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The Czech Economy with Inflation Targeting Represented by DSGE Model: Analysis of Behaviour

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THE CZECH ECONOMY WITH INFLATION TARGETING REPRESENTED BY DSGE MODEL: ANALYSIS OF BEHAVIOUR

Abstract:

The working paper is aimed to the behaviour analysis of the Czech economy with inflation targeting regime represented by a New Keynesian dynamic stochastic general equilibrium model (DSGE) consistently based on theoretical microeconomic foundations. The model is created by the relations of finished–goods producing and intermediate–goods producing firms, representative households and a central bank. Monetary policy of the central bank is represented by the generalized Taylor rule. The working paper contains the method for solving a linearized model containing rational expectations. The Kalman filter with maximum likelihood is introduced for an estimation of the solved model. The Kalman smoother is used for an estimation of the smoothed inflation target, which is an unobserved state. The model seems to give very satisfactory approximation of the Czech economy behaviour. The final part of the working paper is devoted to the analysis of behaviour based on simulated model responses.

Abstrakt:

Studie je zaměřena na analýzu chování české ekonomiky v podmínkách inflačního cílení, která je představována novokeynesiánským dynamickým stochastickým modelem všeobecné rovnováhy (DSGE) důsledně odvozeným na teoretických mikroekonomických základech. Model je tvořen relacemi pro firmy konečné výroby, pro meziprodukty, pro reprezentativní domácnosti a pro centrální banku. Monetární politika centrální banky je v modelu reprezentována zobecněným Taylorovým pravidlem. Studie obsahuje postup řešení lineárního modelu s racionálními očekáváními. Pro odhad parametrů vyřešeného modelu je zvolen Kalmanův filtr s maximální věrohodností odhadovaného modelu. K odhadu vyhlazeného vývoje inflačního cíle, který je nepozorovatelným stavem, je užit Kalmanův smoother. Ukázalo se, že kvantifikovaný DSGE model je velmi uspokojivou aproximací pro chování české ekonomiky. Závěrečná část studie je věnována analýze chování ekonomiky na základě simulací modelových odezev na exogenní šoky.

Recenzoval: Ing. Michal Kejak, M.A., CSc.

CONTENTS

1 INTRODUCTION

Monetary policy plays an important role in the economic policy. During recent years many of central banks have adopted inflation targeting policy to fulfil the monetary target of price stability.

The basic goal of this paper is to analyze the behaviour of the Czech economy with inflation targeting with respect to the implementation of monetary policy of the Czech National Bank. A suitable DSGE model is used to clarify the inflation targeting in the Czech economy.

The first part of this paper introduces a description of the inflation targeting approach, next part introduces a suitable model of the economy as an adequate tool for following interpretation. It is the P. N. Ireland's model of inflation targeting.

The third part introduces a model equilibrium. It is necessary to stationarize the model by appropriate transformations to be stable. The result of all these amendments is a linearized system of equations which is ready for solving. These steps are described in separate sections.

The following part introduces estimation results. In the end the working paper concludes estimated results and behaviour of the model and try to interpret them to be applicable to the current situation. The whole work is ended by a conclusion.

2 INFLATION TARGETING

The first implementation of the inflation targeting policy was introduced in New Zealand (for the experience of New Zealand see a speech of the New Zealand Central Bank Governor Brash (2002)). After this practice some developed economies have accepted this monetary strategy too. This kind of monetary policy was successful in New Zealand, Canada or Great Britain – in this sense that the inflation does not exceed the claimed inflation target (this assessment is based on Ammer and Freeman (1995)). Other states (like Finland, Sweden, Australia, . . .) accepted this kind of policy after this experience.

However, these examples do not mean that inflation targeting is the best way to conduct monetary policy (see Kvasnička (2001) or Mizen (1998)). It is still not clear if inflation targeting is suitable for developing countries (e. g. in Masson, Savastano and Sharma (1997)) or for transitions countries (the period of implementing this policy is too short to make appropriate conclusions – see: Jonáš and Mishkin (2003)).

The method of the inflation targeting is based on a simple idea – a central bank commits itself to fulfil a declared inflation target or target band in the future. The forecast is compared with the target inflation and if there is a difference the central bank adjusts monetary policy instruments. The monetary instruments are used according to the theoretical approach based on a reaction function and inflation forecast of the central bank. For more information see Debelle (1997).

The Czech National Bank has used this method since 1998. Since 2001 the Czech National Bank has targeted headline (total) inflation. The inflation target of 3 % has been announced for the period from 2006 until the accession to the Euro Zone. Possible changes in inflation should not differ from the target by more than one percentage point in either direction. However there exist some exceptions from achieving the inflation target.[1] The detailed analysis of the inflation targeting regime and results for the Czech monetary policy is described for example in Kotlán and Navrátil (2004).

The models of inflation targeting try to describe a suitable behavior of monetary authority for the stabilisation of the price level in the

[1] For more information it is possible to see the official documents of the Czech National Bank on its web site (www.cnb.cz).

economy. The models usually highlight the importance of expectations of agents and credibility of the central bank (Tetlow (1999)) or put stress on a general approach to the inflation targeting based on the true specifications, estimations, etc. (for example Bardsen, Jansen and Nymoen (2003)).

Very useful could be the small model of Bank of Israel introduced in Elkayam (2001) or the model for small and open developing economies (calibrated for Thailand) by Cavoli and Rajan (2005).

The problem is a long lasting different evolution of the real inflation and the inflation target in the Czech economy. For improving this situation we try to propose other way of determination of the Czech inflation target. The generalized Taylor rule plays the main role. The estimation of the model is done by Kalman Filter with Maximum Likelohood. Kalman Smoother is used for the estimation of the evolution of unobservable state (inflation targeting).

3 THE MODEL

The following model is a New Keynesian dynamic stochastic general equilibrium model (DSGE model) strictly based on microfoundations. For our purposes we use a model of Peter N. Ireland (2005a) and the whole next part is based on his paper.[2]

Some aspects of this model correspond to the results of the paper by Clarida, Gali, and Gertler (1999). It is especially their conclusion about inflation targeting, an interest rate as a monetary instrument, etc. Their results seem to be similar to our model results of the Czech economy.

The Taylor rule represents the core of the model[3]. This rule tells the central bank how to change the interest rate if there is an output gap or a deviation of inflation from the target inflation. The rule is expressed by Woodford (2001) as:

$$i_t = i_t^* + \phi_\pi(\pi_t - \pi^*) + \phi_y(y_t - y_t^n - x^*),$$

where i_t^* is the steady state value of nominal interest rate, ϕ_π and ϕ_y are constants and π^* and x^* are the target values for the inflation rate and output gap, π_t the inflation rate (measured by the rate of the gross domestic product deflator growth), y_t the logarithm of the gross domestic product, and y_t^n is a fluctuation in the natural rate of output.

The whole model consists of four representative agents. There are representative households, intermediate goods–producing firms, finished goods–producing firms and central monetary authority that implements the monetary policy in accordance with the generalized Taylor rule. The finished equations of the model are an aggregation of representative behavior of households and firms. For simplicity we omit some characteristics of the real economy.

[2]Authors thank to P. N. Ireland for his permission to use his model for the purpose and applications on the Czech economy data.

[3]There is a general problem of monetary rules and especially Taylor rule: the central bank policy should be forward-looking due to large lags in economy. However this could be very difficult to do in the transition Czech economy, as it is described in Frajt and Zedníček (1999).

3.1 THE REPRESENTATIVE HOUSEHOLDS

The budget constraint of a representative household is following:

$$M_{t-1} + T_t + B_{t-1} + W_t h_t + D_t \geq P_t C_t + M_t + B_t/R_t \tag{1}$$

for $t = 0, 1, 2, \ldots$, where money in the period t is M_t, a lump–sum nominal transfer (from the central bank) T_t, bonds B_t, h_t denotes a supply of labor, W_t a nominal wage, D_t nominal profits in the form of dividends, C_t a consumption, P_t a price of goods and R_t the gross nominal interest rate (1 plus nominal interest rate).

During period t, the household supplies a total of h_t units of labour to the various intermediate goods–producing firms (for the total $h_t = \int_0^1 h_t(i)di$, for $i \in [0,1]$) and gets the nominal wage rate W_t. Also during period t, the household consumes C_t units of the finished good, purchased at the nominal price P_t from the representative finished goods–producing firm. At the end of period t, the household receives nominal profits D_t in the form of dividends paid by the intermediate goods–producing firms (for the total $D_t = \int_0^1 D_t(i)di$, for $i \in [0,1]$).

The household's preferences are described by the expected utility function, where β $(1 > \beta > 0)$ is the discount factor and γ $(1 > \gamma \geq 0)$ is the habit formation parameter.

$$E_0 \sum_{t=0}^{\infty} \beta^t a_t [ln(C_t - \gamma C_{t-1}) + ln(M_t/P_t) - h_t]. \tag{2}$$

The preference shock a_t follows the stationary autoregressive process for $t = 0, 1, 2, \ldots$:

$$ln(a_t) = \rho_a ln(a_{t-1}) + \sigma_a \epsilon_{at} \tag{3}$$

with $1 > \rho_a \geq 0$ and $\sigma_a \geq 0$, where the serially uncorrelated innovation ϵ_t has the standard normal distribution.

The term $ln(M_t/P_t)$ in the utility function is without shocks into the real money balance. This express the situation that money are neutral and a supply of money does not change the utility of households. More precisely, the change of the utility function due to a change of the money supply is so small that we omit it. For more details see Ireland (2005a). These results confirm the work of David and Vašíček (2005) on the data of Czech economy too.

An optimization problem of households means to choose C_t, h_t, B_t and M_t every period and to maximize the value function in respect to their budget constraint. The first order conditions for this problem are (Supplement 1 contains their calculation):

- for C_t:

$$\Lambda_t = \frac{a_t}{C_t - \gamma C_{t-1}} - \beta\gamma E_t\left(\frac{a_{t+1}}{C_{t+1} - \gamma C_t}\right) \tag{4}$$

- for B_t:

$$\Lambda_t = \beta R_t E_t\left(\frac{\Lambda_{t+1}}{P_t/P_{t-1}}\right) \tag{5}$$

- for h_t and M_t together:

$$\frac{M_t}{P_t} = \left(\frac{W_t}{P_t}\right)\left(\frac{R_t}{R_t - 1}\right) \tag{6}$$

for $t = 0, 1, 2, \ldots$

The first order condition identifies the Lagrangian multiplier Λ_t with an intertemporal rate of consumption (with respect to the preference shock and lagged consumption). It positively depends on the (gross) nominal interest rate and expected real value of the intertemporal rate of consumption in the following period in combination with the second equation. The last equation introduces real demand for money as a positive function of real wage and negative function of the nominal interest rate.

This formulation of behaviour of households has some special features that we use in our general model. Utility is additively separable in C_t, M_t/P_t and h_t. Habit formation helps households to smooth their consumption as much as possible in response to various kinds of shocks. The aggregate demand could be derived only from the behaviour of a representative household without any influence of a firm's optimization – the necessary and sufficient conditions are fulfilled: the marginal rate of substitution between consumption in two periods $\left(MRS_{CC} = \beta\frac{a_{t+1}}{a_t}\frac{R_t}{\Pi_{t+1}}\right)$, and between consumption and real balances $\left(MRS_{CM} = \frac{R_t}{R_t-1}\right)$ is independent of hours worked. For more details see Musil (2005).

3.2 THE REPRESENTATIVE INTERMEDIATE GOODS–PRODUCING FIRM

The representative intermediate goods–producing firm uses $h_t(i)$ units of labour to produce its product $Y_t(i)$ according to the constant return to scale technology:

$$Z_t h_t(i) = Y_t(i), \tag{7}$$

where the aggregate technology shock follows this process:

$$ln(Z_t) = ln(z) + ln(Z_{t-1}) + \sigma_z \epsilon_{zt}, \tag{8}$$

for $t = 0, 1, 2, \ldots$, $z \geq 1$, $\sigma_z \geq 0$ and ϵ_{zt} is serially uncorrelated innovation with standard normaly distribution. According to the previous equations the technology shock influences only the level of output without any impact on inflation. The effect of a technology change is permanent because of the random walk.

The random walk process is used for the formulation of the aggregate technology shock. This specification is, however, very close to the theory of a real business cycle. Shocks in technologies influence the value of output and have a long–run impact. That means that they are able to change the level of a long–run rate of the output trend. To the opposite the preference shocks (or cost–push shocks influencing a representative intermediate goods–producing firm) are not permanent and determine the short-run process of output – they cause oscillations of output around its effective level (its potential product); see Ireland (2004).

Every firm tries to maximize its real market value that could be expressed as the maximization of the following term (the discounted value of a marginal utility of consumption of an extra dividend for the representative households):

$$E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \left[\frac{D_t(i)}{P_t} \right]$$

The term $D_t(i)/P_t$ (a real dividend of the intermediate goods–producing firm) can be expressed as:

$$\begin{aligned} \frac{D_t(i)}{P_t} = & \left[\frac{P_t(i)}{P_t} \right]^{1-\theta_t} Y_t - \left[\frac{P_t(i)}{P_t} \right]^{-\theta_t} \left(\frac{W_t}{P_t} \right) \left(\frac{Y_t}{Z_t} \right) \\ & - \frac{\phi}{2} \left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha} (\Pi_t^*)^{1-\alpha} P_{t-1}(i)} - 1 \right]^2 Y_t \end{aligned} \tag{9}$$

and measures real profits during period t as a real price of the whole production (sold at the price $P_t(i)$) reduced by a real cost (in the form of real wages[4]) and a cost of price adjustment.

Since the intermediate goods substitute imperfectly for one another in producing the finished good, the representative intermediate goods–producing firm sells its output in a monopolistically competitive market[5]: during period t, the firm sets the nominal price $P_t(i)$ for its output, subject to the requirement that it satisfies the representative finished goods–producing firm's demand at that chosen price. And the intermediate goods-producing firm faces a quadratic cost of adjusting its price between periods, measured in terms of the finished good and given by

$$\frac{\phi}{2}\left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}P_{t-1}(i)}-1\right]^2 Y_t$$

where $\phi \geq 0$ governs the magnitude of the adjustment cost, Π_t^* denotes the central bank's inflation target for period t, and the parameter α lies between zero and one: $1 \geq \alpha \geq 0$. According to this specification, the extent to which price setting is forward or backward looking depends on whether α is closer to zero or one. At one extreme, when $\alpha = 0$ price setting is purely forward looking, in the sense that firms find it costless to adjust their prices in line with the central bank's inflation target. At the other extreme, when $\alpha = 1$ price setting is purely backward looking, in the sense that firms find it costless to adjust their prices in line with the previous period's inflation rate. (cited Ireland (2005a), page 9)[6]

The price adjustments induce some extra costs and worsen the reputation of the firm. The firm tries to avoid these negative effects (the result of this are sticky prices) and decides whether the continual small prices changes or the irregular huge price changes are better. If the total costs of price adjustment are similar in both cases, the reputation is probably more negatively influenced by large price changes: the price costs of adjustment are quadratic in the percentage change of the price. That means: the bigger the change of the price, the worse reputation and higher costs measured by this lost reputation and cost

[4]There are real wages with the influence of a technology shock in a production: the term $(W_t/P_t)(Y_t/Z_t)$.

