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35 • 2003

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A calibrated structural model of the Czech economy

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Finlands Banks diskussionsunderlag

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I would like to thank to Juha Tarkka and Mika Kortelainen for the very efficient help they provided me with during my work on this paper. I also very much appreciate the useful comments I received from Jouko Vilmunen, Jukka Railavo and Antti Ripatti. Of course, all remaining errors are solely mine.

Suomen Pankin keskustelualoitteita
Finlands Banks diskussionsunderlag

http://www.bof.fi

ISBN 952-462-110-X
ISSN 0785-3572
(print)

ISBN 952-462-111-8
ISSN 1456-6184
(online)

Suomen Pankin monistuskeskus
Helsinki 2003

A calibrated structural model of the Czech economy

Bank of Finland Discussion Papers 35/2003

Tibor Hlédik
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Abstract

The paper presents a structural model framework for a small open economy. The model, based on optimising households and firms, has been calibrated on Czech macroeconomic data in order to develop an analytic framework suitable for analysing key policy questions related to the Czech Republic's anticipated EMU accession. In order to be able to use the model for assessing both pre- and post-accession policy issues, two versions of the model – fixed and flexible exchange rate versions – were developed. The suitability of the two alternative models for policy analysis was subsequently tested on a series of impulse response exercises. The dynamic responses of the two models to selected shocks and policy experiments are plausible. Hence these results suggest that the presented analytic framework can serve as a good starting point for analysing complex policy issues facing the Czech Republic.

Key words: monetary policy, monetary union, EMU accession

JEL classification numbers: E52, E20, E31, F41

Tšekin talouden kalibroitu rakennemalli

Suomen Pankin keskustelualoitteita 35/2003

Tibor Hlédik
Tutkimusosasto

Tiivistelmä

Tässä raportissa esitetään pienen avoimen kansantalouden rakenteellinen malli, joka perustuu optimoiviin, edustaviin yrityksiin ja kotitalouksiin. Malli on kalibroitu Tšekin taloutta kuvaavaan tilastoaineistoon, jotta saataisiin analyysikehikko, jolla voitaisiin tutkia Tšekin tulevaan EMU-jäsenyyteen liittyviä talouspoliittisia kysymyksiä. Jotta mallia voitaisiin käyttää tutkittaessa sekä EMU-jäsenyyttä edeltävän että liittymisen jälkeiseen ajan kysymyksiä, siitä on kehitetty kiinteän ja kelluvan valuuttakurssin versiot. Näiden malliversioiden sopivuutta politiikka-analyysiin testataan raportissa joukolla impulssivastekokeita. Molempien versioiden dynaamiset reaktiot valikoituihin sokkeihin ja politiikkakokeisiin ovat uskottavia. Näiden tulosten perusteella esitetty analyysikehikko voi toimia hyvänä lähtökohtana analysoitaessa niitä monimutkaisia talouspoliittisia kysymyksiä, joita Tšekillä on edessään.

Avainsanat: rahapolitiikka, rahaliitto, EMU-jäsenyys

JEL-luokittelu: E52, E20, E31, F41

Contents

1 Introduction

The main goal of this paper is to present a structural model that has been calibrated to fit the main economic characteristics of the Czech economy and address some of the key policy issues related to the country's anticipated EMU accession. The analysis is carried out within an economic framework based on optimising representative households and firms. The model structure itself is heavily relying on the EDGE model previously developed by Kortelainen (2002) at the Research Department of the Bank of Finland (BoF) for the euro area. The original model has been subsequently modified in two respects. First, the model has been calibrated on Czech macroeconomic data. Second, the originally ad hoc trade block in EDGE has been replaced by micro-optimisation based export and import functions and a corresponding price block.

In order to be able to address policy questions that are arising not only in the currently applied inflation targeting (IT) regime in the Czech Republic but also in the fixed exchange rate regime that will replace the current policy framework, two alternative versions of the model of the Czech economy have been developed. The first model assumes a floating exchange rate regime with active monetary and fiscal policies, the second model is based on a fixed exchange rate regime in which the authorities are able to manage the economy only through fiscal policy.

As it has been stressed previously, the main goal of the paper is to present a model that is designed to address policy questions related to the Czech Republic's EMU accession. Therefore the impulse response results that have been included in the paper were selected not only to assess the dynamic response of the two alternative models to selected shocks but also to compare the dynamic response of the models corresponding with the fixed and flexible exchange rate regimes. Given that the Czech Republic is a small open economy, and as such it is very much dependent on external demand, the first impulse response exercise compares the dynamic response of the two alternative models to a foreign demand shock. The second exercise illustrates the model's response within an IT framework to a series of shocks to the policy rate. The third impulse response results are derived within a fixed exchange rate regime. In this exercise the change in the target level of the nominal exchange rate aims at quantifying the dynamic response of the economy to alternative entry levels of the Czech koruna/euro exchange rate by the Czech authorities.

The paper is structured as follows. The next Section is devoted to a detailed description of the model, including the derivation of the key behavioural equations by solving consumers' and firms' optimisation problem. The third Section describes the data set that is necessary for calibrating the model for the Czech economy. It is followed by a short description of the calibration and the summary table of the obtained parameter values. The fourth Section identifies some of the key policy issues facing policymakers in the Czech Republic in a pre-EMU accession phase. These policy questions are then analysed and discussed within the previously introduced model framework. The final Section focuses on the main conclusions drawn from the previous Sections.

2 Description of the model

The model presented below is based on a modified version of a structural model developed for the euro area by Kortelainen (2002). As already mentioned, the main building blocks of the model, describing consumers' and firms' behaviour, are derived from microeconomic optimisation principles. In the subsections below the individual optimisation problems will be presented and corresponding Euler equations derived. We will start by solving the representative household's and firm's optimisation problem to determine private consumption, investment, labour and inventory demand functions. This will be followed by detailed description of wage and price setting decisions and specification of the reaction functions of fiscal and monetary authorities.

First the dynamic model will be introduced. That will be followed by the description of the corresponding steady-state model. The discussion of both dynamic and steady-state models will closely follow the structure of the presentation of individual behavioural equations as described in Kortelainen (2002).

2.1 Dynamic model

2.1.1 Consumption

Consumption behaviour is based on the Blanchard's stochastic lifetime hypothesis. The approach presented below is based on the paper of Sefton and in't Veld (1999). The representative consumer maximises her lifetime utility given by

$$\Omega_t^s = \sum_{j=0}^{\infty}\left(\frac{1-p}{1+\varphi}\right)^j \cdot U(C_{t+j}^s) \tag{2.1}$$

where $\frac{1}{1+\varphi}$ is the discount factor and φ is the rate of time preference. Given the overlapping generation framework, there is a constant probability of death p for each agent for every time period, C_{t+j}^s is real consumption at time t+j of agent born at time s. The utility of the representative consumer born at time s is given by a logarithmic unity-elasticity of substitution utility function:

$$U(C^s_{t+j}) = \ln(C^s_{t+j}) \tag{2.2}$$

The consumer optimisation is subject to the following budget constraint

$$C^s_t + W^s_t = \frac{1 + Z_{t-1} + \varsigma_t}{1-p} \cdot W^s_{t-1} + Y^s_t \tag{2.3}$$

where W^s_t is the net nominal assets of households of agent born at time s, Z_t is a return on real wealth, $\varsigma_t = Z_{t-1} - E_{t-1}(Z_{t-1})$ is unexpected return on real wealth (windfall gain), Y^s_t is a nominal (non-capital related) income of a representative agent of agent born at time s. In other words, equation (2.3) states that period t financial wealth equals to the financial wealth in the previous period increased by expected return on wealth, windfall gain and all labour income net of consumption.

