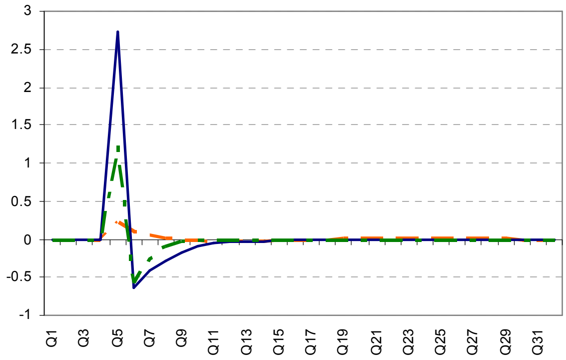


Nominal interest rate

Exchange rate changes

[10] Further information can be found in Gavura and Reľovský (2005).

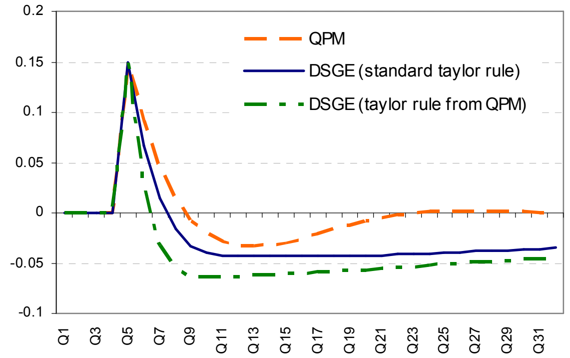




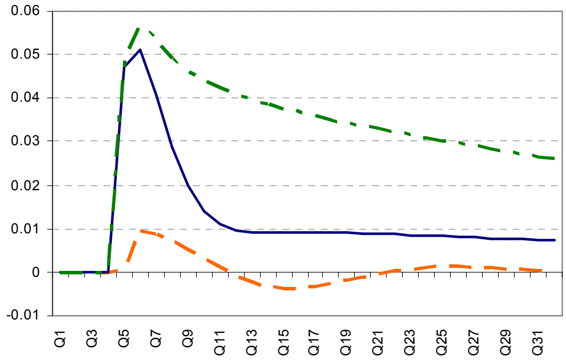
Source: Monetary policy department and authors' calculation

Expansionary fiscal policy

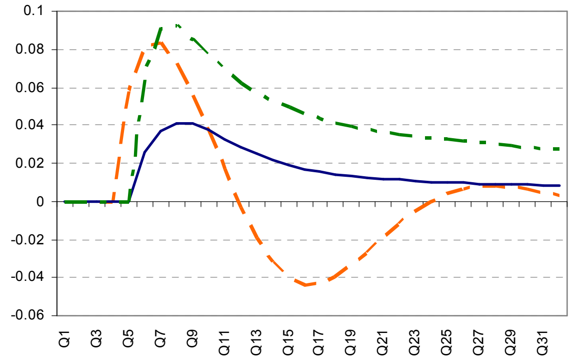
Output



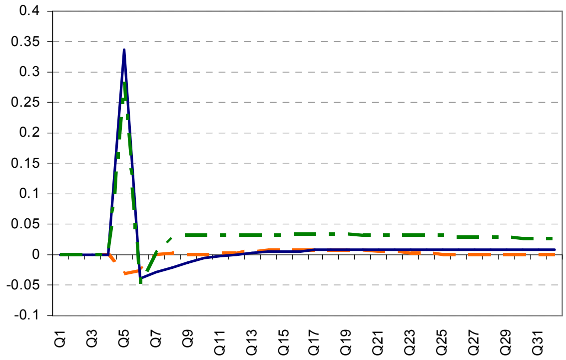
CPI inflation



Nominal interest rate



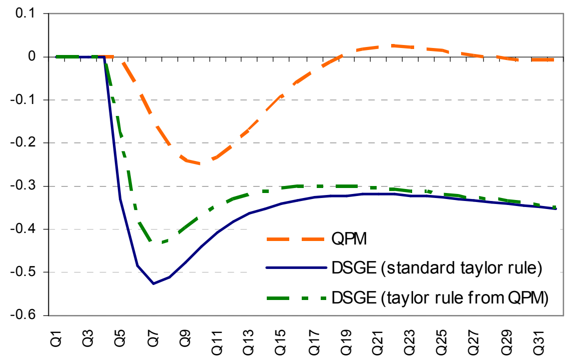
Exchange rate changes



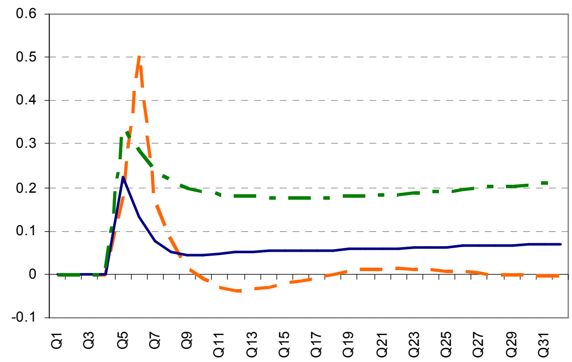
Source: Monetary policy department and authors' calculation

Permanent oil price shock (20 %)

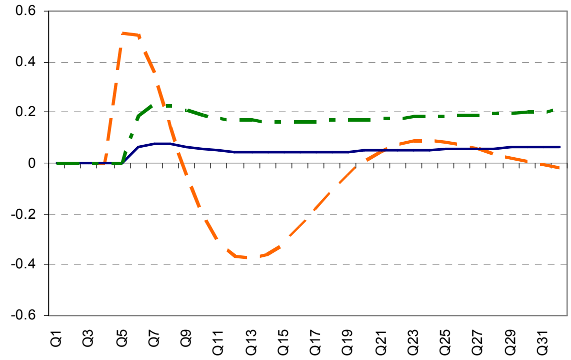
Output



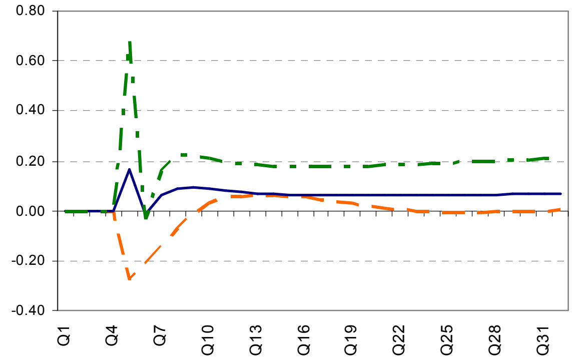
CPI inflation



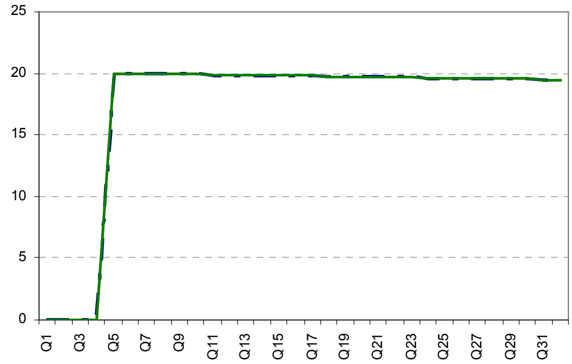
Nominal interest rate



Exchange rate changes



Oil price



Source: Monetary policy department and authors' calculation