[5]Representative Intermediate Goods–Producing Firms sell their production to finished–goods producing firms.

[6]The quadratic costs of the price adjustment make this problem dynamic.

for changing the price. For more details see Rotemberg (1982).

The first order condition is (the calculation is in Supplement 2):

$$0 = (1-\theta_t)\left[\frac{P_t(i)}{P_t}\right]^{-\theta_t} + \theta_t\left[\frac{P_t(i)}{P_t}\right]^{-\theta_t-1}\left(\frac{W_t}{P_t}\right)\left(\frac{1}{Z_t}\right) \tag{10}$$
$$-\phi\left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}P_{t-1}(i)}-1\right]\left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}P_{t-1}(i)}\right]$$
$$+\beta\phi E_t\left\{\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)\left[\frac{P_{t+1}(i)}{\Pi_t^{\alpha}(\Pi_{t+1}^*)^{1-\alpha}P_t(i)}-1\right]\left[\frac{P_{t+1}(i)}{\Pi_t^{\alpha}(\Pi_{t+1}^*)^{1-\alpha}P_t(i)}\right]\right.$$
$$\left.\left[\frac{P_t}{P_t(i)}\right]\left(\frac{Y_{t+1}}{Y_t}\right)\right\}$$

for all t = 0, 1, 2,. . . .

In the absence of price adjustment costs, when $\phi = 0$, the last equation simply implies that the firm sets its price $P_t(i)$ as a markup $\theta_t/(\theta_t-1)$ over marginal cost W_t/Z_t. Hence, as suggested above, $\theta_t/(\theta_t-1)$ can be interpreted as the firm's desired markup, and random fluctuations in θ_t act like shocks to the firm's desired markup. Costly price adjustment $(\phi > 0)$ then implies that actual markups deviate from, but tend to gravitate towards, their desired level as firms respond optimally to the shocks that hit the economy. (cited Ireland (2005a), page 10)

3.3 THE REPRESENTATIVE FINISHED GOODS–PRODUCING FIRM

The production of the intermediate goods–producing firms $Y_t(i)$ for $i \in [0,1]$ is bought at the price $P_t(i)$ and used by a representative finished goods–producing firms for its production of Y_t units of goods. The production can be described by the constant–returns–to–scale technology[7]:

$$\left[\int_0^1 Y_t(i)^{\theta_t-1/\theta_t}di\right]^{\theta_t/\theta_t-1} = Y_t$$

with the autoregressive process for θ_t:

$$ln(\theta_t) = (1-\rho_\theta)ln(\theta) + \rho_\theta ln(\theta_{t-1}) + \sigma_\theta\epsilon_{\theta t} \tag{11}$$

for $t = 0,1,2,\ \ldots,\ 1 > \rho_\theta \geq 0,\ \sigma_\theta \geq 0$, and the serially uncorrelated innovation $\epsilon_{\theta t}$ with the standard normal distribution. The first

[7] It is a representative of a Constant Elasticity of Substitution Function.

order condition for maximizing firm's profits is (for $i \in [0,1]$ and t = 0, 1, 2, ...):

$$Y_t(i) = [P_t(i)/P_t]^{-\theta_t} Y_t.$$

It is evident that the parameter θ_t is time–varying elasticity of output of the finished goods–producing firms. This condition implies the relationship between intermediate and finished–goods producing firms: a shock to θ_t (influencing the demand for intermediate goods of finished firms) changes the intermediate–goods producing firms' desired markups of a price over the marginal cost.

3.4 THE CENTRAL BANK

The central bank implements monetary policy according to the Taylor rule that can be adjusted for our purposes to the following form: we use log–linearized form of this rule, and bank's reaction depends on positive values of parameters ρ_π and ρ_{gy} (an elasticity of the nominal interest rate to the inflation or output gap):

$$ln(R_t) - ln(R_{t-1}) = \rho_\pi ln(\Pi_t/\Pi_t^*) + \rho_{gy} ln(g_t^y/g^y) + ln(v_t) \quad (12)$$

for $t = 0, 1, 2, \ldots$.

According to this equation the central authority increases short-run nominal interest rate if:

- the current inflation (Π_t) is higher than the inflation target (Π_t^*): $\rho_\pi > 0$;
- the output growth:

  $$g_t^y = \frac{Y_t}{Y_{t-1}} \quad (13)$$

  is higher than the long–run equilibrium of the output (g^y): $\rho_{gy} \geq 0$;
- there is a positive transitory monetary policy shock (v_t):

  $$ln(v_t) = \rho_v ln(v_{t-1}) + \sigma_v \epsilon_{vt} \quad (14)$$

  for $t = 0, 1, 2, \ldots$, with $1 > \rho_v \geq 0$ and $\sigma_v \geq 0$, where the serially uncorrelated innovation ϵ_{vt} has the standard normal distribution.

The value of the central bank's inflation target (Π_t^*) is expressed in this way:

$$ln(\Pi_t^*) = ln(\Pi_{t-1}^*) + \delta_a \epsilon_{at} - \delta_\theta \epsilon_{\theta t} - \delta_z \epsilon_{zt} + \sigma_\pi \epsilon_{\pi t} \qquad (15)$$

for $t = 0, 1, 2, \ldots$, $\delta_a, \delta_\theta, \delta_z \geq 0$, $\sigma_\pi \geq 0$ and $\epsilon_{\pi t}$ is serially uncorelated normally distributed innovation.

The inflation target is time–varying and it is changed by technology and cost–push shocks (both of the supply shocks: θ_t and Z_t). An important part is created by random inflationary shocks that the central bank takes into account when introduces its inflation target. The response coefficients within the previous equation (δ_θ and δ_z) are chosen by the central monetary authority.

3.5 THE OUTPUT GAP

The output gap is a relation of real output (Y_t) to the efficient level of output (Q_t). It can be formally expressed as (for $t = 0, 1, 2, \ldots$):

$$x_t = \frac{Y_t}{Q_t}. \qquad (16)$$

Now it is necessary to amend the Taylor rule for the central authority (12) for the impact of the efficient level of output to its decision[8]:

$$ln(R_t) - ln(R_{t-1}) = \rho_\pi ln(\Pi_t/\Pi_t^*) + \rho_x ln(x_t/x) + \rho_{gy} ln(g_t^y/g^y) + ln(v_t) \qquad (17)$$

for $t = 0, 1, 2, \ldots$, for $\rho_x \geq 0$.

The efficient level of output is determined as a result of the optimization problem. Generally it is desirable to maximize the adjusted difference between the efficient level of output and sources for this level of output:

[8]If an economy is always at the efficient level of output, there is no reason to add this term to the modified Taylor rule. By doing so, we express the fact that the economy is probably apart from the efficient level – the real value of output is lower or higher than the efficient one. It influences the short term nominal interest rate R_t according to the generalized Taylor rule.

$$E_0 \sum_{t=0}^{\infty} \beta^t a_t \left(ln(Q_t - \gamma Q_{t-1}) - \int_0^1 n_t(i) di \right)$$

subject to the constraint:

$$Q_t = Z_t \left(\int_0^1 n_t(i)^{\frac{\theta_t - 1}{\theta_t}} di \right)^{\frac{\theta_t}{\theta_t - 1}}$$

for all $t = 0, 1, 2, \ldots$, for all $i \in \langle 0; 1 \rangle$.

Generally we speak about the product for the whole economy and suppose that the decisions are all identical ($n_t = n_t(i)$). It is possible to rewrite the previous expression in the simpler way:

$$E_0 \sum_{t=0}^{\infty} \beta^t a_t \left(ln(Q_t - \gamma Q_{t-1}) - n_t \right)$$

and

$$Q_t = Z_t \left(n_t^{\frac{\theta_t - 1}{\theta_t}} \right)^{\frac{\theta_t}{\theta_t - 1}} = Z_t n_t$$

To solve this problem it is necessary to choose the level of efficient output and the amount of inputs for its production. The Lagrangian for the time t is (Φ_t is the Lagrangian multiplier)

$$L_t = E_t \sum_{t=0}^{\infty} \beta^t a_t \left(ln(Q_t - \gamma Q_{t-1}) - n_t \right) + \Phi_t \beta^t (Z_t n_t - Q_t),$$

and its partial derivatives are:

- for Q_t:

  $$\frac{\partial L_t}{\partial Q_t} = \beta^t a_t \frac{1}{Q_t - \gamma Q_{t-1}} - \Phi_t \beta^t = 0$$

  and

  $$\frac{\partial L_{t+1}}{\partial Q_t} = \beta^{t+1} E_t \left[a_{t+1} \frac{1}{Q_{t+1} - \gamma Q_{t-1}} (-\gamma) \right] = 0,$$

together we get

$$\Phi_t = \frac{a_t}{Q_t - \gamma Q_{t-1}} - \beta\gamma E_t \frac{a_{t+1}}{Q_{t+1} - \gamma Q_t}$$

or

$$\frac{\Phi_t}{a_t} = \frac{1}{Q_t - \gamma Q_{t-1}} - \beta\gamma E_t \left(\frac{a_{t+1}}{a_t} \frac{1}{Q_{t+1} - \gamma Q_t} \right)$$

- for n_t:

$$\frac{\partial L_t}{\partial n_t} = -\beta^t a_t + \Phi_t \beta^t Z_t = 0,$$

  the previous equation implies:

$$\frac{\Phi_t}{a_t} = \frac{1}{Z_t}$$

for $t = 0, 1, 2, \ldots.$

Both optimal conditions can be put together to form the final condition for the efficient level of output:

$$\frac{1}{Z_t} = \frac{1}{Q_t - \gamma Q_{t-1}} - \beta\gamma E_t \left(\frac{a_{t+1}}{a_t} \frac{1}{Q_{t+1} - \gamma Q_t} \right). \qquad (18)$$

3.6 THE MODEL EQUILIBRIUM

We have introduced the behaviour of the representative agents in our model and now we aggregate it to the basic equations that represent the equilibrium of the model. For this purposes we assume these conditions:

- the market cleaning condition of an aggregate money holding – the sum of money holding at any moment is equal to the sum of present transfers and the last period money holding: $M_t = T_t + M_{t-1}$ for $t = 0, 1, 2, \ldots$
- the market cleaning condition for bonds – at any moment every debtor must have his creditor: $B_t = 0$ for $t = 0, 1, 2, \ldots$

- conditions for intermediate goods–producing firms and for their identical decisions related to the output $(Y_t(i) = Y_t)$, dividends $(D_t(i) = D_t)$, prices – this influences finished goods–producing firms too $(P_t(i) = P_t)$ and the labor demand $(h_t(i) = h_t)$ for all firms and t = 0, 1, 2, ...

After these modifications we get the aggregate relationship (the households budget constraint (1)) for the output of our economy that is partly used for consumption and partly as a source for the price adjustment of the intermediate goods–producing firms:[9]

$$Y_t = C_t + \frac{\phi}{2}\left[\frac{\Pi_t}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}} - 1\right]^2 Y_t,$$

the rule for price adjustment (10) is simplified to the following form:

$$\theta_t - 1 = \theta_t\left(\frac{a_t}{\Lambda_t Z_t}\right) - \phi\left[\frac{\Pi_t}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}} - 1\right]\left[\frac{\Pi_t}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}}\right]$$
$$+ \beta\phi E_t\left\{\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)\left[\frac{\Pi_{t+1}}{\Pi_t^{\alpha}(\Pi_{t+1}^*)^{1-\alpha}} - 1\right]\left[\frac{\Pi_{t+1}}{\Pi_t^{\alpha}(\Pi_{t+1}^*)^{1-\alpha}}\right]\left(\frac{Y_{t+1}}{Y_t}\right)\right\}$$

for all $t = 0, 1, 2, \ldots$.

[9] For this calculation it is used:

- modified (1): $\frac{W_t}{P_t}h_t + \frac{D_t}{P_t} = C_t$
- modified (7): $Z_t h_t = Y_t$
- modified (9): $\frac{D_t}{P_t} = Y_t - \frac{W_t}{P_t}\frac{Y_t}{Z_t} - \frac{\phi}{2}\left[\frac{P_t}{\Pi_{t-1}^{\alpha}(\Pi_t^*)^{1-\alpha}P_{t-1}} - 1\right]^2 Y_t$

The rest equations (3) – (5), (8), (11), (13) – (15), (16) – (18) are unchanged (for $t = 0,\, 1, 2,\, \ldots$):

$$
\begin{aligned}
ln(a_t) &= \rho_a ln(a_{t-1}) + \sigma_a \epsilon_{at} \\
\Lambda_t &= \frac{a_t}{C_t - \gamma C_{t-1}} - \beta\gamma E_t\left(\frac{a_{t+1}}{C_{t+1} - \gamma C_t}\right) \\
\Lambda_t &= \beta R_t E_t\left(\frac{\Lambda_{t+1}}{P_t/P_{t-1}}\right) \\
ln(Z_t) &= ln(z) + ln(Z_{t-1}) + \sigma_z \epsilon_{zt} \\
ln(\theta_t) &= (1-\rho_\theta) ln(\theta) + \rho_\theta ln(\theta_{t-1}) + \sigma_\theta \epsilon_{\theta t} \\
ln(R_t) - ln(R_{t-1}) &= \rho_\pi ln(\Pi_t/\Pi_t^*) + \rho_x ln(x_t/x) + \rho_{gy} ln(g_t^y/g^y) + ln(v_t) \\
g_t^y &= Y_t/Y_{t-1} \\
ln(v_t) &= \rho_v ln(v_{t-1}) + \sigma_v \epsilon_{vt} \\
x_t &= \frac{Y_t}{Q_t} \\
ln(\Pi_t^*) &= ln(\Pi_{t-1}^*) + \delta_a \epsilon_{at} - \delta_\theta \epsilon_{\theta t} - \delta_z \epsilon_{zt} + \delta_\pi \epsilon_{\pi t} \\
\frac{1}{Z_t} &= \frac{1}{Q_t - \gamma Q_{t-1}} - \beta\gamma E_t\left(\frac{a_{t+1}}{a_t}\frac{1}{Q_{t+1} - \gamma Q_t}\right)
\end{aligned}
$$

It is useful to add to these conditions the growth rate of observable variables

$$
\begin{aligned}
g_t^\pi &= \Pi_t/\Pi_{t-1} \\
g_t^r &= R_t/R_{t-1},
\end{aligned}
$$

as well as the Fisher equation (the ratio of the nominal interest rate to the inflation rate):

$$r_t^{\pi r} = R_t/\Pi_t$$

for $t = 0, 1, 2, \ldots$.