The lifetime budget constraint obtained directly from equation (2.3) is given by

$$\sum_{j=0}^{\infty} \frac{(1-p)^j}{\prod_{k=0}^{j-1}(1 + Z_{t+k} + \varsigma_{t+k+1})} \cdot C^s_t = H^s_t + \frac{1 + Z_{t-1} + \varsigma_t}{1-p} W^s_{t-1} \tag{2.4}$$

where the human wealth H^s_t of agent born at time s is given by

$$H^s_t = \sum_{j=0}^{\infty} \frac{(1-p)^j}{\prod_{k=0}^{j-1}(1 + Z_{t+k} + \varsigma_{t+k+1})} \cdot Y^s_{t+j} \tag{2.5}$$

The transversality condition captured by equation (2.6) ensures that for every time period t agents' debt in the long run converges to zero

$$\lim_{T\to\infty} E_t \left(\frac{(1-p)^T}{\prod_{k=0}^{T-1}(1 + Z_{t+k} + \varsigma_{t+k+1})} \cdot W^s_{t+T} \right) = 0 \tag{2.6}$$

The equations (2.1)–(2.6) are sufficient for determining the Lagrangean of the representative consumer's optimisation problem, that is of the following form

$$\begin{aligned} L_t = {} & E_t \sum_{j=0}^{\infty} \left(\frac{1-p}{1+\varphi}\right)^j \cdot \ln(C^s_{t+j}) \\ & + \lambda_1 E_t \left(H^s_t + \frac{1+Z_{t-1}+\varsigma_t}{1-p} W^s_{t-1} - \sum_{j=0}^{\infty} \frac{(1-p)^j}{\prod\limits_{k=0}^{j-1}(1+Z_{t+k}+\varsigma_{t+k+1})} \cdot C^s_t \right) \\ & + \lambda_2 \cdot E_t \left(\frac{(1-p)^T}{\prod\limits_{k=0}^{T-1}(1+Z_{t+k}+\varsigma_{t+k+1})} \cdot W^s_{t+T} \right) \end{aligned} \tag{2.7}$$

where λ_1 resp. λ_2 are Lagrange multipliers associated with the consumers' lifetime budget constraint resp. the transversality condition.

The first order conditions of the optimisation problem above are given by equations (2.8)–(2.10) below

$$\frac{\partial L_t}{\partial C^s_t} = \frac{1}{C^s_t} - \lambda_1 = 0 \tag{2.8}$$

$$\frac{\partial L_t}{\partial C^s_{t+1}} = \frac{1-p}{1+\varphi} \cdot E_t \frac{1}{C^s_{t+1}} - \lambda_1 \cdot E_t \left(\frac{1-p}{1+Z_t+\varsigma_{t+1}} \right) = 0 \tag{2.9}$$

$$\begin{aligned} \frac{\partial L_t}{\partial C^s_{t+2}} = {} & \left(\frac{1-p}{1+\varphi}\right)^2 \cdot E_t \left(\frac{1}{C^s_{t+2}} \right) \\ & - \lambda_1 \cdot E_t \left(\frac{(1-p)^2}{(1+Z_t+\varsigma_{t+1}) \cdot (1+Z_{t+1}+\varsigma_{t+2})} \right) = 0 \end{aligned} \tag{2.10}$$

These three equations are solved for the following equation that is used later on to derive aggregate consumption behaviour

$$\frac{1}{1+\varphi} \cdot E_t \left(\frac{1}{C^s_{t+1}} \right) = \frac{1}{C^s_t} \cdot E_t \left(\frac{1}{1+Z_t+\varsigma_{t+1}} \right) \tag{2.11}$$

By taking a second order Taylor approximation of equation (2.11) around $E_t(C^s_{t+1})$ and $E_t(1+Z_t+\varsigma_{t+1}) = E_t(Z_t)$ and assuming zero risk premiums on expected consumption and expected return on wealth, the Euler equation above collapses into the following simple relationship

$$\frac{1}{1+\varphi} \cdot E_t(1+Z_t) \cdot C_t^s = E_t(C_{t+1}^s) \tag{2.12}$$

The consumption function of the representative agent born at time s can be obtained by inserting the Euler equation above into the lifetime budget constraint, linearising and assuming that total successive returns on financial wealth are uncorrelated. The resulting behavioural relationship for consumption of cohort s is then the following

$$C_t^s = (1 - \frac{1}{1+\varphi} \cdot (1-p)) \cdot \left(E_t H_t^s + \frac{1+Z_{t-1}+\varsigma_t}{1-p} W_{t-1}^s \right) \tag{2.13}$$

Let’s define the following aggregation functions for consumption, human wealth and financial wealth respectively

$$Y_t = \sum_{s=-\infty}^{t} p \cdot (1-p)^{t-s} \cdot Y_t^s \tag{2.14}$$

$$C_t = \sum_{s=-\infty}^{t} p \cdot (1-p)^{t-s} \cdot C_t^s \tag{2.15}$$

$$H_t = \sum_{s=-\infty}^{t} p \cdot (1-p)^{t-s} \cdot H_t^s \tag{2.16}$$

$$W_t = \sum_{s=-\infty}^{t} p \cdot (1-p)^{t-s} \cdot W_t^s \tag{2.17}$$

Given the periodic budget constraint captured by equation (2.3) and aggregation functions (2.14)–(2.17) it s easy to see that the budget constraint at aggregate level is of the following form

$$C_t + W_t = (1+Z_{t-1}+\varsigma_t) \cdot W_{t-1} + Y_t \tag{2.18}$$

Similarly, it is straightforward to obtain consumption at aggregate level by combining equation (2.13) with the aggregation functions (2.15)–(2.17) above

$$C_t = \left(1 - \frac{1}{1+\varphi}(1-p) \right) \cdot \left(E_t H_t + (1+Z_{t-1}+\varsigma_t) \cdot W_{t-1} \right) \tag{2.19}$$

By leading aggregate human wealth and using some simple algebra equation (2.19) can be transformed into the following equation

$$
\begin{aligned}
C_t = {} & E_t(C_{t+1}) + \left(1 - \frac{1}{1+\varphi}(1-p)\right) \\
& \cdot \left(E_t(H_t - H_{t+1}) + \left(1 + Z_{t-1} + \varsigma_t\right) \cdot W_{t-1} - E_t(1+Z_t) \cdot W_t\right)
\end{aligned}
\tag{2.20}
$$

By defining disposable income as $YDN_t = Z_{t-1} \cdot W_{t-1} + Y_t$ and $E_t(1+Z_t) = (1+r_t) \cdot (1+\chi)$ where r_t is the real interest rate and χ is the equity premium and PC_t is the private consumption deflator, one can easily obtain the final behavioural specification of the aggregate level consumption function of the following form

$$
\begin{aligned}
C_t = {} & \frac{1-p}{1-(1-p)\cdot(1-\theta\cdot(1-p))} \cdot \frac{E_t C_{t+1}}{(1+r_t)\cdot(1+\chi)} \\
& + \frac{p\cdot(1-\theta\cdot(1-p))}{1-(1-p)\cdot(1-\theta\cdot(1-p))} \cdot \left((1+\varsigma_t) \cdot \frac{A_{t-1}}{PC_t} + \frac{YDN_t}{PC_t}\right)
\end{aligned}
\tag{2.21}
$$

Since asset wealth is an important determinant of consumption, let’s discuss shortly how are assets determined in the model The asset accumulation equation below defines current nominal assets as a discounted net present value of capital income

$$
\begin{aligned}
A_t = {} & \frac{1}{(1+R_t/100)^{0.25} \cdot (1+\chi)} E_t\left(A_{t+1} - GDN_{t+1} - NFA_{t+1}\right) \\
& + PF_t \cdot Y_t - WN_t \cdot L_t - \delta \cdot PI_t \cdot K_{t-1} + GDN_t + NFA_t
\end{aligned}
\tag{2.22}
$$

where NFA_t denotes the net foreign asset position of the country, GDN_t are interest payments paid on government bonds $PF_t \cdot Y_t - WN_t \cdot L_t - \delta \cdot PI_t \cdot K_{t-1}$ is capital income received from firms. $PF_t \cdot Y_t$ denotes nominal GDP at factor cost, $WN_t \cdot L_t$ is total wage income and $\delta \cdot PI_t \cdot K_{t-1}$ stands for the depreciation of capital.

2.1.2 Investment

Firms’ behaviour is modelled identically to Kortelainen (2002). The investment decision in the model are based on an optimising behaviour described in Hubbart et al (1993). Firms maximise their discounted value of real dividends in the presence of adjustment costs related to both the level and the rate of the change of the capital stock. The firms real dividends are given by the following functional specification

$$d_t = p_t F(K_t, N_t) - w_t N_t - \Gamma(K_t, K_{t-1}, K_{t-2}) - I_t \tag{2.23}$$

where $p_t = \frac{P_t}{P_t^I}$ is the relative price of output to investment, $F(K_t, N_t)$ is the production function (where K_t is the capital stock and N_t is labour input), $\Gamma(K_t, K_{t-1}, K_{t-2})$ is adjustment cost function to be specified later and I_t is real investment.

The discounted value of expected real dividends of firm i is given by

$$Z_t^i = E_t \sum_{j=0}^{\infty} \left[\prod_{h=0}^{t+1} \rho_h \right] d_{i,t+j} \tag{2.24}$$

The representative firm minimises Z_t^i subject to the standard capital accumulation equation of the form

$$K_{i,t} = I_{i,t} + (1-\delta) K_{i,t-1} \tag{2.25}$$

The first order condition is given by

$$\begin{aligned} &\frac{\partial \Gamma(K_{i,t}, K_{i,t-1}, K_{i,t-2})}{\partial K_{i,t}} + \rho \cdot E_t \frac{\partial \Gamma(K_{i,t+1}, K_{i,t}, K_{i,t-1})}{\partial K_{i,t}} \\ &+ \rho^2 \cdot E_t \frac{\partial \Gamma(K_{i,t+2}, K_{i,t+1}, K_{i,t})}{\partial K_{i,t}} \\ &= p_t \cdot \frac{\partial F(K_{i,t}, N_{i,t})}{\partial K_{i,t}} - 1 + \rho \cdot (1-\delta) \end{aligned} \tag{2.26}$$

where $\rho_t = (1 + r_t + \chi)^{-1}$ and χ is the equity premium.

The adjustment cost function is given by

$$\begin{aligned} \Gamma(K_{i,t}, K_{i,t-1}, K_{i,t-2}) &= \frac{a_1}{2} \frac{(\Delta K_{i,t} - b_1 \cdot \Delta K_{i,t-1})^2}{K_{i,t}} \\ &\approx \frac{a_1}{2} \cdot \Delta K_{i,t} \cdot \Delta \log K_{i,t} + \frac{a_1 \cdot b_1^2}{2} \cdot \Delta K_{i,t-1} \cdot \Delta \log K_{i,t-1} \\ &\quad - a_1 \cdot b_1 \cdot \Delta K_{i,t} \cdot \Delta \log K_{i,t-1} \end{aligned} \tag{2.27}$$

where $0 < b_1 < 1$.

In order to be able to express the first order condition captured by equation (2.26) in an analytically treatable form, we take the following partial derivatives of the adjustment cost function

$$\begin{aligned}
&\frac{\partial\Gamma(K_{i,t},K_{i,t-1},K_{i,t-2})}{\partial K_{i,t}}=\frac{a_1}{2}\cdot\left(\Delta\log K_{i,t}+\frac{\Delta K_{i,t}}{K_{i,t}}\right)-a_1\cdot b_1\cdot\Delta\log K_{i,t-1}\\
&\approx a_1\Delta\log K_{i,t}-a_1b_1\Delta\log K_{i,t-1}
\end{aligned}\tag{2.28}$$

$$\begin{aligned}
&\frac{\partial\Gamma\left(K_{i,t+1},K_{i,t},K_{i,t-1}\right)}{\partial K_{i,t}}=-\frac{a_1}{2}\left(\Delta\log K_{i,t+1}+\frac{\Delta K_{i,t+1}}{K_{i,t+1}}\right)\\
&+\frac{a_1b_1^2}{2}\left(\Delta\log K_{i,t}+\frac{\Delta K_{i,t}}{K_{i,t}}\right)\\
&+a_1b_1\left(\Delta\log K_{i,t}-\frac{\Delta K_{i,t+1}}{K_{i,t}}\right)\\
&\approx -a_1\left(1+b_1\right)\Delta\log K_{i,t+1}+a_1b_1\left(1+b_1\right)\Delta\log K_{i,t}
\end{aligned}\tag{2.29}$$

where $b_1\in\left(0,1\right)$ and $\Delta\log K_t=\log K_t-\log K_{t-1}$

$$\begin{aligned}
&\frac{\partial\Gamma\left(K_{i,t+2},K_{i,t+1},K_{i,t}\right)}{\partial K_{i,t}}=a_1b_1\frac{\Delta K_{i,t+2}}{K_{i,t}}-\frac{a_1b_1^2}{2}\left(\Delta\log K_{i,t+1}+\frac{\Delta K_{i,t+1}}{K_{i,t}}\right)\\
&\approx a_1b_1\Delta\log K_{i,t+2}-a_1b_1^2\Delta\log K_{i,t+1}
\end{aligned}\tag{2.30}$$

Substituting equations (2.28)–(2.30) into the first order condition given by equation (2.26) we obtain the capital accumulation equation that directly enters into the model

$$\begin{aligned}
&\rho^2\cdot b_1\cdot\Delta k_{t+2}-(\rho^2\cdot b_1^2+\rho\cdot(1+b_1))\cdot\Delta k_{t+1}\\
&+(\rho\cdot b_1\cdot(1+b_1)+1)\cdot\Delta k_t-b_1\cdot\Delta k_{t-1}\\
&=\frac{1}{a_1}\cdot\left(p_t\cdot\frac{\partial F(K_t,N_t)}{\partial K_t}-\frac{r_t+\chi+\sigma}{r_t+\chi+1}\right)
\end{aligned}\tag{2.31}$$

2.1.3 Labour demand

The labour demand function is defined similarly as in Tarkka et al (1990b) and Willman et al (2000). The basic idea behind the specification of labour demand function in both of these papers is that it is costly for the firms to deviate from the long run labour demand l_t^* given by the inverted Cobb-Douglas production function

$$l_t^* = \left(\frac{Y_t}{T \cdot K_t^{\beta}} \right)^{\frac{1}{1-\beta}} \tag{2.32}$$

As noted by Kortelainen (2002), this particular specification ensures that the change in the capital stock and technological progress is consistent with the chosen production technology in the long run. Thus assuming a quadratic loss function, a representative firm i sets its labour demands by minimising L_t specified as

$$L_i = \frac{1}{2} \cdot E_t \sum_{j=1}^{\infty} \rho^j \cdot \left[(l_{i,t+j} - l_{i,t+j-1})^2 + b \cdot (l_{i,t+j} - l_{t+j}^*)^2 \right] \tag{2.33}$$

Calculating the first order conditions and substituting the value of the inverted Cobb-Douglas function for long-term labour demand into the resulting equation yields

$$l_{i,t} = \frac{1}{1+b+\rho} \cdot l_{i,t-1} + \frac{\rho}{1+b+\rho} \cdot E_t l_{i,t+1} + \frac{b}{1+b+\rho} \cdot \left(\frac{Y_t}{T \cdot K_t^{\beta}} \right)^{\frac{1}{1-\beta}} \tag{2.34}$$