This system of equations expresses equilibrium for 11 variables: Y_t, C_t, Q_t, Π_t, R_t, g_t^y, Λ_t, a_t, θ_t, Z_t, x_t,v_t and Π_t^*.

3.7 THE STATIONARY SYSTEM

The equations (7) and (15) within the equilibrium are not stationary. It is the random walk for the technology shock: $ln(Z_t) = ln(z) + ln(Z_{t-1}) + \sigma_z\epsilon_{zt}$, and the random walk for inflation target: $ln(\Pi_t^*) = ln(\Pi_{t-1}^*) - \delta_\theta\epsilon_{\theta t} - \delta_z\epsilon_{zt} + \delta_\pi\epsilon_{\pi t}$. Some variables inherit the unit root from these processes and it is necessary to transform them to be all of them stable.

To get rid of the unstability of Z_t we use:

- $y_t = \frac{Y_t}{Z_t}$
- $c_t = \frac{C_t}{Z_t}$
- $q_t = \frac{Q_t}{Z_t}$
- $\lambda_t = \Lambda_t Z_t$
- $z_t = \frac{Z_t}{Z_{t-1}}$

To eliminate the impact of Π_t^*:

- $\pi_t = \frac{\Pi_t}{\Pi_t^*}$
- $r_t = \frac{R_t}{\Pi_t^*}$
- $\pi_t^* = \frac{\Pi_t^*}{\Pi_{t-1}^*}$

The rest of variables remain unchanged: a_t, θ_t, v_t, x_t, g_t^y, g_t^π, g_t^r and $r_t^{r\pi}$.

For the stationary variables the whole system can be rewritten in this form:

$$
\begin{aligned}
y_t &= c_t + \frac{\phi}{2}\left[\pi_t\left(\frac{\pi_t^*}{\pi_{t-1}}\right)^{\alpha} - 1\right]^2 y_t && (19)\\
\theta_t - 1 &= \theta_t\left(\frac{a_t}{\lambda_t}\right) - \phi\left[\pi_t\left(\frac{\pi_t^*}{\pi_{t-1}}\right)^{\alpha} - 1\right]\left[\pi_t\left(\frac{\pi_t^*}{\pi_{t-1}}\right)^{\alpha}\right] && (20)\\
&\quad + \beta\phi E_t\left\{\left(\frac{\lambda_{t+1}}{\lambda_t}\right)\left[\pi_{t+1}\left(\frac{\pi_{t+1}^*}{\pi_t}\right)^{\alpha} - 1\right]\right.\\
&\quad \left.\left[\pi_{t+1}\left(\frac{\pi_{t+1}^*}{\pi_t}\right)^{\alpha}\right]\left(\frac{y_{t+1}}{y_t}\right)\right\}\\
ln(a_t) &= \rho_a ln(a_{t-1}) + \sigma_a\epsilon_{at} && (21)\\
\lambda_t &= \frac{a_t z_t}{z_t c_t - \gamma c_{t-1}} - \beta\gamma E_t\left(\frac{a_{t+1}}{z_{t+1}c_{t+1} - \gamma c_t}\right) && (22)\\
\lambda_t &= \beta r_t E_t\left(\frac{1}{z_{t+1}}\frac{1}{\pi_{t-1}^*}\frac{\lambda_{t+1}}{\pi_{t+1}}\right) && (23)\\
ln(z_t) &= ln(z) + \sigma_z\epsilon_{zt}{}^{10} && (24)\\
ln(\theta_t) &= (1-\rho_\theta)ln(\theta) + \rho_\theta ln(\theta_{t-1}) + \sigma_\theta\epsilon_{\theta t} && (25)\\
ln(r_t) &= ln(r_{t-1}) + \rho_\pi ln(\pi_t) - ln(\pi_t^*) + \rho_x ln(x_t/x) && (26)\\
&\quad + \rho_{gy} ln(g_t^y/g^y) + ln(v_t)\\
g_t^y &= \frac{y_t}{y_{t-1}} z_t && (27)\\
ln(v_t) &= \rho_v ln(v_{t-1}) + \sigma_v\epsilon_{vt} && (28)\\
x_t &= \frac{y_t}{q_t} && (29)\\
ln(\pi_t^*) &= \delta_a\epsilon_{at} - \delta_\theta\epsilon_{\theta t} - \delta_z\epsilon_{zt} + \delta_\pi\epsilon_{\pi t} && (30)\\
1 &= \frac{z_t}{z_t q_t - \gamma q_{t-1}} - \beta\gamma E_t\left(\frac{a_{t+1}}{a_t}\frac{1}{z_{t+1}q_{t+1} - \gamma q_t}\right) && (31)\\
g_t^\pi &= \frac{\pi_t}{\pi_{t-1}}\pi_t^* && (32)\\
g_t^r &= \frac{r_t}{r_{t-1}} && (33)\\
r_t^{\pi r} &= \frac{r_t}{\pi_t} && (34)
\end{aligned}
$$

[10]The result of the appropriate calculation of the stationary equation for the tech-

3.8 THE STEADY STATE

In the steady state (the economy contains no shocks an all variables are constants) these condition hold: $a = a_t = 1$, $\pi_t^* = \pi^* = 1$, $v_t = v = 1$, $\pi_t = \pi = 1$, $g_t^\pi = g^\pi = 1$, $g_t^r = g^r = 1$ and $\theta_t = \theta$ and $z_t = z$.

After next calculations we get: $g_t^y = g^y = z$, $\lambda_t = \lambda = \frac{\theta}{\theta-1}$, $y_t = y = \left(\frac{\theta-1}{\theta}\right)\left(\frac{z-\beta\gamma}{z-\gamma}\right)$, $q_t = q = \frac{z-\beta\gamma}{z-\gamma}$, $x_t = x = \frac{\theta-1}{\theta}$, $r_t = r = \frac{z}{\beta}$ and $r_t^{r\pi} = r^{r\pi} = \frac{z}{\beta}$ for $t = 0, 1, 2, \ldots$ The last two equations imply $r = r^{r\pi} = z/\beta$ and are used as a starting conditions for solving the model.

Supplement 3 contains all the calculation of this steady state value of this model.

3.9 THE LINEARIZED SYSTEM

The system of the stationary equations can be log–linearized around the steady state to describe the behaviour of the economy influenced by a shock. For this purpose there are used these expressions as a percentage deviation of the variable from its steady state: $\hat{y}_t = ln(y_t/y)$, $\hat{c}_t = ln(c_t/c)$, $\hat{\pi}_t = ln(\pi_t)$, $\hat{r}_t = ln(r_t/r)$, $\hat{q}_t = ln(q_t/q)$, $\hat{x}_t = ln(x_t/x)$, $\hat{g}_t^y = ln(g_t^y/g^y)$, $\hat{g}_t^\pi = ln(g_t^\pi)$, $\hat{y}_t = ln(y_t/y)$, $\hat{g}_t^r = ln(g_t^r)$, $\hat{r}_t^{r\pi} = ln(r_t^{r\pi}/r^{r\pi})$, $\hat{\lambda}_t = ln(\lambda_t/\lambda)$, $\hat{a}_t = ln(a_t)$, $\hat{\theta}_t = ln(\theta_t/\theta)$, $\hat{z}_t = ln(z_t/z)$, $\hat{v}_t = ln(v_t)$, and $\hat{\pi}_t^* = ln(\pi_t^*)$.

A first–order approximation to the aggregate resource constraint re-

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nology shock is following:

$$\begin{aligned} ln(Z_t) &= ln(z) + ln(Z_{t-1}) + \sigma_z\epsilon_{zt} \\ ln(Z_t) - ln(Z_{t-1}) &= ln(z) + \sigma_z\epsilon_{zt} \\ ln(Z_t - Z_{t-1}) &= ln(z) + \sigma_z\epsilon_{zt} \\ ln(z_t) &= ln(z) + \sigma_z\epsilon_{zt} \end{aligned}$$

veals that $\hat{c}_t = \hat{y}_t$ and for the remaining equations imply:

$$(1+\beta\alpha)\hat{\pi}_t = \alpha\hat{\pi}_{t+1} + \beta E_t\hat{\pi}_{t+1} + \psi(\hat{a}_t - \hat{\lambda}_t) - \hat{e}_t - \alpha\hat{\pi}^*_t \quad (35)$$

$$\hat{a}_t = \rho_a\hat{a}_{t-1} + \sigma_a\epsilon_{at} \quad (36)$$

$$(z-\gamma)(z-\beta\gamma) = \gamma z\hat{y}_{t-1} + \beta\gamma z E_t\hat{y}_{t+1} - (z^2+\beta\gamma^2)\hat{y}_t + (z-\gamma)(z-\beta\gamma\rho_a)\hat{a}_t - \gamma z\hat{z}_t \quad (37)$$

$$\hat{\lambda}_t = E_t\hat{\lambda}_{t+1} + \hat{r}_t - E_t\hat{\pi}_{t+1} \quad (38)$$

$$\hat{z}_t = \sigma_z\epsilon_{zt} \quad (39)$$

$$\hat{e}_t = \rho_e\hat{e}_{t-1} + \sigma_e\epsilon_{et} \quad (40)$$

$$\hat{r}_t = \hat{r}_{t-1} + \rho_\pi\hat{\pi}_t + \rho_{gy}\hat{g}^y_t - \pi^*_t + \hat{v}_t \quad (41)$$

$$\hat{g}^y_t = \hat{y}_t - \hat{y}_{t-1} + \hat{z}_t \quad (42)$$

$$\hat{v}_t = \rho_v\hat{v}_{t-1} + \sigma_v\epsilon_{vt} \quad (43)$$

$$\hat{x}_t = \hat{y}_t - \hat{q}_t \quad (44)$$

$$\hat{\pi}^*_t = \sigma_\pi\epsilon_{\pi t} - \delta_e\epsilon_{et} - \delta_z\epsilon_{zt} \quad (45)$$

$$0 = \gamma z\hat{q}_{t-1} - (z^2+\beta\gamma^2)\hat{q}_t + \beta\gamma z E_t\hat{q}_{t+1} + \beta\gamma(z-\gamma)(1-\rho_a)\hat{a}_t - \gamma z\hat{z}_t \quad (46)$$

$$\hat{g}^\pi_t = \hat{\pi}_t - \hat{\pi}_{t-1} + \hat{\pi}^*_t \quad (47)$$

$$\hat{g}^r_t = \hat{r}_t - \hat{r}_{t-1} + \hat{\pi}^*_t \quad (48)$$

$$\hat{r}^{r\pi}_t = \hat{r}_t - \hat{\pi}_t \quad (49)$$

for $t = 1, 2, \ldots$. The new variables are: $\hat{e}_t = (1/\phi)\hat{\theta}_t, \psi = (\theta - 1)/\phi, \delta_e = \delta_\theta$, and $\sigma_e = \sigma_\theta/\phi$.

There are five equations that form the core of the model: a New Keynesian Phillips curve (35), a marginal utility of households' consumption (37), a New Keynesian IS curve (38) and a description for the monetary policy in (41) and (45). There are three equations for the definitions of the output gap (44), the growth rate for the output (42), the inflation (47) and the rate for the nominal interest rate to the inflation (49). The (46) states the condition for the efficient level of output and the rest equations describe the process for the households' preference (36), technology (39), cost–push (40) and monetary (43) shock. The Fisher equation is expressed in (48).

4 SOLVING THE MODEL

As the first step we substitute the $\hat{g}_t^y$, $\hat{g}_t^\pi$, and $\hat{r}_t^{r\pi}$ to the remaining equations and solve this system of nine equations.

The linearized model can be rewritten as:

$$AE_t s_{t+1}^0 = Bs_t^0 + C\xi_t$$

and

$$\xi_t = P\xi_{t-1} + X\epsilon_t$$

where $s_t^0 = [\hat{y}_{t-1}\ \hat{\pi}_{t-1}\ \hat{r}_{t-1}\ \hat{q}_{t-1}\ \hat{\lambda}_t\ \hat{y}_t\ \hat{\pi}_t\ \hat{q}_t]'$, $\xi_t = [\hat{a}_t\ \hat{e}_t\ \hat{z}_t\ \hat{v}_t\ \hat{\pi}_t^*]'$ and $\epsilon_t = [\epsilon_{at}\ \epsilon_{et}\ \epsilon_{zt}\ \epsilon_{vt}\ \epsilon_{\pi t}]'$. The matrices A, B, C, P and X are matrices of the relevant parametres in the system of equations:

$$A = \begin{bmatrix} z^2+\beta\gamma^2 & 0 & 0 & 0 & 0 & -\beta\gamma z & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & -1 & 0 \\ 0 & 1+\beta\gamma & 0 & 0 & 0 & 0 & -\beta & 0 \\ 0 & 0 & 0 & z^2+\beta\gamma^2 & 0 & 0 & 0 & -\beta\gamma z \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} \gamma z & 0 & 0 & 0 & -(z-\gamma)(z-\beta\gamma) & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & \alpha & 0 & 0 & -\psi & 0 & 0 & 0 \\ 0 & 0 & 0 & \gamma z & 0 & 0 & 0 & 0 \\ -\rho_{gy} & 0 & 1 & 0 & 0 & \rho_x+\rho_{gy} & \rho_\pi & -\rho_x \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$C = \begin{bmatrix} (z-\gamma)(z-\beta\gamma\rho_a) & 0 & -\gamma z & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \psi & -1 & 0 & 0 & -\alpha \\ \beta\gamma(z-\gamma)(1-\rho_a) & 0 & -\gamma z & 0 & 0 \\ 0 & 0 & \rho_{gy} & 1 & -1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$P = \begin{bmatrix} \rho_a & 0 & 0 & 0 & 0 \\ 0 & \rho_e & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \rho_v & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$X = \begin{bmatrix} \sigma_a & 0 & 0 & 0 & 0 \\ 0 & \sigma_e & 0 & 0 & 0 \\ 0 & 0 & \sigma_z & 0 & 0 \\ 0 & 0 & 0 & \sigma_v & 0 \\ \delta_a & -\delta_e & -\delta_z & 0 & \sigma_p \end{bmatrix}$$

There are 19 parameters[11] and 3 observable variables in the model: the growth rate of output ($\hat{g}_t^y$), of inflation ($\hat{g}_t^\pi$) and the nominal interest rate to the inflation ($\hat{r}_t^{y\pi}$).

For the solving of the model we use the Czech economy quarterly data (from the first quarter of 1994 to the second quarter of 2005) of a real GDP, consumer quarterly–to–quarterly inflation and the three–months interbank real interest rate. These inputs are transformed to the relevant growth rates.

For the estimation of the model it is necessary to transform the original matrices notation to a more suitable form. Generally the system of equations can be rewritten into the form:

$$s_{t+1} = \Pi s_t + W\epsilon_{t+1}$$

and

$$f_t = U s_t,$$

where Π, W and U are matrices and the vector s_t and f_t are following:

$$s_t = [\hat{y}_{t-1}\ \hat{\pi}_{t-1}\ \hat{r}_{t-1}\ \hat{q}_{t-1}\ \hat{a}_t\ \hat{e}_t\ \hat{z}_t\ \hat{v}_t\ \hat{\pi}_t^*]',$$
$$f_t = [\hat{\lambda}_t\ \hat{g}_t^y\ \hat{g}_t^\pi\ \hat{g}_t^r\ \hat{r}_t^{\pi r}\ \hat{x}_t]'.$$

[11]The parameters are: $z, \beta, \psi, \gamma, \alpha, \rho_\pi, \rho_x, \rho_{gy}, \rho_a, \rho_e, \rho_v, \sigma_a, \sigma_e, \sigma_z, \sigma_v, \sigma_\pi, \delta_a, \delta_e$, and δ_z. We introduce an unconstrained endogenous target version of the model but there is a possibility to use a constrained exogenous target version (the inflation target response coefficients δ_e and δ_z equal zero) but it gives worse results.

The vector f_t expresses all the predetermined variables meanwhile the vector s_t consists of all the non–predetermined variables. This system is used as a basic form for the subsequent estimation.

4.1 Q–Z DECOMPOSITION

One possible way how to transform the original system to the modified one is the Q–Z decomposition. It is an approach to the computation of generalized eigenvalues. Matrices with special features are found and they are used for the calculation of the desired form of equations. This approach is used by Klein (2000).

For square matrices A and B it is possible to calculate upper quasi-triangular matrices AA and BB, and unitary matrices Q and Z such that $QAZ = AA$ and $QBZ = BB$.

In our case the matrices A and B are transformed by unitary matrices Q and Z such that:

$$QAZ = S$$

and

$$QBZ = T,$$

where matrices S and T are both upper triangular and the generalized eigenvalues of A and B create the diagonal elements of T and S.

It is not hard to recalculate the original formula to the following (with using the new matrices):

$$SE_t s_{t+1}^1 = Ts_t^1 + QC\xi_t,$$

for $s_t^1 = Z' s_t^0$ and after some amendments we get

$$s_{t+1} = \Pi s_t + W\epsilon_{t+1} \quad (50)$$

and

$$f_t = Us_t, \quad (51)$$

where W is a zero matrix and matrix X, matrices Π and U are calculated by the elements of not only the matrices A, B, C, P, but also by Q, Z, S and T and the vectors are:
$s_t = [\hat{y}_{t-1}\ \hat{\pi}_{t-1}\ \hat{r}_{t-1}\ \hat{a}_t\ \hat{e}_t\ \hat{z}_t\ \hat{v}_t\ \hat{\pi}^*_t]'$ and
$f_t = [\hat{\lambda}_t\ \hat{g}^y_t\ \hat{g}^\pi_t\ \hat{g}^r_t\ \hat{r}^{\pi r}_t]'$.

4.2 THE ALTERNATIVE METHOD

It is not easy to calculate the Q–Z decomposition. There is an alternative technique for solving the original system to get the final form for estimation.

If the linearized system in matrix form is as follows:

$$DE_t s^0_{t+1} + FE_t f^0_{t+1} = Gs^0_t + Hf^0_t$$

and

$$Af^0_t = Bs^0_t + C\epsilon_t,$$

it is possible to rewrite it as a structural model described in the Blanchard–Kahn setup:

$$E_t s^0_{t+1} = Ks^0_t + L\epsilon_t.$$

The solving of this transformed model has the well–known form:

$$s_{t+1} = \Pi s_t + W\epsilon_{t+1}$$

and

$$f_t = Us_t.$$

The matrices Π, W and U are identical to the matrices calculated by the Q–Z decomposition.

Detailed description of this approach is in Maley (2004).

5 ESTIMATING

The parameters of this linearized model with rational expectations are estimated via the maximum likelihood. The used method is the Kalman filter evaluating a maximum likelihood function and the Kalman smoother evaluating time series of smoothed estimate of target inflation. Target inflation presents the unobserved state variable.

5.1 THE KALMAN FILTER

The Kalman filter is a method for solving the system expressed by these equations:

$$\begin{aligned} s_{t+1} &= AXs_t + BX\epsilon_t + v_t \\ d_t &= CXs_t + DX\epsilon_t + w_t, \end{aligned}$$

where the matrices of parameters AX, BX, CX and DX are known and the whole system has following characteristics:

- $s_0 \sim N(\mu_0, \Sigma_0)$
- $v_t \sim N(0, \Sigma_v)$ for all t
- $w_t \sim N(0, \Sigma_w)$ for all t
- $E(v_t w_t') = 0$
- $E(s_0 v_t') = 0$

where we know the initial value for s_0, the vector μ_0 and matrices $\Sigma_0, \Sigma_v, \Sigma_w$. Then we define the sample of observable variables in this form: $D_T = \{d_t\}_{t=1}^T$ and $s_{t|k} = s_t|D_k$. If the following holds:

$$\begin{aligned} s_{t|t-1} &\sim N(\mu_{t|t-1}, \Sigma_{t|t-1}) \\ s_{t|t} &\sim N(\mu_{t|t}, \Sigma_{t|t}), \end{aligned}$$

then the mean value $\mu_{t|t-1}, \mu_{t|t}$ together with the variance matrix $\Sigma_{t|t-1}, \Sigma_{t|t}$ could be calculated according to following forms. We use only the first[12] and the second moments to get the estimation of $s_{1|0}, s_{1|1}, s_{2|1}, s_{2|2}, \ldots, s_{t|t-1}, s_{t|t}$:

[12]We use the expression of the first moment – the mean value: μ_t for the estimated values of the state s_t.

$$\mu_{t|t} = \mu_{t|t-1} + K_t(d_t - CX\mu_{t|t-1} - DX\epsilon_t) \quad (52)$$

$$\Sigma_{t|t} = \Sigma_{t|t-1} - K_t CX \Sigma_{t|t-1} \quad (53)$$

$$K_t = \Sigma_{t|t-1} CX'(CX\Sigma_{t|t-1}CX' + \Sigma_w)^{-1} \quad (54)$$

and

$$\mu_{t+1|t} = AX\mu_{t|t} + BX\epsilon_t \quad (55)$$

$$\Sigma_{t+1|t} = AX\Sigma_{t|t}AX' + \Sigma_v, \quad (56)$$

These recursive equations express the filtration step (52) – (54) and subsequently the prediction step (55) – (56). For more details about the method see Trojan (1998).

5.2 THE LIKELIHOOD FUNCTION

The parameters within the matrices AX, BX, CX, DX and the value for s_0 are expected to be known. In case that some of them are unknown it is possible to estimate them. We create a vector of them (θ_0) and estimate the Kalman filter with this vector[13].

The next step is based on calculating the logarithmic likelihood function[14]:

$$lnL = \frac{-T+m}{2} ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T} ln\,|\sigma_t(\theta_0)| - \frac{1}{2}\sum_{t=1}^{T}(d_t - \mu(\theta_0))'\sigma_t(\theta_0)^{-1}(d_t - \mu(\theta_0)),$$

where T is the number of observations of d and $d_t \sim N(\mu(\theta_0), \sigma_t(\theta_0))$, m is the number of output equations.

We amend the vector of the unknown parameters from θ_0 to θ_1 to increase a value of the likelihood function. This procedure is repeated until the function is maximized.

[13]It is enough to set the vector equal to zeros as a starting value.

[14]The logarithm is a way of linearization $e \sim N(\mu, \sigma) : p(e) = \frac{1}{\sqrt{(2\pi)' det(\sigma)}} exp^{-\frac{1}{2}e'\sigma^{-1}e}$.

5.3 THE KALMAN SMOOTHER

Smoothing is an estimation of s_t based on all data D_N for $N > t$ (new data are available). The Kalman filter used the prediction and filtration step in a forward run. The algorithm of the Kalman smoother is backward and the calculation is on the same data set. The result of smoothing should be better because we have more information. After computation we have a set of the past states of $s_0, s_1, \ldots, s_{t-1}$.

The smoother goes from the present state to the past and the smoothed outputs are inputs for the next stage. It is an iterative method similar to the Kalman filter.

The smoother (Rauch – Tung – Streibel Smoother) for the previous system estimated by the Kalman filter is for $s_{t|N} \sim N(\mu_{t|n}, \Sigma_{t|N})$ following:

$$\mu_{t|N} = \mu_{t|t} + F_t(\mu_{t+1|N} - \mu_{t+1|t}) \tag{57}$$

$$\Sigma_{t|N} = \Sigma_{t|t} - (\Sigma_{t+1|t} - \Sigma_{t+1|N})F_t' \tag{58}$$

$$F_t = \Sigma_{t|t} AX' \Sigma_{t+1|t}^{-1} \tag{59}$$

For the calculation is used the mean value and variance of the estimator with no data. All information is concentrated in $x_{t+1|N}$ and $x_{t|t}$. We need only the values of $\mu_{t+1|N}$ and $\Sigma_{t+1|N}$ that are available after the last filtration step of the Kalman filter.

5.4 ESTIMATING THE MODEL

Our model for estimation by the Kalman filter procedure takes this form:

$$s_{t+1} = AXs_t + BX\epsilon_{t+1}$$
$$d_t = CXs_t,$$

and the estimation could be expressed:

$$\hat{s}_{t|t-1} = E(s_t | d_{t-1}, d_{t-2}, \ldots, d_1)$$
$$\Sigma_{t|t-1} = E(s_t - \hat{s}_{t|t-1})(s_t - \hat{s}_{t|t-1})'$$

For the estimation we use these steps:

- filtration:

$$\begin{aligned}
w_t &= d_t - \hat{d}_{t|t-1} = CX(s_t) - CX(\hat{s}_{t|t-1}) \\
&= CX(s_t - \hat{s}_{t|t-1}) \\
d_t &= CX\hat{s}_{t|t-1} + w_t{}^{15} \\
E(w_t w_t') = \Omega_t &= E(d_t - \hat{d}_{t|t-1})(d_t - \hat{d}_{t|t-1})' \\
&= E[CX(s_t - \hat{s}_{t|t-1})][(s_t - \hat{s}_{t|t-1})'CX'] \\
&= CX\Sigma_{t|t-1}CX' \\
K_t &= AX\Sigma_{t|t-1}CX'(CX\Sigma_{t|t-1}CX')^{-1} \\
&= AX\Sigma_{t|t-1}CX'\Omega_t^{-1}
\end{aligned}$$

- prediction:

$$\begin{aligned}
\hat{s}_{t+1|t} &= AX\hat{s}_{t|t-1} + K_t u_t \\
\Sigma_{t+1|t} &= BXVBX' + AX\Sigma_{t|t-1}AX' \\
&\quad - AX\Sigma_{t|t-1}CX'(CX\Sigma_{t|t-1}CX')^{-1}CX\Sigma_{t|t-1}AX'
\end{aligned}$$

where V is the covariance matrix of ϵ_{t+1} $(V = E(\epsilon_{t+1}\epsilon_{t+1}') = I)$ and the starting value for the the prediction step is following:

$$\begin{aligned}
\hat{s}_{1|0} &= E(s_1) = 0^{16} \\
vec(\Sigma_{1|0}) &= vec(E(s_1 s_1')) = [I - AX \otimes AX]^{-1} vec(BXVBX')
\end{aligned}$$

In our case the log likelihood function is following:

$$lnL = \frac{-3T}{2} ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T} ln\,|\Omega_t| - \frac{1}{2}\sum_{t=1}^{T} u_t'\Omega_t^{-1}u_t,$$

where the variance of d_t is $\Omega_t = Eu_t'u_t = CX\Sigma_t CX'$ and $u_t = d_t - \hat{d}_t = d_t - E(d_t|d_{t-1}, d_{t-2}, \ldots, d_1)$.

The task is transformed to the minimization of the log likelihood function by multiplying the whole term by (-1). The first part of the

[15] The equation implies: $d_t = CX\hat{s}_{t|t-1} + w_t = CX\hat{s}_{t|t-1} + (d_t - \hat{d}_{t|t-1})$ and $\hat{d}_{t|t-1} = CX\hat{s}_{t|t-1}$.

[16] It is a vector $[9 \times 1]$ of zeros.

function $\frac{-3T}{2} ln(2\pi)$ is only a constant term with no impact on the location of the extreme of the function. It is possible to omit it. We try to minimize the value of the covariance matrix expressed as the logarithm of a matrix determinant $\sum_{t=1}^{T} ln\left|\Omega_t\right|$ together with the quadrate errors weighted by the inverted covariance matrix $\sum_{t=1}^{T} u_t' \Omega_t^{-1} u_t$ for $t = 0, 1, 2, \dots$

For the backward estimation is employed the Kalman smoother and the equations for smoothing are used in the same form as descbibed in the previous section. The starting value for the state vector and the covariance matrix are used from the last output of the Kalman filter during the forward estimation.

6 RESULTS

Before we try to interpret the estimation results of the model it is meaningful to take a notice of used data.

6.1 DATA AND GENERAL CIRCUMSTANCES ABOUT THE MODEL

In the steady state $g^y = z$ and $r^{r\pi} = z/\beta$. That means we need to know the level of output growth rate ($z = 1.0059$) and the level of the nominal interest rate to inflation divided by the value of parameter z ($\beta = 0.99851$). The coefficient on real marginal cost in Phillips curve is set to $\psi = 0.1$ which corresponds to an individual goods price–fixing for 3.7 quarters on average (see Ireland (2005a)). The remaining parameters are estimated with maximum likelihood, or more precisely: the method is the Kalman filter evaluating a likelihood function and the Kalman smoother evaluating time series of smoothed estimate of the unobserved state variable (target inflation).

There are 19 parameters[17] and 3 observable variables in the model: the growth rate of the output ($\hat{g}_t^y$), of inflation ($\hat{g}_t^\pi$) and of the nominal interest rate to inflation ($\hat{r}_t^{\pi r}$). Before estimating we simplify the model with omitting the equations for the efficient level of output (equations (16) and (18)) and consequently we amend the generalized Taylor rule by using the original form (equation (12)).

For the solving the model we use the Czech economy quarterly data of a real GDP, the consumer quarterly–to–quarterly inflation and three–months interbank real interest rate. These inputs are transformed to the relevant growth rates.