2.1.4 Inventory demand

There are two basic assumptions behind the derivation of inventory demand, that are based on the approach chosen by Willman, et al (2000) for the BOF5 model. First, it is assumed that firms target their inventory levels to be a constant share of production determined by the actual level of capital and labour input and existing Cobb-Douglas production technology. In other words, the ‘optimal’ level of inventories is considered to be $KI_t^* = k \cdot Q_t^* = k \cdot T_t \cdot K_t^{\beta} \cdot L_t^{1-\beta}$. Second, firms face (quadratic) transaction costs in trying to keep their inventories at this targeted level. At the same time, there is an associated cost for the firms to deviate from the full capacity utilisation level of output. The resulting loss function, therefore, is of the following functional form

$$\frac{1}{2} E_t \sum_{j=0}^{\infty} \rho^j \left[\varpi (KI_{i,t+j} - KI_{t+j}^*)^2 + (Q_{i,t+j} - Q_{t+j}^*)^2 \right] \tag{2.35}$$

The first order conditions are resulting in the following behavioural relationship for the optimal level of inventories for firm i given adjustment costs

$$KI_{i,t} = k \cdot Q_t^* - \frac{1}{\varpi} \cdot (Q_{i,t} - Q_t^*) + \frac{\rho}{\varpi} E_t(Q_{i,t+1} - Q_{t+1}^*) \tag{2.36}$$

Inventories at aggregate level are given therefore by

$$KI_t = k \cdot Q_t^* - \frac{1}{\varpi} \cdot (Q_t - Q_t^*) + \frac{\rho}{\varpi} E_t(Q_{t+1} - Q_{t+1}^*) \tag{2.37}$$

2.1.5 Prices

Firms' price setting behaviour is based on a Rotemberg (1982) type specification with quadratic adjustment costs related to price changes or deviations from equilibrium price level. Similarly as in the case of inventory and labour demand, the quadratic adjustment terms ensure realistic price inertia for policy simulations. At the same time introducing price stickiness through adjustment costs is entirely consistent with microeconomic optimisation principles.

Given Cobb-Douglas production technology the marginal cost p* in the long-run is given by: $p^* = \frac{WN_t \cdot L_t}{(1-\tau_t^{indirect}) \cdot (1-\beta) \cdot Y_t}$ where WN_t is the average wage, $\tau_t^{indirect}$ is the indirect tax rate.

By assuming that it is costly for the firms to change their prices or deviate from the price level given by long run marginal cost, the loss function of the firm is determined by

$$L = \frac{1}{2} \cdot E_t \sum_{j=0}^{\infty} \tilde{\rho}^j \cdot \left[(p_{i,t+j} - p_{i,t+j-1})^2 - a \cdot (p_{i,t+j} - p_{t+j}^*)^2 \right] \tag{2.38}$$

where $\tilde{\rho}$ is the discount factor.

The first order condition is given by

$$\begin{aligned} \frac{\partial L}{\partial p_{i,t}} &= (p_{i,t+j} - p_{i,t+j-1}) - a \cdot (p_{i,t+j} - p_{t+j}^*) \\ &- \tilde{\rho} \cdot E_t(p_{i,t+1} - p_{i,t}) = 0 \end{aligned} \tag{2.39}$$

Aggregating equation (2.39) through all firms yields

$$\begin{aligned}P_t = \frac{1}{1+a+\tilde{\rho}}\cdot P_{t-1} + \frac{\tilde{\rho}}{1+a+\tilde{\rho}}\cdot E_t P_{t+1} \\ + \frac{a}{1+a+\tilde{\rho}}\cdot\frac{WN_t \cdot L_t}{(1-\tau_t^{\text{indirect}})\cdot(1-\beta)\cdot Y_t}\end{aligned} \qquad (2.40)$$

2.1.6 Wages

Wage contracts are based on the results presented by Rotemberg (1987) and Walsh (1998) that are a discrete time versions of wage contracts derived in Calvo's (1983) influential paper. The key assumption behind all of the three models is that prevailing wages are changed randomly with a constant probability of q and they remain unchanged with a probability of 1–q. Let's assume further that the optimal wage is given by a marginal product of labour being adjusted for the cyclical position of the economy approximated by the unemployment gap[1]. To be more exact it is assumed that

$$wn_t^* = p_t \frac{(1-\beta)\cdot Y_t}{N_t.(1-\overline{U}_t)}\cdot(1-\eta\cdot(U_t-\overline{U}_t)) \qquad (2.41)$$

where, given Cobb-Douglas production technology, $p_t \frac{(1-\beta)\cdot Y_t}{N_t}$ is the nominal marginal product of labour and $\overline{U}$ is the NAIRU. Given the two main assumptions of the model above combined with the assumption of quadratic cost function, firm i minimising the following loss function

$$L_i = \frac{1}{2}\cdot\sum_{j=0}^{\infty}(1-q)^j\cdot\tilde{\rho}^j E_t(wn_{i,t} - wn_{t+j}^*)^2 \qquad (2.42)$$

After aggregating the resulting first order conditions we obtain the following nominal wage wn_t that is set by all firms who are adjusting at time t their nominal wage contracts

$$wn_t = (1-(1-q)\cdot\tilde{\rho})\cdot wn_t^* + (1-q)\cdot\tilde{\rho}\cdot E_t wn_{t+1} \qquad (2.43)$$

Since it has been assumed that at time t a q fraction of firms will adjust their wages and a fraction of 1–q will keep their nominal wages at unchanged level, per capita nominal wages can be expressed as follows

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[1] As it is noted in Kortelainen (2002) there is an ad hoc element in setting the optimal nominal wage insted of deriving it within a dynamic optimisation framework.

$$WN_t = q \cdot wn_t + (1-q) \cdot WN_{t-1} \tag{2.44}$$

After the substitution of equations (2.41) and (2.43) into equation (2.44) we obtain the aggregate level nominal average wage

$$\begin{aligned} WN_t = {} & \frac{1-q}{1+(1-q)\cdot(1-q)\cdot\tilde{\rho}} \cdot WN_t + \frac{(1-q)\cdot\tilde{\rho}}{1+(1-q)\cdot(1-q)\cdot\tilde{\rho}} \cdot E_t WN_{t+1} \\ & + \frac{q\cdot(1-(1-q)\cdot\tilde{\rho})}{1+(1-q)\cdot(1-q)\cdot\tilde{\rho}} \cdot \left[p_t \frac{(1-\beta)\cdot Y_t}{N_t} \cdot (1-\eta\cdot(U_t-\overline{U}_t)) \right] \end{aligned} \tag{2.45}$$

2.1.7 Foreign trade and prices of consumption, investment and exported goods

The microeconomic foundations of the foreign trade block have been slightly deepened in the Czech version of the EDGE model in that most equations are derived from microeconomic optimisation principles. Import volumes and corresponding optimal price indices will be derived and not imposed as in the European version of EDGE. This slight modification in the model should ensure the mutual consistency of volumes and prices in the foreign trade block of the model. Since we concentrate on a one-country set-up, the behaviour of foreign agents is implicitly assumed and not modelled here. Our approach presented below is similar to that in the literature, it should be viewed as a specific case of a more complex approach presented for instance in Laxton and Pesenti (2003).

Since the derivation of import demand is in the centrepiece of the whole trade-price block, let us first specify how imports are determined in the model. Based on the Czech economic reality, we assume that Czech households and firms import consumption and investment goods, and, in addition, a part of their imports are re-exported.

Let's start with consumption goods. We assume that a basket of consumption goods C_t is produced by a continuum of home firms indexed by $x\in[0,1]$ at time t, using a Cobb-Douglas production technology determined by

$$C_t = \frac{\left(C_t^H\right)^{\gamma} \cdot \left(C_t^F\right)^{1-\gamma}}{\gamma^{\gamma} \cdot (1-\gamma)^{1-\gamma}} \tag{2.46}$$

where C_t^H resp. C_t^F is a basket of domestic value added resp. foreign value added consumption goods defined over a continuum of consumption goods produced by domestic resp. foreign firms. Specifically, we assume that domestic resp. foreign firms produce a continuum of consumption goods indexed by h∈(0,s) resp. f∈(s,1), where s is the country size

$$C_t^H = \int_0^s c_t(h)dh = \int_0^1\int_0^s c_t(h,x)\cdot dh\cdot dx \tag{2.47}$$

$$C_t^F = \int_s^1 c_t(f)df = \int_0^1\int_s^1 c_t(f,x)\cdot df\cdot dx \tag{2.48}$$

where equations (2.47) resp. (2.48) define the domestic resp. foreign value added aggregate level consumption.

The nominal value of intermediate consumption baskets are defined as

$$PC_t^H\cdot C_t^H = \int_0^1 pc_t(h)\cdot c_t(h)\cdot dh = \int_0^1\int_0^s pc_t(h,x)\cdot c_t(h,x)\cdot dh\cdot dx \tag{2.49}$$

and

$$PC_t^F\cdot C_t^F = \int_0^1 pc_t(f)\cdot c_t(f)\cdot df = \int_0^1\int_s^1 pc_t(f,x)\cdot c_t(f,x)\cdot df\cdot dx \tag{2.50}$$

where PC_t^H resp. PC_t^H is a minimum expenditure required to buy a one unit of a basket of domestic resp. foreign of value added consumption goods at time t.

Assuming that each firm x takes the price PC_t of differentiated consumption goods as given and solves the following cost minimisation problem we set up the following optimisation problem

$$\begin{aligned} C_t^D(h,f,x) = \min_{c_t(h,x),c_t(f,x)} \Bigg\{ & \int_0^s pc_t(h)\cdot c_t(h,x)\cdot dh + \int_s^1 pc_t(f)\cdot c_t(f,x)\cdot df \\ & PC_t\cdot\left(C_t(x) - \frac{\left(\int_0^s c_t(h,x)\cdot dh\right)^{\gamma}\cdot\left(\int_s^1 c_t(f,x)\cdot df\right)^{1-\gamma}}{\gamma^{\gamma}\cdot(1-\gamma)^{1-\gamma}} \right) \end{aligned} \tag{2.51}$$

where PC_t is the cost minimising price of one unit of differentiated consumption good.

The first order conditions w.r.t. domestic value added goods is given by

$$\frac{\partial C_t^D(h,f,x)}{\partial c_t(h,x)} = pc_t(h,x) - \gamma \cdot PC_t \cdot \frac{\left(\int_0^s c_t(h,x)\cdot dh\right)^{\gamma} \cdot \left(\int_s^1 c_t(f,x)\cdot df\right)^{1-\gamma}}{\gamma^{\gamma}\cdot(1-\gamma)^{1-\gamma}} = 0 \tag{2.52}$$

The equation above holds only if $pc_t(h,x)\cdot c_t(h,x) = \gamma \cdot PC_t \cdot C_t$. By aggregating across value added goods and firms we get

$$PC_t^H \cdot C_t^H = \gamma \cdot PC_t \cdot C_t \tag{2.53}$$

Now it is straightforward to express the demand for domestic value added consumption goods in terms of relative prices and total consumption

$$C_t^H = \gamma \cdot \left(\frac{P_t^H}{PC_t}\right)^{-1} \cdot C_t \tag{2.54}$$

By calculating the first order conditions with respect to imported foreign value added consumption goods we similarly as in the case of domestic value added goods obtain

$$C_t^F = (1-\gamma)\cdot \left(\frac{PC_t^F}{PC_t}\right)^{-1} \cdot C_t \tag{2.55}$$

The private consumption deflator can be obtained by substituting the right hand sides of the two equations for C_t^H and C_t^F above into the aggregate consumption equation. After some simple algebra we obtain

$$CPI_t = \left(P_t\right)^{\gamma} \cdot \left(PC_t^F\right)^{1-\gamma} \tag{2.56}$$

Let's assume further, that PPP holds

$$PC_t^F = e_t \cdot P_t^* \tag{2.57}$$

Let's define the real exchange rate as

$$Q_t = \frac{P_t^* \cdot e_t}{P_t} \tag{2.58}$$

Combining the law of one price and the definition of the real exchange rate above it is easy to derive that the volume of imported consumption goods is given by

$$IM_t^C = C_t^F = (1-\gamma)\cdot(Q_t)^{-\gamma}\cdot C_t \tag{2.59}$$

The consumer price deflator is of the following form

$$PC_t = (P_t)^{\gamma}\cdot(e_t\cdot P_t^*)^{1-\gamma} \tag{2.60}$$

Let's assume a similar Cobb-Douglas basket for investment and exported goods as we it has been the case for consumption goods

$$I_t = \frac{(I_t^H)^{\kappa}\cdot(I_t^F)^{1-\kappa}}{\kappa^{\kappa}\cdot(1-\kappa)^{1-\kappa}} \tag{2.61}$$

$$X_t = \frac{(X_t^H)^{\theta}\cdot(X_t^F)^{1-\theta}}{\theta^{\theta}\cdot(1-\theta)^{1-\theta}} \tag{2.62}$$

where I_t denotes real investment, X_t are real exports.

The corresponding optimisation based price deflators PI_t for a price of investment goods and PX_t for a price of exported goods can be obtained analogously as it has been derived for consumption

$$PI_t = (P_t)^{\kappa}\cdot(e_t\cdot P_t^*)^{1-\kappa} \tag{2.63}$$

$$PX_t = (P_t)^{\theta}\cdot(e_t\cdot P_t^*)^{1-\theta} \tag{2.64}$$

Identically the demand for foreign investment resp. exported goods is given by

$$IM^I = I_t^F = (1-\kappa)\cdot(Q_t)^{-\kappa}\cdot I_t \tag{2.65}$$

resp.

$$IM^X = X_t^F = (1-\kappa)\cdot(Q_t)^{-\theta}\cdot X_t \tag{2.66}$$

By summing up all imported consumption, investment goods and imports used for the production of exported goods, we get the total real imports at the aggregate level of the following form

$$IM_t = (1-\gamma)\cdot\left(Q_t\right)^{-\gamma}\cdot C_t + (1-\kappa)\cdot\left(Q_t\right)^{-\kappa}\cdot I_t + (1-\theta)\cdot\left(Q_t\right)^{-\theta}\cdot X_t \tag{2.67}$$

Since we are not modelling the foreign country explicitly here, we assume standard export functions and the import price function in the following form

$$X_t = Q^{\varepsilon^X}\cdot Y_t^* \tag{2.68}$$

$$P_t^{IM} = e_t \cdot P_t^* \tag{2.69}$$

2.1.8 Policy rules

The authorities can exert a stabilising impact on the economy by determining the functional form for fiscal and monetary policy rules. Fiscal policy is represented by setting direct and indirect taxes. The indirect tax rate is set at a constant level. The direct tax rate is adjusted when the debt to GDP ratio in nominal terms exceeds the long-term (targeted) debt to GDP ratio ψ of or whenever the net public lending to GDP ratio differs the steady-state level[2].

$$\begin{aligned}\tau_t^{direct} = \tau_{t-1}^{direct} &+ \alpha^{GDN/YEN}\cdot(GDN_t/YEN_t - \psi)\\ &-\beta^{GLN/YEN}\cdot(GLN_t/YEN_t + \psi\cdot(\pi_{t-1}+g))\end{aligned} \tag{2.70}$$

Monetary policy is modelled by a simple Taylor-type inflation-targeting rule of the following form

$$\begin{aligned}R_t = (1-\Omega^R)\cdot R_{t-1} &+ \Omega^R\cdot 100\cdot((1+r^*)^4\cdot(1+\pi_t)^4 - 1\\ &+\phi^{INF}\cdot(PCD_t/PCD_{t'-4} - (1+\overline{\pi})^4) - \phi^U\cdot(U_t - \overline{U}_t))\end{aligned} \tag{2.71}$$

where $0 < \Omega^R < 1$. The choice of Ω^R determines the level of inertia in short-term interest rate setting by the monetary authorities. Parameter values ϕ^{INF} and ϕ^U play a fundamental role in how stabilising the policy rule is in terms of output and inflation[3] volatility within the class of simple myopic Taylor type rules considered above.