During the estimation are used the series of the logarithmic deviations of the growth rate of output and inflation $\hat{g}_t^y, \hat{g}_t^\pi$ and the ratio of the nominal interest rate to the inflation. For their calculation we use log–linearization around the steady state from the subsection 3.9 and the steady state values presented in subsection 3.8. The formulation

[17] The parameters are: $z, \beta, \psi, \gamma, \alpha, \rho_\pi, \rho_x, \rho_{gy}, \rho_a, \rho_e, \rho_v, \sigma_a, \sigma_e, \sigma_z, \sigma_v, \sigma_\pi, \delta_a$, δ_e, and δ_z.

is following:

$$\hat{g}_t^y = ln\left(\frac{g_t^y}{g^y}\right) = ln\left(\frac{\frac{Y_t}{Y_{t-1}}}{z}\right) = ln(Y_t) - ln(Y_{t-1}) - ln(z)$$

$$\hat{g}_t^\pi = ln(g_t^\pi) = ln\left(\frac{\Pi_t}{\Pi_{t-1}}\right) = ln\left(\frac{\frac{P_t}{P_{t-1}}}{\frac{P_{t-1}}{P_{t-2}}}\right) = ln\left(\frac{P_t}{P_{t-1}}\frac{P_{t-2}}{P_{t-1}}\right)$$

$$= ln(P_t) - 2ln(P_{t-1}) + ln(P_{t-2})$$

$$\hat{r}_t^{r\pi} = ln\left(\frac{r_t^{r\pi}}{r^{r\pi}}\right) = ln\left(\frac{\frac{R_t}{\Pi_t}}{\frac{z}{\beta}}\right) = ln\left(\frac{R_t}{\frac{P_t}{P_{t-1}}}\frac{\beta}{z}\right)$$

$$= ln(R_t) - ln(P_t) + ln(P_{t-1}) + ln(\beta) - ln(z)$$

for $t = 0, 1, 2, \ldots$ and Y_t, P_t and R_t are observable values of GDP, consumer price index (for calculating inflation) and the real interest rate. Figure 1 introduces the used original and transformed data.

It is possible to estimate the model as an endogenous or exogenous model of inflation targeting. In case that the inflation target is exogenous, the parameters δ_a, δ_e and δ_z are fixed to the value of zero and the rest of parameters is estimated. The inflation target equation (15) is simplified into the form $ln(\Pi_t^*) = ln(\Pi_{t-1}^*) + \sigma_\pi\epsilon_{\pi t}$. That means the inflation target depends only on the latest value of the inflation target and on an inflation shock. For the endogenous targeting all variables are estimated.

The endogenous (unconstrained) model offers better results for the Czech economy and that is why we are interested only in behaviour of this model.

6.2 ESTIMATION RESULTS

Table 1 contains the maximum likelihood estimates of all parameters and standard errors. The first three parameters are set in advance and the rest of them is estimated with the Kalman filter evaluating the likelihood function. The value of maximized log likelihood function is 459.1327.

The discount factor β equals 0.99851 which implies relatively high patience of the representative household. The quarterly values for z and $r^{\pi r}$ correspond to the situation in the Czech economy: the

Table 1: Estimates of the Model with Endogenous Target

Parameter	**Estimate**	**Standard Error**
z	1.0059	0
β	0.99851	0
ψ	0.1	0
γ	0.8103	0.06397
α	0	**
ρ_π	0.29794	0.07166
ρ_{gy}	0.18386	0.10287
ρ_a	0	**
ρ_e	0	**
ρ_v	0	**
σ_a	0.024803	0.0087137
σ_e	0.0039264	0.001779
σ_z	0.017693	0.0061814
σ_v	0.004874	0.00057711
σ_π	0.0024665	*
δ_e	0.00245866	0.00068566
δ_z	0.0011999	0.0010765

* the value for the parameter σ_π was calibrated

** estimate lies up against the boundary of the parameter space

The maximized value of the log likelihood function is 459.1327.

growth rate for output is 0.59 % quarterly (that is 2.38 % annually); the real interest rate is 0.74 % quarterly (which corresponds to the value 2.99 % p.a.). In our model there is no capital and no growth rate of population as a labour input. That implies that the growth rate of output expresses an average quarterly rate of the technological shock (progress) together with productivity of labour. There is no other source of growing output. Similarly the real interest rate is not a price of capital (there is no financial market) but only represents the rate of return to bonds. The value of the parameter ψ is fixed to 0.1 This coefficient is a part of the New Keynesian Phillips curve and implies that the price remains unchanged for 3.7 quarters. The probability that the price can be changed in any period is therefore 27 %.

The model shows quite high consumption habit of households ($\gamma = 0.81$) that is a typical backward–looking behaviour. Unlike this there is just forward–looking behaviour in price settings of firms ($\alpha = 0$) that is consistent with a rational expectations approach.

If $\gamma = 1$, only the last period consumption is important. The presence of habit in consumption is important in the Czech economy data too. If there is a time series of seasonally adjusted real consumption quarterly data, it is possible to find the habit formation parameter of the value 0.84. We estimated the first order autoregressive process $C_t = \gamma C_{t-1} + \epsilon_t$, for $t = 0, 1, 2, \ldots$, $0 < \gamma \leq 1$, ϵ_t is the standard normally distributed serially uncorrelated innovation. The reaction according to the impulse response to one standard deviation shock in this case is about 40 quarters. That means that households try to smooth their consumption as much as possible.

The price setting of the representative intermediate goods–producing firm does not depend on the previous period inflation rate. The new price is set with respect to the latest period price and the inflation target of the central authority. The role of inflation expectations is very important because they influence the actual rate of inflation and consequently the inflation target through the Taylor rule. But on the other hand the expectations concerning the inflation rate are not formed only by inflation target.

The result reveals that both output as well as inflation growth enter the Taylor rule: the impact of a change in inflation is higher (1.62 fold) than output growth rate. The generalized Taylor rule takes this form (for $t = 0, 1, 2, \ldots$):

$$ln(R_t) = ln(R_{t-1}) + 0.29794\, ln(\Pi_t/\Pi_t^*) + 0.18386\, ln(g_t^y/g^y) + ln(v_t)$$

The central bank reacts to any change in inflation and output growth: 1 % increase in inflation to the Bank's inflation target increases the short–term nominal interest rate by 0.29794 %; similarly for the output: as a response to the 1 % increase in growth rate of output above its steady–state level[18] increases the short–term interest rate by 0.18386 %.

The basic goal of the Czech National Bank is a price stability. But the Bank must take into account the present level of the production

[18] In steady state holds the following: $g^y = z$.

in the economy too.

The model indicates there is no influence of the previous value of the preference shock, cost-push, and monetary shock to its present value – there is no persistence.

For the preference shock a_t holds that the parameter $\rho_a = 0$ (no influence of lagged value) and $\sigma_a = 0.024803$ (small influence of a shock to the preference). This is consistent with the theory of smoothing of the consumption: if there is a shock, the representative household takes it into account and adjusts the present consumption to the new situation. This shock is just temporary and has no impact to the preference in the next period ($\rho_a = 0$). The shock has no effect to permanent change in the preference but it influences the behaviour of the household through the habit formation[19].

The cost–push shock θ_t was estimated as e_t (where $e_t = (1/\phi)\theta_t$). The value of $\rho_e = \rho_\theta = 0$ and $\sigma_e = \sigma_\theta \, \phi$. The autoregressive process (11) for θ_t for $t = 0, 1, 2, \ldots$ can be rewritten:

$$ln(\theta_t) = ln(\theta) + \sigma_e \phi \epsilon_{\theta t}.$$

If the inflation rate corresponds to the inflation target[20] and the inflation target is nonzero (the inflation target is 3 % in conditions of the Czech economy), the costs of inputs also grow at the certain rate because intermediate goods–producing firms adapt their prices to the condition of the inflation target. Other relevant circumstances that can influence the cost–push shock enter this equation through $\epsilon_{\theta t}$ and their impact depends on the value of coefficients σ_e and ϕ.

For the transitory monetary shock is $\sigma_v = 0.004874$, that is very low value of the parameter, and $\rho_v = 0$. The generalized Taylor rule can be rewritten as:

$$ln(R_t) = ln(R_{t-1}) + 0.29794 \; ln(\Pi_t/\Pi_t^*) + 0.18386 \; ln(g_t^y/g^y) + \sigma_v \epsilon_{vt}$$

for $t = 0, 1, 2, \ldots$.

This shock lasts only one period and its impact is longer and insignificant to the change of the short–term nominal interest rate. The

[19] The preference shock influences the marginal utility of consumption and change the consumption within two periods.

[20] If this situation does not hold the Bank adjusts the interest rate according to the generalized Taylor rule to hold.

reason is evident: the central bank reacts to eliminate it as much as possible but the firms behave according to the rational expectations hypothesis:

- it is a short–term change that will be spread into more periods: the impact within the current period is small
- firms know that the central bank will remedy this situation by changing the nominal interest rate to keep the same condition in the economy for the next period

The result is that agents in the economy needn't change their behaviour. In these circumstances the only acceptable value for ρ_v is zero and very low number for the parameter σ_v.

The value of the coefficient σ_z is 0.0117693. New technologies are usually introduced slowly (in respect to the quarterly periods) and the random walk for the technology shock (8) expresses a situation of continuous using new technologies.

The coefficients for the time–varying inflation target are $\delta_e = \delta_\theta = 0.0014586$, $\delta_z = 0.0011999$, and $\sigma_\pi = 0.0024665$. The parameter δ_z is not satistically significant and the value of the rest parameters are very low. According to this model Czech National Bank doesn't change its time–varying inflation target very significantly. Possible changes are very small and gradual. On the other hand if the shock to the inflation target is important[21], a turn in the inflation target could be substantial.

6.3 BEHAVIOR ANALYSIS

The overall fit of the model is presented in Figure 1. The basic workings of the model is illustrated by impulse responses in Figure 2. The figure expresses impulse responses in terms of percentage–points to a one standard deviation shock of preference, cost–push, technology, monetary policy and inflation targeting (the inflation and the interest rate is are annualized).

[21] This situation would have occurred after the monetary crisis in 1997 if the central authority had targeted the inflation in this period.

There are five different temporary shocks (one standard–deviation shock of preference, cost–push, technology, monetary policy and inflation targeting) into the output, inflation and the interest rate in Figure 2.

A preference shock seems to be a demand shock. It increases the output of the economy. It influences the behavior of the households for quite a long period due to high consumption habits that makes the quick adaptation to the new situation impossible. The output increases by 0.4 percentage point and lasts almost 4 years.

The higher level of the output is accompanied by an increase in inflation by 0.6 percentage point and by an increase of the interest rate. The initial high output increases the inflation and the (intertemporal) marginal rate of substitution. The shock is only temporary the new equilibrium is therefore reached by an adjustment of the price level. To reach a new equilibrium after the increase of inflation, inflation has to decrease.

On the other hand a cost–push shock acts as a supply side shock. It causes a rise in the output and a fall of inflation and the interest rate. Because of rational expectations the behaviour of the representative firms influences only a sudden and unpredictable change in cost–push: this unpredictable change in costs leads to a lower price and consequently to the decreasing inflation rate. It creates an impulse for the monetary policy through the Taylor rule to adapt the short–run nominal interest rate to the new condition to keep the inflation target.

The change in output is very small and after several periods it disappears. A change in prices is quite high and the process of changing costs uses some part of output. In case of no cost of adjusting the nominal prices between periods, the increase in output would be much more higher. The decrease of inflation by more than 1 percentage point causes (according to the Generalized Taylor rule) the decrease of the interest rate by 0.3 percentage point.

A shock in technologies proves itself negatively in the output and inflation and positively in the interest rate. This kind of shock is permanent according to the equation (8):

$$ln(Z_t) = ln(z) + ln(Z_{t-1}) + \sigma_z \epsilon_{zt}.$$

It means a higher output growth rate in steady state but this long–run level of output is not reached immediately. If the firms behave rationally, they must change their behaviour to adapt to new conditions – it is connected especially with changes in costs, mark–ups, etc., and subsequently they change the price of their production. The changes in behaviour does not concern only firms but other agents as well: households' consumption, monetary changes of the central bank, etc. These costs expressed in real terms mean some loss in output (almost 1.5 percentage points)[22].

When costs disappear, the output goes back to its steady state level at the higher growth rate. The long–run change needs longer adaptation time in the output. The needed time is shorter for inflation and the interest rate.

The positive technology shock means that the representative intermediate goods–producing firm is able to produce more goods at the lower price. This new price expresses lower costs for the finished goods–producing firms and cheaper production (the profit margin is unchanged). The inflation must decline by 2 percentage points.

The impact to the change of the short term nominal rate is not evident: the higher output (measured by higher growth rate of output) due to a positive technology shock and lower inflation rate have opposite impacts to the interest rate according to the generalized Taylor rule. The result depends on the coefficients within the rule. In our case the short run interest rate tends to rise by more than 0.4 percentage point.

One standard deviation monetary shock induces an insignificant drop in output (0.2 percentage points) connected with an important fall in inflation by two percentage points. An adequate reaction of the central bank in correspondence with the Taylor rule means to increase the interest rate: the monetary shocks enter the Taylor rule. This expresses the restrictive monetary policy that leads to the lower output and inflation rate.

The transmission channel formulated by the generalized Taylor rule is aimed from the short run nominal interest rate to inflation. The impact to inflation is therefore much more higher than to the level of

[22]The level of output is increased in the economy with no costs of adjusting.

output. Opposite situation would appear in case of the output stability as a main goal of the Czech National Bank.

A change in inflation targets invokes no change. With rational expectations the new inflation target is accepted by all agents in the economy. They take into account the announced target inflation and the output, inflation and the interest rate remain unchanged.

During this analysis there is another dimension of the behavior that is important too. It is necessary to stress the growth possibilities of the Czech economy with inflation targeting in the context of the appropriate monetary policy presenteed by the central authority. The previous part or the whole introduced model could be used as an efficient tool for this purpose.

Figure 1: Data for Model

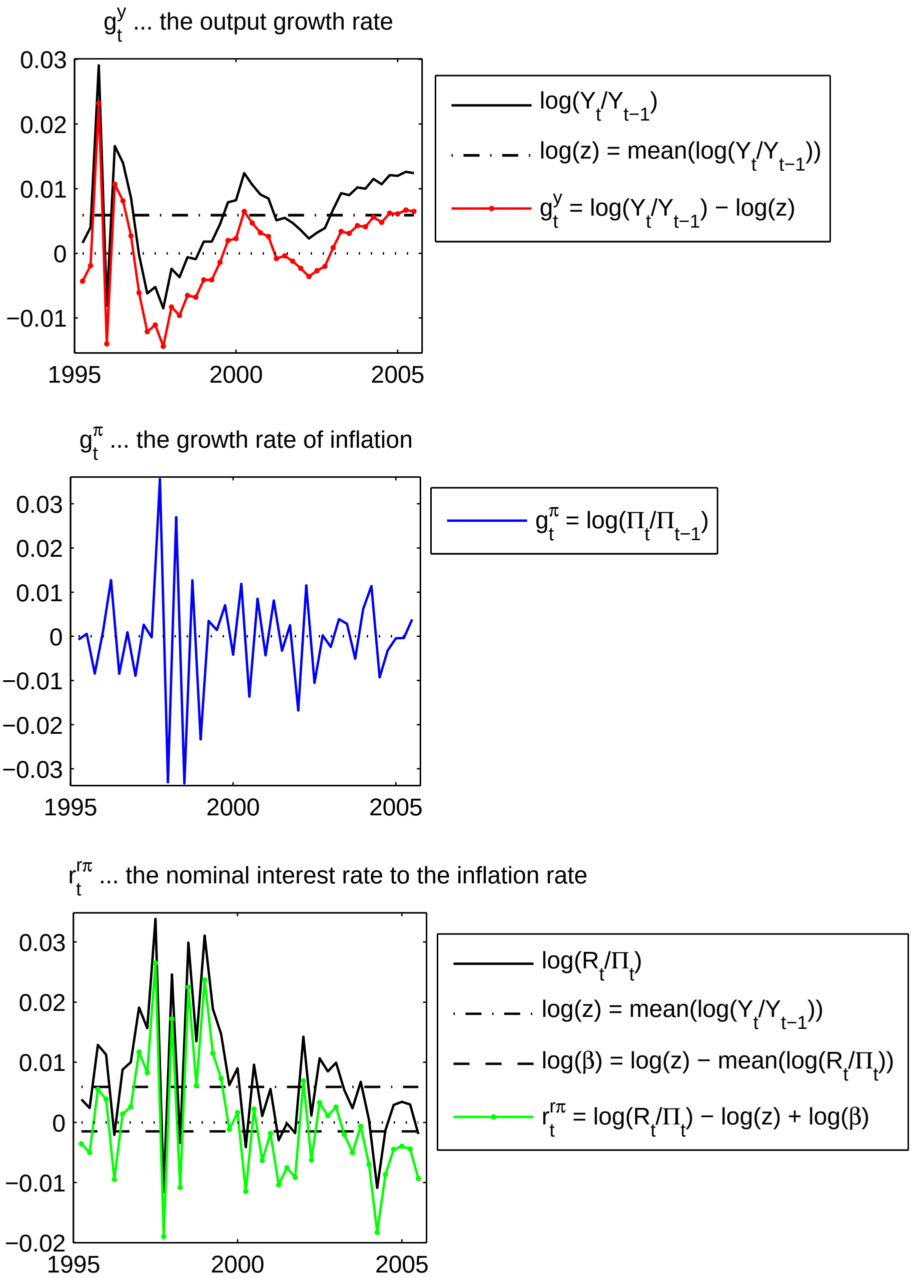


Figure 2: Consumer Price Index Inflation and Inflation Target

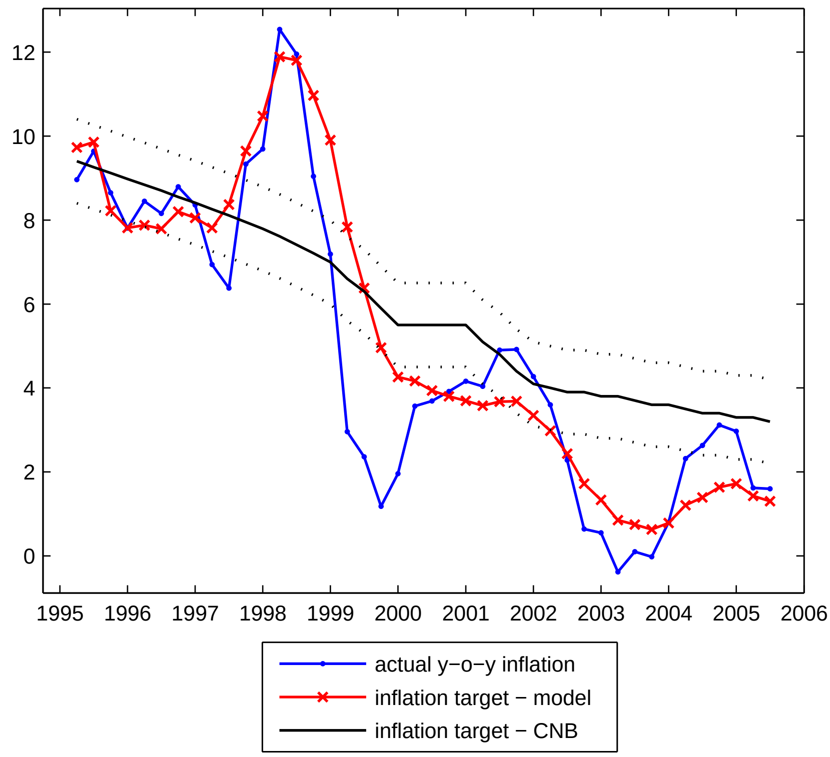
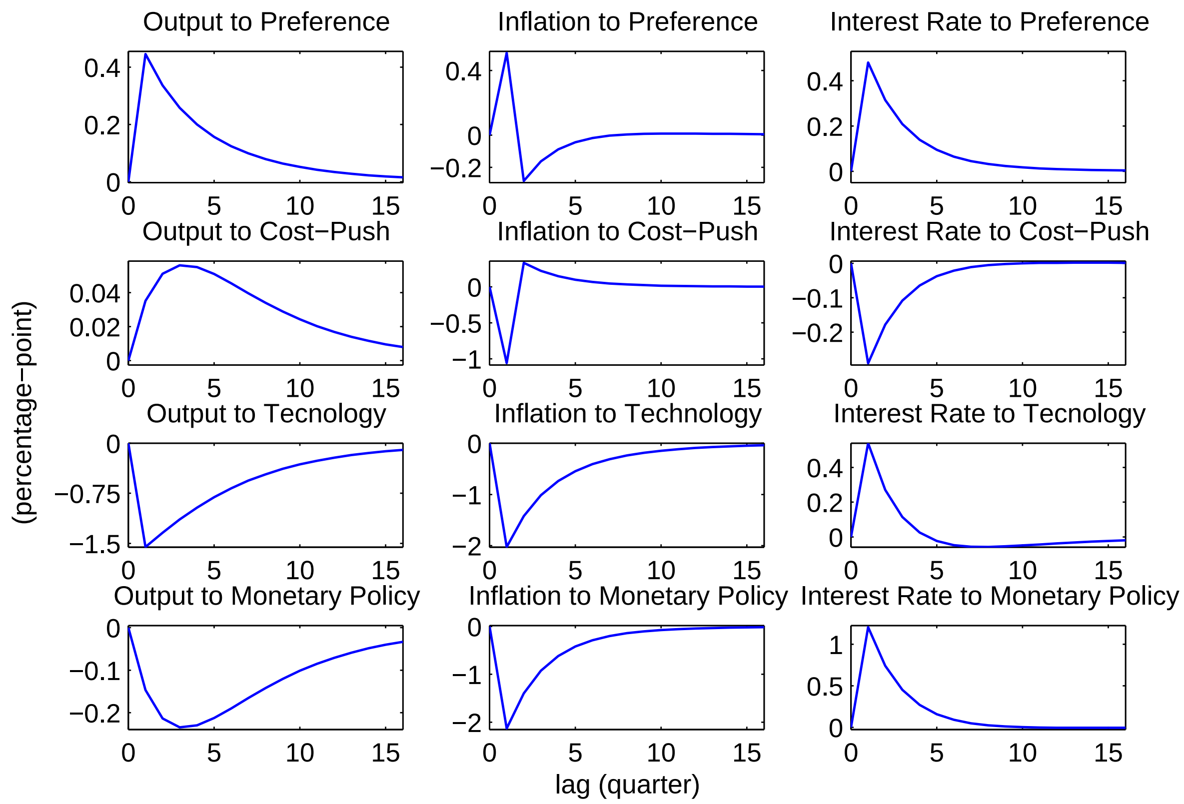


Figure 3: Impulse Responses



7 CONCLUSIONS

The model seems to give quite suitable approximation of the behaviour of the Czech economy with respect to the results. The used method of estimation offers convenient and interpretable values of parameters. The model is stable and converges to its steady state in the long run.

It is evident from the results that every shock (except for the shock to the inflation target) has very different impact on the output and often important impact on inflation and the interest rate. All changes influence inflation and if the central bank is obliged to the goal of the price stability, it must react to this situation according to the Taylor rule: to adjust the interest rate. The whole model is importantly influenced by the rational expectation hypothesis.

Although we are able to use this model for the description of the Czech economy, we need to make some notes. This model is a closed model of a complex economy. Our next task in further research is to modify it to our conditions which is a small open economy model[23]. Next steps will also lead to a better and more precise description of the behaviour of agents in economy which is e.g. an introduction of a full version of input market, an inspection of possible influence of money[24] to the behviour of the economy, etc. We will also try to use another estimation method to get more robust estimations too (for example Dynare).

[23]The analysis of the similar model in context of the small open economy is introduced by Dib (2003).

[24]Some important results in this respect give us the work of Vašíček and David (2005).

8 REFERENCES

AMMER, J. – FREEMAN, R. T. (1995): Inflation Targeting in the 1990s: The Experience of New Zealand, Canada, and the United Kingdom. *Journal of Economics and Business*, Volume 47, Issue 2, Pages 165–192. Access from internet <www.sciencedirect.com/science?_ob=MImg&_imagekey=B6V7T-3YXBJ4K-V-2&_cdi=5851&_user=835458&_orig=na&_coverDate=05% 2F31%2F1995&_sk=999529997&view=c&wchp=dGLbVzz-zSkWb&md5=1b7ca603f76f74295cd50bd8fbe57d1e&ie=/sdarticle.pdf> (cited to date: 12. 5. 2005).

BARDSEN, G. – JANSEN, E. S. – NYMOEN, R. (2003): Econometric inflation targeting, *Econometric Journal*, Volume 6, Pages 429–460. Access from internet <www.res.org.uk/econometrics/pdfs/latestarticles /ectjBardsen-2.pdf> (cited to date 19. 5. 2005).

BRASH, D. T. (2002): Inflation Targeting 14 years on. Reserve bank of New Zealand. Access from internet <www.rbnz.govt.nz/speeches/0114682.html> (cited to date: 19. 5. 2005).

CAVOLI, T. – RAJAN, R. S. (2005): Inflation Targeting and Monetary Policy Rules for Small and Open Developing Economies: Simple Analytics with Application to Thailand, National University of Singapore. Access from internet <www.spp.nus.edu.sg/docs/wp/wp0505b.pdf> (cited to date 12. 5. 2005).

CLARIDA R. – GALI, J. – GERTLER, M. (1999): The Science of Monetary Policy: A New Keynesian Perspective, NBER. Access from internet <www.nber.org/papers/w7147> (cited to date: 21. 10. 2004).

CNB (2003–2005): Cílování inflace v ČR, Czech National Bank. Access from internet <www.cnb.cz/c.php?shortcut=yes> (cited to date: 2. 5. 2005).

DEBELLE, G. (1997): Inflation Targeting in Practice, ELDIS. Access from interenet: <www. eldis.org/static/DOC3892.htm> (cited to date: 2. 5. 2005).

DIB, A. (2003): Monetary Policy in Estimated Models of Small Open and Closed Economies, Bank of Canada. Access from internet <www. bankofcanada.ca/en/res/wp/2003/wp03-27.pdf> (cited to date: 12. 9. 2005).

ELKAYAM, D. (2001): A Model for Monetary Policy Under Inflation Targeting: The Case of Israel, Bank of Israel. Access from internet <www.bankisrael.gov.il/deptdata/monetar/studies/ mns0103e.pdf> (cited to date: 12. 1. 2005).

FRAJT, J. – ZEDNÍČEK, R. (1999): Měnová pravidla v české ekonomice, Czech Economical Society in Ostrava. Paper of seminar.

IRELAND, P. N. (2001): Money's Role in the Monetary Business Cycle, Boston College Personal Web Server. Access from internet <fmwww.bc.edu/ec-p/wp458.pdf> (cited to date: 29. 3. 2005).

IRELAND, P. N. (2004): Technology Shocks in the New Keynesian Model, Boston College Personal Web Server. Access from internet <fmwww.bc.edu/ec-p/wp536.pdf> (cited to date: 29. 3. 2005).

IRELAND, P. N. (2005a): Changes in the Federal Reserve's Inflation Target: Causes and Consequences, Boston College Personal Web Server. Access from internet <www2.bc.edu/ ˜ irelandp/targets.pdf> (cited to date: 12. 1. 2005).

IRELAND, P. N. (2005b): Data and Programs (zip): Changes in the Federal Reserve's Inflation Target: Causes and Consequences, Boston College Personal Web Server. Access from internet <www2.bc.edu/ ˜ irelandp/#programs> (cited to date: 12. 1. 2005).

JONÁŠ, J. – MISHKIN, F. S. (2003): Inflation Targeting in Transition Countries: Experience and Prospects, National Bureau of Economic Research. Access from internet <www2.gsb.columbia.edu/faculty/ fmishkin/PDFpapers/W9667.pdf> (cited to date: 19. 5. 2005).

KLEIN, P. (2000): Using the Generalized Schur Form to Solve a Multivariate Linear Rational Expectations Model, *Journal of Economic Dynamics and Control*, Volume 24, Pages 416–427..

KOTLÁN, V. – NAVRÁTIL, D. (2004): Inflation Tagreting as a Stabilisation Tool: Its Design and Performance in the Czech Republic, Czech National Bank. Access from internet <www.financeauver.org/pdf_eng/ 200305vk.pdf> (cited to date: 2. 5. 2005).

KVASNIČKA, M. (2001): Cílování inflace: teorie a praxe, M. Kvasnička personal page. Access from internet <www.econ.muni.cz/˜ qasar/ papers/cilovinfl.pdf> (cited to date 28. 4. 2005).

MALLEY, J. (2004): Lecture Notes on the Theory, Calibration & Estimation of Dynamic Stochastic General Equilibrium Models. Lecture notes, so far not publicated.

MANDEL, M. – TOMŠÍK, V. (2003): *Monetární ekonomie v malé otevřené ekonomice*, 1. vyd. Praha, Managment press. Number of pages 287. ISBN 80–7261–094–5.

MASSON, P. R. – SAVASTANO, M. A. – SHARMA, S. (1997): Can Inflation Targeting Be a Framework for Monetary Policy in Developing Countries?, World Bank. Access from internet <www.worldbank.org/fandd/english/0398/articles/0100398.htm> (cited to date 7. 5. 2005).

MIZEN, P. (1998): Message to Inflation Targeting Central Banks: Say what you do and Do what you say, Royal Economic Society. Access from internet <www.res.org.uk/society/ mediabriefings/pdfs/1998/November/Mizen2.pdf> (cited to date: 19. 5. 2005).