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[2] To see how this steady-state level has been derived see the section related to the steady-state equivalent of the dynamic model below.

[3] To mention the most frequently considered macroeconomic variables i the literature. Of course, the parameter choices in our case are not based on optimized weights. They are a result of some experiments with alternative parametrisations of the policy rule.

2.2 Steady-state model

The steady-state model is a representation of the dynamic model in the long-run when no shock are hitting the economy. Besides its theoretical usefulness, it is used for deriving terminal conditions for the lead variables to be able to numerically solve the model forward. The equations of the steady-state model are directly derived from the dynamic model described above. There are, however several small differences between the solution of the dynamic and steady-state models. In the subsequent sections we are concentrating only on those.

Since EGDE is a balanced growth model as opposed to a stationary model, the dynamic equations cannot be transferred into their steady-state counterparts by simply assuming that current and lagged variables have the same steady-state value[4]. Instead, for all i = …–2,–1,0,1,2… we will transform every real variable X_t^R, nominal variable X_t^N and price level P_t as follows

$$X_{t+i}^R = (1+g)\cdot X_{t+i-1}^R$$
$$X_{t+i}^N = (1+g)\cdot(1+\overline{\pi})\cdot X_{t+i-1}^N$$
$$P_{t+i} = (1+\overline{\pi})\cdot P_{t+i-1}$$

where g is the assumed steady-state growth rate of the economy, $\overline{\pi}$ is the inflation target. The comparison of the dynamic and steady-state equations in Appendix 1 reveals that most dynamic equations are transformed into their steady-state counterpart by using one of the three transformations listed above. There are, however, a few exceptions when the steady-state equations are based on some implicit assumptions that are not derived directly from the dynamic specification.

The probably most important steady-state equation specifying the production technology is given by the standard Cobb-Douglas production function using technological progress, capital and labour as inputs: $Y_t = T_t \cdot K_t^{\beta} \cdot L_t^{1-\beta}$. The Cobb-Douglas production function on the one hand offers computationally very plausible unity elasticity of substitution on the other hand in comparison with the more general CES production function it offers less degree of freedom for the calibration exercise. Since population growth is assumed to be zero in the long-run, the share of capital in production is β and the steady-state capital growth rate is g, it is easy to derive that the percentage change in technological progress is $(1-\beta)\cdot g$.

There are two more equations of the steady-state model that are not derived directly from the dynamic equations. The steady-state trajectories for government

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[4] In that case deriving the corresponding steady-state model is straightforward and it can be obtained by 'deleting' all leads and lags in all equations.

debt and net foreign assets, similarly as it has been done for the Canadian QPM model Black et al (1994) and Coletti et al (1996), are derived from the assumption that the government debt to GDP ratios resp. NFA to GDP ratios are constant in the long-run.

In order to derive the steady-state equations for nominal public lending and net foreign asset position, let's take a first derivative of the shares of these variables to nominal GDP and let's use basic national accounts identities to obtain the final steady-state specifications.

$$\left(\frac{\mathrm{GDN}_t}{\mathrm{YEN}_t}\right)' = \frac{\mathrm{GDN}' \cdot \mathrm{YEN}_t - \mathrm{YEN}_t{}' \cdot \mathrm{GDN}_t}{\mathrm{YEN}^2} = \frac{-\mathrm{GLN}_t}{\mathrm{YEN}_t} - \frac{\mathrm{YEN}_t{}'}{\mathrm{YEN}_t} \cdot \frac{\mathrm{GDN}_t}{\mathrm{YEN}_t} = 0$$

where: GDN = nominal public debt;
YEN = nominal GDP;
GLN = nominal public net lending

Since $\frac{\mathrm{YEN}_t{}'}{\mathrm{YEN}_t} = (1+g)*(1+\overline{\pi})-1$, it directly follows that

$$\mathrm{GLN}_t = \frac{-\mathrm{GDN}_t}{(1+g)*(1+\overline{\pi})-1}$$

The steady-state equations for net foreign assets and net factor income from abroad are derived analogously.

3 Data and calibration

3.1 Data

This section is devoted to description of the Czech and foreign macroeconomic and financial data at quarterly frequency used for the model and the calibration technique applied.

It is important to note that due to the split of Czechoslovakia in 1993, the earliest data observations for most macroeconomic data for the Czech Republic are available only since 1993. The most important quarterly data for the model, the real and nominal GDP and its components, are dated from 1995 with the same base year.

The following table contains all model variables and indicates the main data source in the case when data were available or clearly states if any of the data values were calibrated.

The main data source for the model is, of course, the Czech Statistical Office (CZSO). We accounted for even more serious data limitation for public sector related data as in the case of the already mentioned GDP series. In order to have mutually stock-flow consistent data series for the model, all public sector data had to be obtained in the ESA 95 methodology. The CZSO, however, has released those data only at a yearly frequency and with a substantial delay. All public sector data, therefore, were available to the author only for the period of 1995–2000.

All balance of payments (BOP) related data are collected and released by the Czech National Bank (CNB). Similarly, the main source for all domestic financial data, including domestic nominal interest rates and exchange rate, is the CNB. It is important to note that the nominal exchange rate in the model is identical to the (converted euro equivalent of the) nominal exchange rate of the Czech crown against the DEM for the period before 1999 and the nominal exchange rate against the euro since the beginning of 1999.

Foreign data were obtained from two main sources. The OECD GDP deflator, short-term interest rates in the EMU (and in Germany for the pre-EMU period), and the Eurozone's real GDP could be found in the ECB's Monthly Bulletin. World commodity prices are identical with the HWWA Raw materials index from the from the Institute fur Wirtchaftsforschung database.