MUSIL, K. (2005): A Model Approach to the Consumption Behaviour. So far not publicated.

TAYLOR J. B. (1993): Discretion Versus Policy Rules in Practice, Carnegie–Rochester Conference Series on Public Policy 39, pages 195–214.

TETLOW, R. J. (1999): Inflation Targeting and Target Instability, Federal Reserve Bank. Access from internet <www.federalreserve.gov/pubs/feds/2000/200001/200001pap.pdf> (cited to date: 9. 5. 2005).

TROJAN, F. (1998): Dynamické systémy. Lecture notes, so far not publicated.

ROTEMBERG, J. J. (1982): Sticky Prices in the United States. *Journal of Political Economy*, Volume 90, no. 60.

VAŠÍČEK, O. – DAVID, S. (2005): *Money's Role in the Monetary Business Cycle*, Proceedings of the 23rd International Conference of MME_05, University of Hradec Kralove, Gaudeamus. ISBN: 80 7041 535-5.

VAŠÍČEK, O. – MUSIL, K. (2005): *A Model Interpretation of the Czech Inflation Targeting and the Monetary Policy*, Proceedings of the 23rd International Conference of MME_05, University of Hradec Kralove, Gaudeamus. ISBN: 80 7041 535-5.

WOODFORD M. (2001): The Taylor Rule and Optimal Monetary Policy, Princeton University - M. Woodford personal page. Access from internet <www.princeton.edu/˜ woodford/ taylor.pdf> (cited to date 2. 5. 2005).

SUPPLEMENT 1: FIRST ORDER CONDITION FOR THE REPRESENTATIVE HOUSEHOLD

The optimization problem for the representative household is the following: the household tries to maximize its utility subject to its budget constraint. This could be expressed as:

$$max\ E_0 \sum_{t=0}^{\infty} \beta^t a_t [ln(C_t - \gamma C_{t-1}) + ln(M_t/P_t) - h_t]$$

subject to:

$$M_{t-1} + T_t + B_{t-1} + W_t h_t + D_t \geq P_t C_t + M_t + \frac{B_t}{R_t}$$

and this equation could be rewritten into this form (divided by P_t):

$$\frac{M_{t-1} + T_t + B_{t-1} + W_t h_t + D_t}{P_t} \geq C_t + \frac{M_t + B_t/R_t}{P_t}$$

for $t = 0, 1, 2, \ldots$.

The representative household chooses C_t (consumption), h_t (hours worked), B_t (amount of nominal bonds) and M_t (money balances). The Lagrangian takes this form (consists of a discounted value of utility function and a discounted value of budget constraint for the time $t = 0$)[25]:

$$L = E_0 \sum_{t=0}^{\infty} \beta^t a_t [ln(C_t - \gamma C_{t-1}) + ln(M_t/P_t) - h_t] +$$

$$E_0 \sum_{t=0}^{\infty} \Lambda_t \beta^t \left[\frac{M_{t-1} + T_t + B_{t-1} + W_t h_t + D_t}{P_t} - C_t - \frac{M_t + B_t/R_t}{P_t} \right].$$

For the time t it is possible to rewrite it into this form:

$$L_t = \beta^t a_t \left[ln(C_t - \gamma C_{t-1}) + ln\left(\frac{M_t}{P_t}\right) - h_t \right] +$$

[25]Sometimes the Lagrangian function is expressed in the following form: $L = E_0 \sum_{t=0}^{\infty} \beta^t a_t [ln(C_t - \gamma C_{t-1}) + ln(M_t/P_t) - h_t] + E_0 \sum_{t=0}^{\infty} \Lambda_t^* (M_{t-1} + T_t + B_{t-1} + W_t h_t + D_t \geq P_t C_t + M_t + B_t/R_t)$. In this case $\Lambda_t^* = \Lambda_t \beta^t$ for $t = 0, 1, 2, \ldots$.

$$\Lambda_t\beta^t\left[\frac{M_{t-1}}{P_t}+\frac{T_t}{P_t}+\frac{B_{t-1}}{P_t}+\frac{W_t}{P_t}h_t+\frac{D_t}{P_t}-C_t-\frac{M_t}{P_t}-\frac{B_t/R_t}{P_t}\right].$$

The first order conditions are following:

- for C_t:

$$\frac{\partial L_t}{\partial C_t}=\beta^t a_t\frac{1}{C_t-\gamma C_{t-1}}-\Lambda_t=0$$
$$\frac{\partial L_{t+1}}{\partial C_t}=E_t\beta^{t+1}a_{t+1}\frac{1}{C_{t+1}-\gamma C_t}(-\gamma)=0$$

We multiply the first equation by (-1) and sum both equations:

$$-\beta^t a_t\frac{1}{C_t-\gamma C_{t-1}}+\Lambda_t=E_t\beta^{t+1}a_{t+1}\frac{1}{C_{t+1}-\gamma C_t}(-\gamma)$$
$$-\frac{a_t}{C_t-\gamma C_{t-1}}+\Lambda_t=-\beta\gamma E_t\frac{a_{t+1}}{C_{t+1}-\gamma C_t}$$

The first order condition is following:

$$\Lambda_t=\frac{a_t}{C_t-\gamma C_{t-1}}-\beta\gamma E_t\left(\frac{a_{t+1}}{C_{t+1}-\gamma C_t}\right)$$

- for h_t:

$$\frac{\partial L_t}{\partial h_t}=-\beta^t a_t+\Lambda_t\beta^t\frac{W_t}{P_t}=0$$

We rearrange it:

$$-\beta^t a_t=-\Lambda_t\beta^t\frac{W_t}{P_t},$$

the first order condition:

$$a_t=\Lambda_t\left(\frac{W_t}{P_t}\right)$$

- for B_t:

$$\frac{\partial L_t}{\partial B_t}=\Lambda_t\beta^t\left(-\frac{1/R_t}{P_t}\right)=0$$
$$\frac{\partial L_{t+1}}{\partial B_t}=E_t\Lambda_{t+1}\beta^{t+1}\frac{1}{P_{t+1}}=0$$

We multiply the first equation by (-1) and put both of equations together:

$$\Lambda_t\beta^t\left(\frac{1/R_t}{P_t}\right) = E_t\Lambda_{t+1}\beta^{t+1}\frac{1}{P_{t+1}}$$
$$\Lambda_t\frac{1}{R_t} = \beta E_t\Lambda_{t+1}\frac{P_t}{P_{t+1}}$$

The first order condition is following (for $\Pi_{t+1} = P_{t+1}/P_t$):

$$\Lambda_t = \beta R_t E_t\left(\frac{\Lambda_{t+1}}{\Pi_{t+1}}\right)$$

- for M_t:

$$\frac{\partial L_t}{\partial M_t} = \beta^t a_t\frac{1}{M_t/P_t}\frac{1}{P_t} - \Lambda_t\beta_t\frac{1}{P_t} = 0$$
$$\frac{\partial L_{t+1}}{\partial M_t} = E_t\Lambda_{t+1}\beta^{t+1}\frac{1}{P_{t+1}} = 0$$

From the second term arise that:

$$E_t\Lambda_{t+1}\beta^{t+1}\frac{1}{P_{t+1}} = \frac{\partial L_{t+1}}{\partial M_t} = \frac{\partial L_{t+1}}{\partial B_t}$$

It makes no difference for the maximizing the representative household's expected utility with respect to its budget whether the household holds money or bonds. A change in an amount of M_t or B_t has the same impact on a change of the utility function in $t+1$. That should be valid for all periods – as well as for t. Then it is possible to write:

$$\frac{\partial L_t}{\partial M_t} = \frac{\partial L_t}{\partial B_t}$$
$$\beta^t a_t\frac{1}{M_t/P_t}\frac{1}{P_t} - \Lambda_t\beta^t\frac{1}{P_t} = \Lambda_t\beta^t\left(-\frac{1}{R_t}\frac{1}{P_t}\right)$$
$$a_t\frac{P_t}{M_t} = \Lambda_t\left(-\frac{1}{R_t}\right) + \Lambda_t$$
$$\frac{P_t}{M_t} = \frac{1}{a_t}\Lambda_t\left(\frac{R_t-1}{R_t}\right)$$

And the first order condition is following:

$$\frac{M_t}{P_t} = \left(\frac{a_t}{\Lambda_t}\right)\left(\frac{R_t}{R_t-1}\right)$$

SUPPLEMENT 2: THE REPRESENTATIVE INTERMEDIATE–GOODS PRODUCING FIRM'S FIRST ORDER CONDITION

The Representative Intermediate–Goods Producing Firm maximizes its real market value:

$$E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \left[\frac{D_t(i)}{P_t} \right],$$

where

$$\begin{aligned} \frac{D_t(i)}{P_t} = & \left[\frac{P_t(i)}{P_t} \right]^{1-\theta_t} Y_t - \left[\frac{P_t(i)}{P_t} \right]^{-\theta_t} \left(\frac{W_t}{P_t} \right) \left(\frac{Y_t}{Z_t} \right) \\ & - \frac{\phi}{2} \left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha} (\Pi_t^*)^{1-\alpha} P_{t-1}(i)} - 1 \right]^2 Y_t \end{aligned}$$

for $t = 0, 1, 2, \ldots$ and $i \in \langle 0; 1 \rangle$.

The representative intermediate–goods producing firm chooses its production price $P_t(i)$ to maximize the real market value through the real profits. The Lagrangian is following:

$$\begin{aligned} L = E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t & \left\{ \left[\frac{P_t(i)}{P_t} \right]^{1-\theta_t} Y_t - \left[\frac{P_t(i)}{P_t} \right]^{-\theta_t} \left(\frac{W_t}{P_t} \right) \left(\frac{Y_t}{Z_t} \right) \right. \\ & \left. - \frac{\phi}{2} \left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha} (\Pi_t^*)^{1-\alpha} P_{t-1}(i)} - 1 \right]^2 Y_t \right\} \end{aligned}$$

for all t.

To express the first order condition it is necessary to calculate the partial derivatives:

- $\frac{\partial L_t}{\partial P_t(i)}$:

$$\begin{aligned} \beta^t \Lambda_t & \left\{ (1-\theta_t) \left[\frac{P_t(i)}{P_t} \right]^{1-\theta_t-1} \frac{1}{P_t} Y_t - (-\theta_t) \left[\frac{P_t(i)}{P_t} \right]^{-\theta_t-1} \frac{1}{P_t} \left(\frac{W_t}{P_t} \right) \left(\frac{Y_t}{Z_t} \right) \right. \\ & \left. -2 \frac{\phi}{2} \left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha} (\Pi_t^*)^{1-\alpha} P_{t-1}(i)} - 1 \right]^{2-1} Y_t \frac{1}{\Pi_{t-1}^{\alpha} (\Pi_t^*)^{1-\alpha} P_{t-1}(i)} \right\} = \end{aligned}$$

$$\beta^t \Lambda_t Y_t \frac{1}{P_t} \left\{ (1-\theta_t) \left[\frac{P_t(i)}{P_t} \right]^{-\theta_t} + \theta_t \left[\frac{P_t(i)}{P_t} \right]^{-\theta_t - 1} \left(\frac{W_t}{P_t} \right) \left(\frac{1}{Z_t} \right) \right.$$
$$\left. -\phi \left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha} (\Pi_t^*)^{1-\alpha} P_{t-1}(i)} - 1 \right] \left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha} (\Pi_t^*)^{1-\alpha} P_{t-1}(i)} \right] \right\}$$

- $\frac{\partial L_{t+1}}{\partial P_t(i)}$:

$$E_t \beta^{t+1} \Lambda_{t+1} \left\{ -2 \frac{\phi}{2} \left[\frac{P_{t+1}(i)}{\Pi_t^{\alpha} (\Pi_{t+1}^*)^{1-\alpha} P_t(i)} - 1 \right] Y_{t+1} \left[\frac{P_{t+1}(i)}{\Pi_t^{\alpha} (\Pi_{t+1}^*)^{1-\alpha} P_t^2(i)} \right] (-1) \right\} =$$

$$-E_t \beta^{t+1} \Lambda_{t+1} Y_{t+1} \frac{1}{P_t(i)} \left\{ \left[\frac{P_{t+1}(i)}{\Pi_t^{\alpha} (\Pi_{t+1}^*)^{1-\alpha} P_t(i)} - 1 \right] \left[\frac{P_{t+1}(i)}{\Pi_t^{\alpha} (\Pi_{t+1}^*)^{1-\alpha} P_t(i)} \right] \right\}$$

for $t = 0, 1, 2, \ldots$.

Both partial derivatives equal to zero:

$$\frac{\partial L_t}{\partial P_t(i)} = 0 = \frac{\partial L_{t+1}}{\partial P_t(i)}$$

and this implies:

$$\frac{\partial L_t}{\partial P_t(i)} = \frac{\partial L_{t+1}}{\partial P_t(i)}$$

and subsequently:

$$0 = \frac{\partial L_t}{\partial P_t(i)} - \frac{\partial L_{t+1}}{\partial P_t(i)}.$$

The first order condition takes this form:

$$0 = (1-\theta_t) \left[\frac{P_t(i)}{P_t} \right]^{-\theta_t} + \theta_t \left[\frac{P_t(i)}{P_t} \right]^{-\theta_t - 1} \left(\frac{W_t}{P_t} \right) \left(\frac{1}{Z_t} \right)$$
$$- \phi \left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha} (\Pi_t^*)^{1-\alpha} P_{t-1}(i)} - 1 \right] \left[\frac{P_t(i)}{\Pi_{t-1}^{\alpha} (\Pi_t^*)^{1-\alpha} P_{t-1}(i)} \right]$$
$$+ \beta \phi E_t \left\{ \left(\frac{\Lambda_{t+1}}{\Lambda_t} \right) \left[\frac{P_{t+1}(i)}{\Pi_t^{\alpha} (\Pi_{t+1}^*)^{1-\alpha} P_t(i)} - 1 \right] \left[\frac{P_{t+1}(i)}{\Pi_t^{\alpha} (\Pi_{t+1}^*)^{1-\alpha} P_t(i)} \right] \right.$$
$$\left. \left[\frac{P_t}{P_t(i)} \right] \left(\frac{Y_{t+1}}{Y_t} \right) \right\}$$

for $t = 0, 1, 2, \ldots$.