Table 1. **Data description**

Model	Explanation	Source	Data
A	Asset wealth	calculated	Appendix 1
C	Real consumption	CZSO	CZSO-GDPR, ESA 95: P31
CA	Current account	CNB	CNB-BOP, raw 13
CG	Real public consumption	CZSO	CZSO-GDPR
DD	Domestic demand	calculated	from table CZSO-GDPR
e	Nominal exchange rate of the Czech koruna	CNB	CNB-XR
g	Steady-state real growth rate	calibrated	–
GCN	Nominal public consumption	CZSO	CZSO-GDPN, ESA 95: P3
GDN	Nominal public debt	CZSO	Data obtained from Ministry of Finance
GIN	Nominal public investment	CZSO	Data obtained from Ministry of Finance ESA 95: P5
GLN	Nominal net lending	CZSO	Data obtained from Ministry of Finance ESA 95: B9
GOY	Nominal public other income	calculated	Appendix 1
GYN	Nominal public disposable income	calculated	Appendix 1
I	Real investment	CZSO	CZSO-GDPR, ESA 95: P51
IG	Real public investment	calculated	from GIN and PI, see Appendix 1
INN	Nominal public interest outlays	CZSO	Data obtained from Ministry of Finance, ESA 95: D.4
K	Fixed capital stock	CZSO	Obtained in the Czech National Bank
ΔKI	Change in inventories	CZSO	CZSO GDPR, ESA 95: P52+P53
KI	Inventories	CZSO	CZSO-INV, Table M16
N	Labour force	CZSO	CZSO-LAB, Table 10A
L	Labour demand	CZSO	CZSO-LAB
M	Imports	CZSO	CZSO GDPR, ESA 95: P7
NFA	Net foreign assets	calculated	from CA, see Appendix 1
NFN	Net factor income from abroad	calculated	NFA and R*
P	GDP deflator	CZSO	CZSO-GDPN/CZSO-GDPR, ESA 95: P6
PC	Consumer price index	CZSO	CNB-CPI
PC*	World commodity prices	HWWA	Raw materials index, 1990=100, USD
PF	GDP deflator at factor cost	calculated	P and τ^{indir}
P*	OECD GDP deflator	ECB	ECB Monthly Bulletin, Table 5.1.c1/5.1/c10
PM	Import price deflator	CZSO	CZSO-GDPN/CZSO-GDPR, ESA 95: P7
PI	Investment deflator	CZSO	CZSO-GDPN/CZSO-GDPR, ESA 95: P51
PX	Export price deflator	CZSO	CZSO-GDPN/CZSO-GDPN, ESA 95: P6
π	Quarterly inflation rate	calculated	PC
$\overline{\pi}$	Quarterly inflation target	calibrated	–
r	Czech short-term real interest rate	calculated	R and π
r*	Foreign short-term real interest rate	calculated	R* and P*
R	Czech nominal interest rate	CNB	CNB-INT
R*	EMU nominal interest rate	ECB	ECB Monthly Bulletin, Table 3.1. c3
T	Technical progress	calibrated	–
TAX	Direct taxes	CZSO	ESA 95: D.5+D61
τ^{dir}	Direct tax rate	calculated	TAX and YEN
τ^{indir}	Indirect tax rate	calculated	TIN and YEN
TIN	Indirect taxes	CZSO	Data obtained from Ministry of Finance, ESA 95: D2-D3
TRF	Public transfers	CZSO	Data obtained from Ministry of Finance, ESA 95: ESA 95: D62+D7
U	Unemployment rate	CZSO	CZSO-ETC, Table 18
$\bar{U}$	NAIRU	calibrated	–
WIN	Nominal wage sum	CZSO	Obtained in the Czech National Bank
WN	Nominal wages per employee	calculated	WIN and L
χ	Equity premium	calibrated	–
X	Exports	CZSO	CZSO GDPR, ESA 95: P6
Y	Real GDP	CZSO	CZSO GDPR, ESA 95: P3
Y*	EU real GDP	ECB	ECB Monthly Bulletin, Table 5.1 c17
YDN	Nominal private disposable income	calculated	See Appendix 1 (identities)
YEN	Nominal GDP	CZSO	CZSO-GDPN, ESA 95: P3
YFN	Nominal GDP at factor costs	calculated	Y and τ^{indir}

Abbreviations used for the main data sources:

CZSO-GDPR = http://www.czso.cz/eng/redakce.nsf/i/gdp_time_series, select table Gross Domestic product by Type of Expenditure at 1995 constant prices;

CZSO-GDPN = http://www.czso.cz/eng/redakce.nsf/i/gdp_time_series, select table Gross Domestic Product by Type of Expenditure at current prices;

CNB-XR = http://wdb.cnb.cz/cnbeng/KURZY.K_PRUM_F_ENG.show, select historic averages of the CZK nominal exchange rates against the EUR and DEM;
CNB-BOP = http://wdb.cnb.cz/cnbeng/docs/BALOFPAY/PB_EN.XLS
CNB-INT = http://www.cnb.cz/en/stat_mb.php, select average interest rates;
CNB-CPI = http://www.czso.cz/csu/edicniplan.nsf/xls.gif
CZSO-LAB = http://www.czso.cz/eng/edicniplan.nsf/p/3104-03, Table 10A
CZSO-ETC = http://www.czso.cz/eng/edicniplan.nsf/p/1404-03
CZSO-INV = http://www.czso.cz/eng/edicniplan.nsf/p/5005-02, Table M16

3.2 Calibration

Given the quite serious data limitations mentioned above, no standard estimation techniques could be applied to obtain reliable econometric estimates for the parameters of the model. The main criteria for the model calibration, therefore has been to obtain reasonable dynamic properties when the model is run on real data as opposed to purely artificial values. In other words, the calibration values of parameters aimed at minimising the volatility of the main macroeconomic variables for generating a baseline scenario on real data and at the same time to obtain plausible overall properties of the model judged by some impulse response results obtained for selected shocks. For those equations with at least some available data the sum of square of residuals were minimised on a constrained parameter set by limiting the coefficient values to exhibit theoretically correct sign or being within a theoretically justified range. This concerns especially trade and price equations. Of course, the reliability of these estimates is relatively low given this is a single equation calibration technique.

As it has been mentioned earlier, most quarterly time series in the Czech Republic are available since 1994–1995, therefore the calibration of the model is based on maximally 6–7 years of data. Data for the public sector in the ESA 95 methodology were available only at yearly frequency for the period 1995–2000.

Let’s start the description of the calibration by pinning down the small number of parameters that are entering only into the steady-state model only. The steady-state growth rate g was set to 3% p.a. The choice is based on the assumption that the Czech Republic would grow at a higher rate than its main trading partners for a long enough time period due to the real convergence of the country to the EU. The inflation target was chosen at a broadly accepted 2% level. Given the serious data limitations regarding the level of the capital stock, the calibration of the production function relied more heavily on determining the income share of labour. That has been directly calculated from the steady-state version of the wage equation. This shortcut could be done due to the relatively reliable statistics on the nominal wage sum in the Czech Republic as opposed to capital stock statistics. Subsequently the capital stock series have been calculated based on available investment data and the assumption that the depreciation rate of the capital stock is 4% p.a.

All other parameters of the model are based on the calibration of the dynamic model, of course by simultaneously taking into account the overall properties of the steady-state model. Let's start with the calibration of the consumption function. There has been a relatively little room for changing the properties of the micro-optimisation based consumption function, since only two deep parameters could be changed. The first of them, the discount factor that has been calibrated to 0.99, the second, the constant probability of death of the representative consumer, was set to 0.0125. Given that the model is based on quarterly data, this choice approximately means an average 40 working life for a representative consumer[5]. A straightforward implication of the considered consumption function is that since no habit formation has been incorporated into the model, consumption exhibits less inertia than available consumption data would suggest. Future incorporation of habit formation into the consumption function would mitigate the problem of too jumpy reaction of consumption to shocks. In comparison with the consumption function the calibration of the capital stock equation was somewhat easier in that two adjustment cost parameters, a_1, b_2 and the equity premium χ could be changed to obtain realistic dynamic properties for investment. Parameter b_1 was set to 0.98 in order to minimise the implied volatility of investment. The values of $a_1 = 112$ and $\chi = 0.014$ have been obtained by experimenting with various adjustment cost values to obtain reasonable baseline solution of the model by starting the solution from real data[6]. The calibrated values of adjustment costs in the labour and inventory demand functions, the adjustment costs related to price adjustments and the probability of changing wage contracts at the representative firm level[7], similarly as in the previous case, were obtained by experimenting with alternative calibration values. The low level of adjustment cost in the inventory demand equation ensures that inventories act as a buffer since inventories they adjust quickly in case of any shock. The deep parameter values set for these equations are listed in Table 2 below. The calibration of the coefficients of import equation[8] is based on a simple constrained optimisation that

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[5] This approximation is based on the assumption that a 50 % of the representative consumer's working life is already gone.