SUPPLEMENT 3: THE STEADY STATE CALCULATION

In the steady state there are no shocks and the variables follows the same path. During the calculation we set the value for all shocks in the model equal to zero and remove time subscript from variables (the variables are constant). We use these stationarized equations for the calculation of the steady state value of this model:

- $a = 1$, equation (21): $ln(a_t) = \rho_a ln(a_{t-1}) + \sigma_a \epsilon_{at}$

$$\begin{aligned} ln(a) &= \rho_a ln(a) + \sigma_a 0 \\ ln(a)(1-\rho_a) &= 0 \\ ln(a) &= 0 \\ a &= 1 \end{aligned}$$

- $\pi^* = 1$, equation (30): $ln(\pi_t^*) = \delta_a \epsilon_{at} - \delta_\theta \epsilon_{\theta t} - \delta_z \epsilon_{zt} + \delta_\pi \epsilon_{\pi t}$

$$\begin{aligned} ln(\pi^*) &= \delta_a 0 - \delta_\theta 0 - \delta_z 0 + \delta_\pi 0 \\ ln(\pi^*) &= 0 \\ \pi^* &= 1 \end{aligned}$$

- $v = 1$, equation (28): $ln(v_t) = \rho_v ln(v_{t-1}) + \sigma_v \epsilon_{vt}$

$$\begin{aligned} ln(v) &= \rho_v ln(v) + \sigma_v 0 \\ ln(v)(1-\rho_v) &= 0 \\ ln(v) &= 0 \\ v &= 1 \end{aligned}$$

- $\pi = 1$, equation (26): $ln(r_t) - ln(r_{t-1}) = \rho_\pi ln(\pi_t) - ln(\pi_t^*) + \rho_x ln(x_t/x) + \rho_{gy} ln(g_t^y/g^y) + ln(v_t)$

$$\begin{aligned} ln(r) - ln(r) = \rho_\pi ln(\pi) - ln(\pi^*) + \rho_x ln(x/x) + \rho_{gy} ln(g^y/g^y) \\ + ln(v_t) \end{aligned}$$

$$\begin{aligned} 0 &= \rho_\pi ln(\pi) - ln(1) + \rho_x ln(1) + \rho_{gy} ln(1) + ln(1) \\ 0 &= \rho_\pi ln(\pi) - 0 + \rho_x 0 + +\rho_{gy} 0 + 0 \\ 0 &= \rho_\pi ln(\pi) \\ 0 &= ln(\pi) \\ \pi &= 1 \end{aligned}$$

- $c = y$, equation (19): $y_t = c_t + \frac{\phi}{2}\left[\pi_t\left(\frac{\pi_t^*}{\pi_{t-1}}\right)^{\alpha} - 1\right]^2 y_t$

$$y = c + \frac{\phi}{2}\left[\pi\left(\frac{\pi^*}{\pi}\right)^{\alpha} - 1\right]^2 y$$
$$y = c + \frac{\phi}{2}\left[1\left(\frac{1}{1}\right)^{\alpha} - 1\right]^2 y$$
$$y = c + \frac{\phi}{2}[1-1]^2 y$$
$$y = c + \frac{\phi}{2}0^2 y$$
$$y = c$$

- g^y, equation (27): $g_t^y = \frac{y_t}{y_{t-1}} z_t$

$$g^y = \frac{y}{y} z$$
$$g^y = z$$

- g^π, equation (32): $g_t^\pi = \frac{\pi_t}{\pi_{t-1}} \pi_t^*$

$$g^\pi = \frac{\pi}{\pi} \pi^*$$
$$g^\pi = 1$$

- g^r, equation (33): $g_t^r = \frac{r_t}{r_{t-1}}$

$$g^r = \frac{r}{r}$$
$$g^r = 1$$

- λ, equation (20): $\theta_t - 1 = \theta_t\left(\frac{a_t}{\lambda_t}\right) - \phi\left[\pi_t\left(\frac{\pi_t^*}{\pi_{t-1}}\right)^{\alpha} - 1\right]\left[\pi_t\left(\frac{\pi_t^*}{\pi_{t-1}}\right)^{\alpha}\right]$

$$+\ \beta\phi E_t\left\{\left(\frac{\lambda_{t+1}}{\lambda_t}\right)\left[\pi_{t+1}\left(\frac{\pi^*_{t+1}}{\pi_t}\right)^{\alpha}-1\right]\left[\pi_{t+1}\left(\frac{\pi^*_{t+1}}{\pi_t}\right)^{\alpha}\right]\left(\frac{y_{t+1}}{y_t}\right)\right\}$$

$$\begin{aligned}
\theta-1 &= \theta\left(\frac{a}{\lambda}\right)-\phi\left[\pi\left(\frac{\pi^*}{\pi}\right)^{\alpha}-1\right]\left[\pi\left(\frac{\pi^*}{\pi}\right)^{\alpha}\right] \\
&\quad +\beta\phi\left\{\left(\frac{\lambda}{\lambda}\right)\left[\pi\left(\frac{\pi^*}{\pi}\right)^{\alpha}-1\right]\left[\pi\left(\frac{\pi^*}{\pi}\right)^{\alpha}\right]\left(\frac{y}{y}\right)\right\} \\
\theta-1 &= \left(\frac{\theta}{\lambda}\right)-\phi\left[1\left(\frac{1}{1}\right)^{\alpha}-1\right]\left[1\left(\frac{1}{1}\right)^{\alpha}\right] \\
&\quad +\beta\phi\left\{\left[1\left(\frac{1}{1}\right)^{\alpha}-1\right]\left[1\left(\frac{1}{1}\right)^{\alpha}\right]\right\} \\
\theta-1 &= \frac{\theta}{\lambda}-\phi[1-1][1]+\beta\phi\left\{[1-1]\,[1]\right\} \\
\theta-1 &= \frac{\theta}{\lambda}-\phi\ 0\ 1+\beta\phi\ 0\ 1 \\
\theta-1 &= \frac{\theta}{\lambda}-0+0 \\
\lambda &= \frac{\theta}{\theta-1}
\end{aligned}$$

- y, equation (22): $\lambda_t=\frac{a_t z_t}{z_t c_t-\gamma c_{t-1}}-\beta\gamma E_t\left(\frac{a_{t+1}}{z_{t+1}c_{t+1}-\gamma c_t}\right)$

$$\begin{aligned}
\lambda &= \frac{az}{zc-\gamma c}-\beta\gamma\left(\frac{a}{zc-\gamma c}\right) \\
\frac{\theta}{\theta-1} &= \frac{1z}{zy-\gamma y}-\beta\gamma\left(\frac{1}{zy-\gamma y}\right) \\
\frac{\theta}{\theta-1} &= \frac{1}{zy-\gamma y}\,(z-\beta\gamma) \\
zy-\gamma y &= \frac{\theta-1}{\theta}\,(z-\beta\gamma) \\
y(z-\gamma) &= \left(\frac{\theta-1}{\theta}\right)(z-\beta\gamma) \\
y &= \left(\frac{\theta-1}{\theta}\right)\left(\frac{z-\beta\gamma}{z-\gamma}\right)
\end{aligned}$$

- q, equation (31): $1 = \frac{z_t}{z_t q_t - \gamma q_{t-1}} - \beta\gamma E_t\left(\frac{a_{t+1}}{a_t}\frac{1}{z_{t+1}q_{t+1} - \gamma q_t}\right)$

$$\begin{aligned}
1 &= \frac{z}{zq - \gamma q} - \beta\gamma\left(\frac{a}{a}\frac{1}{zq - \gamma q}\right) \\
1 &= \frac{1}{zq - \gamma q}(z - \beta\gamma) \\
zq - \gamma q &= z - \beta\gamma \\
q(z - \gamma) &= z - \beta\gamma \\
q &= \frac{z - \beta\gamma}{z - \gamma}
\end{aligned}$$

- x, equation (29): $x_t = \frac{y_t}{q_t}$

$$\begin{aligned}
x &= \frac{y}{q} \\
x &= \frac{\left(\frac{\theta-1}{\theta}\right)\left(\frac{z-\beta\gamma}{z-\gamma}\right)}{\frac{z-\beta\gamma}{z-\gamma}} \\
x &= \frac{\theta - 1}{\theta}
\end{aligned}$$

- r, equation (23): $\lambda_t = \beta r_t E_t\left(\frac{1}{z_{t+1}}\frac{1}{\pi^*_{t-1}}\frac{\lambda_{t+1}}{\pi_{t+1}}\right)$

$$\begin{aligned}
\lambda &= \beta r\left(\frac{1}{z}\frac{1}{\pi^*}\frac{\lambda}{\pi}\right) \\
1 &= \beta r\left(\frac{1}{z}\frac{1}{1}\frac{1}{1}\right) \\
r &= \frac{z}{\beta}
\end{aligned}$$

- $r^{\pi r}$, equation (34): $r_t^{\pi r} = \frac{r_t}{\pi_t}$

$$\begin{aligned}
r^{\pi r} &= \frac{r}{\pi} \\
r^{\pi r} &= \frac{r}{1} \\
r^{\pi r} &= r = \frac{z}{\beta}
\end{aligned}$$

THE ORIGINAL DATA

Following figures contain original data used before their transformation for the solving of the model. There are data for the gross domestic products (Figure 4), interest rate (Figure 5), inflations (Figure 6 and Figure 7) and inflation target (Figure 8).

The data are then transformed as it is introduced in Subsection 6.1. After the suitable transformation Figure 1 presents the amended data.

Figure 4: Gross Domestic Product

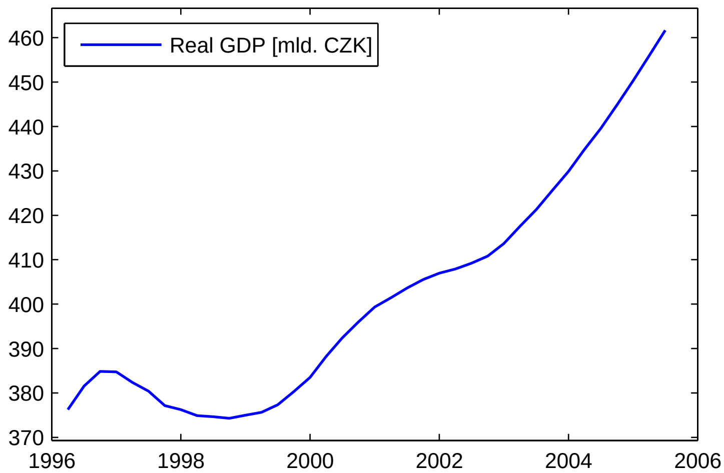


Figure 5: Interest Rate

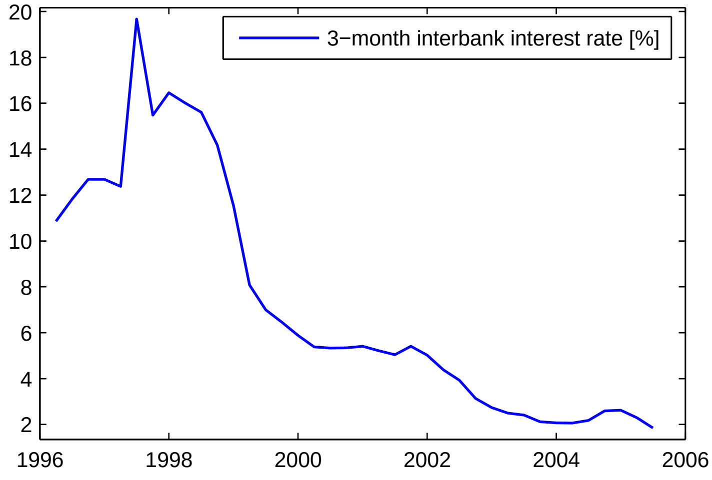


Figure 6: CPI Inflation (quarterly)

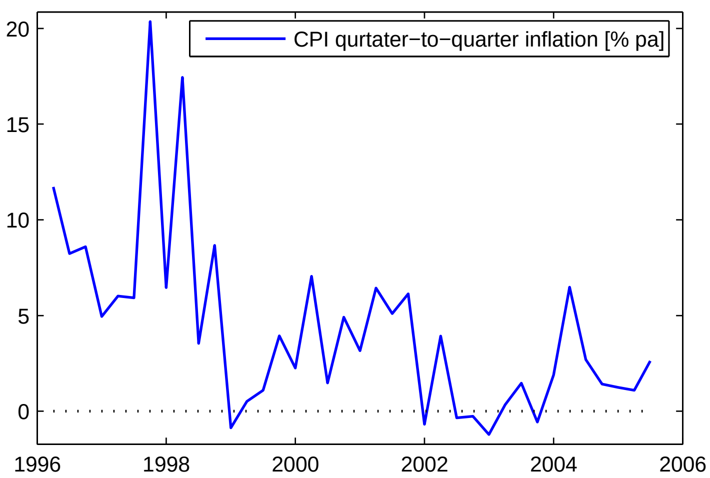


Figure 7: CPI Inflation (yearly)

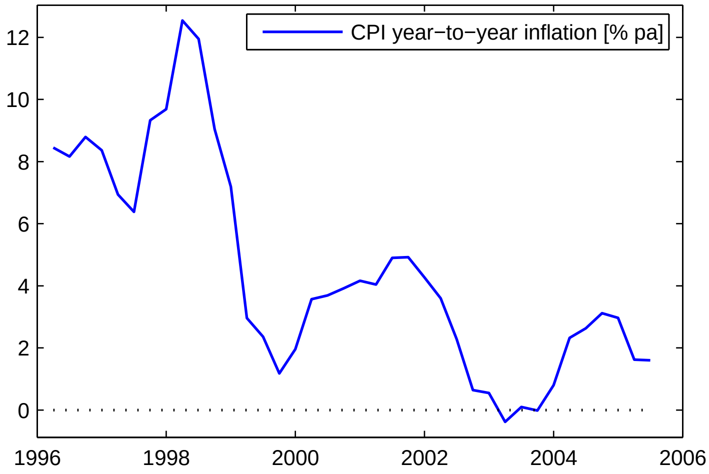
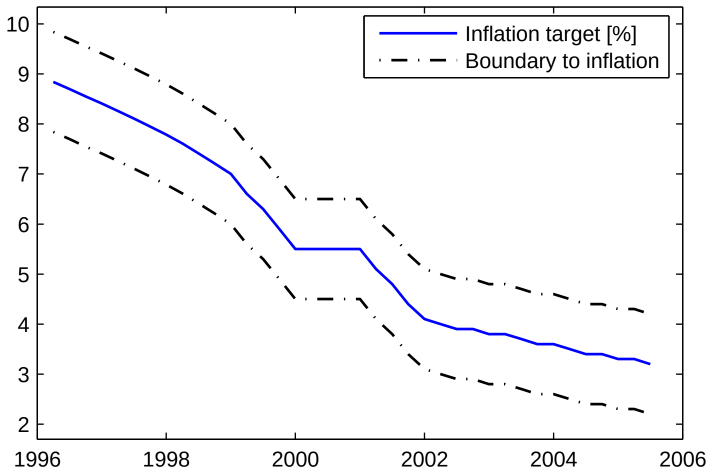


Figure 8: Inflation Target



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