[6] The choice of the deep parameter values of the model has got a strong influence on how large is the initial jump of the forward-looking variables of the model (such as consumption, investment, exchange rate, etc) in the initial quarters of the solution period.

[7] Coefficient η quantifying the impact of the unemployment gap in the wage demand equation was set to 8 in order to model a relatively fast response of wages to the cyclical position of the economy.

[8] Given the assumed Cobb-Douglas basket division between domestically produced and imported consumption, investment goods and the constant share of reexported imported goods in total imports and the microeconomic optimisation of representative agents the import shares of individual national account groups are identical with the share of import prices in the corresponding price indices.

aimed at minimising the sum of square residuals under the assumption that the import share of consumption and investment goods and the share of re-exported imported goods lies within a plausible range. The resulting 21% import share of consumption goods in total consumption, the 42% share in total investment and the more than 67% share of re-exports of imported goods are consistent with the large openness of the Czech economy. The calibration of the myopic Taylor-type monetary policy rule reflects significant inertia in short-term interest rate setting by assuming a 50% weight put on lagged short-term interest rates. The coefficients of the inflation resp. NAIRU-gap (values 2.1 and 0.1 respectively) were set to stabilise the model and at the same time not to be too aggressive in terms of inflation or employment stabilisation[9]. The parameters of the fiscal policy rule (0.3 on net public lending to GDP and 0.05 on public debt to GDP) are ad hoc at the moment. The parameter choices, however, ensure that fiscal policy has a stabilising effect over the economic cycle and simultaneously it ensures sustainable public debt position relative to GDP.

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[9] Of course, it is possible to fine-tune the policy rule by founding a calibration of the rule that would minimise the standard deviation of selected macroeconomic variables such as inflation output or employment, etc.

Table 2. **The deep parameter values of the model equations**

Parameter	**Value**	**Description**
g	0.0075	Steady-state growth rate
$\bar{\pi}$	0.005	Inflation target
β	0.49	Income share of capital
δ	0.012	Depreciation rate of the capital stock
χ	0.014	Equity premium
b	0.3	Adjustment cost parameter in the labour demand equation
a_1	112	Adjustment cost parameter in the capital accumulation equation
b_1	0.998	Adjustment cost parameter in the capital accumulation equation
ρ	0.99	Discount factor
q	0.5	The probability of changing the existing wage contracts
η	6.5	Coefficient of the NAIRU gap in the wage equation
a	0.15	Adjustment cost in the price equation
p	0.0125	Probability of death of the representative consumer
γ	0.79	The share of domestic value added in consumption
κ	0.58	The share of domestic value added in investment
θ	0.67	The share of re-exported goods in total imports
$\bar{\varpi}$	0.1	Adjustment cost parameter in the inventory demand equation
ε^X	0.6	Real exchange rate elasticity of exports
Ω^R	0.5	Parameter determining the level of inertia of short-term interest rates in the policy rule
ϕ^{INF}	2.1	Parameter measuring the responsiveness of the policy rate on the deviation of inflation from the target
ϕ^U	–0.1	Parameter measuring the responsiveness of the policy rate on the deviation of the unemployment rate from the NAIRU
$\alpha^{GDN/YEN}$	0.005	Parameter of the fiscal policy rule determining the responsiveness of the rule to the share of nominal public debt in GDP
$\beta^{GLN/YEN}$	0.2	Parameter of the fiscal policy rule determining the responsiveness of the rule to the share of nominal public net lending in GDP
μ_1	0.06	The share of real public investment in real GDP
μ_2	0.2246	The share of real public consumption in real GDP
μ_3	0.03	The share of nominal public other income in nominal GDP
μ_4	0.2	Parameter value for the transfer equation
μ_5	0.2	Parameter value for the transfer equation

4 Policy experiments related to the Czech Republic's EMU accession

The main goal of this section is to illustrate how the structural model based on optimising agents described in the previous two sections can be applied to address current policy issues related to the Czech Republic's pre-EMU accession phase. Since the timing of the Czech Republic's EMU accession is expected to be no earlier than 2009, there are two policy challenges that must be met in the interim period. First, the currently applied inflation-targeting regime requires a conduct of monetary policy based on a floating exchange rate regime. Therefore policy decisions in coming years still will have to be based on a model framework that enables a qualified assessment of alternative monetary policy decisions. Second, the expected participation of the Czech Republic within the ERM II raises an important policy question regarding the 'optimal' entry level of the nominal exchange rate and simultaneously it requires a sensitivity analysis related to the risks of being off the 'right' entry level.

Since the model framework introduced above is based on a floating exchange rate regime, it is an appropriate framework for addressing inflation targeting related policy questions. In order to be able to consider policy choices under a fixed exchange rate regime, an alternative – fixed exchange rate version – of the above presented model framework has been developed. There were made only a few changes in the floating exchange rate version of the model to obtain the alternative fixed exchange rate version. First, the Taylor-type interest rate rule (E 26) has been replaced by the usual interest rate equality $R_t = R_t^*$, equating domestic and foreign short-term money market returns. Second, the uncovered interest rate parity condition determining the nominal exchange rate was transformed into a simple relationship $e_t = e_t^{tar}$ that fixes the nominal exchange rate e_t at a target level e_t^{tar} decided upon by the authorities. The third change in the model structure is related to the way the model is solved. It is worth noticing that in the floating exchange rate version of the model the level of the real exchange rate in the steady-state is pinned down by equation (E 16) determining export volumes. In the fixed exchange rate version of the model – given the nominal exchange rate is at a constant targeted level, it is the price level PC_t that is determined directly from the export volume equation.

To illustrate how the models with the two alternative policy regimes can be used for analysing policy questions related to the Czech Republic's pre-EMU phase, the remaining part of this section will be devoted to the analysis of impulse response results related to two selected policy experiments. First, the impact of a 100 basis points shock to the level of foreign demand for the most important model variables is considered for a period of 8 quarters. The experiment is carried out for both fixed and flexible exchange rate versions of the model. The second policy experiment is even more directly related to the Czech Republic's anticipated EMU accession. The fixed exchange rate version of the model is used for quantifying the dynamic response of the model to a 1% depreciation in the targeted level of the nominal exchange rate. As such, the experiment illustrates how can the model be used for analysing the uncertainty related to the determination of the Czech koruna's entry level into the EMU. The final experiment aims at quantifying the impact of an anticipated 100 basis point shock to the policy rate for the period of 8 quarter.

4.1 Policy experiments 1 and 2: an anticipated 100 basis points shock to the level of foreign demand for the period of 8 quarters

Since the Czech Republic is an open economy, with crucial trade links to the EU and to many accession countries in the region, one of the key policy questions in the past has been the assessment of the impact of the change in foreign demand for Czech goods. The impact of the cyclical position of main trading partners on Czech domestic conditions is expected to be even more crucial after introducing the euro in the Czech Republic, since domestic monetary policy will not be at the authorities' disposal as one of the main macroeconomic stabilisation tools. Therefore, the anticipated demand shocks were generated for both fixed and flexible exchange rate versions of the model. Including both impulse response results for selected macroeconomic end financial variables into one graph enables the comparison of the dynamic response of the model for the two alternative policy regimes.

The impulse response results are depicted in Appendix 2 below. The anticipated foreign demand shocks (generated for 8 quarters) result in a small initial increase in output. This positive effect, however, is relatively short lived and it is directly linked to the temporary improvement of the net exports induced by the expected positive foreign demand shock. In both policy regimes real consumption and investment gradually fall bellow their equilibrium level. The negative impact of the shock, however, is deeper in the case of the fixed exchange rate regime compared with the IT framework. The transmission channels through which the alternative policy regimes eliminate the impact of these shocks can largely explain the difference in the dynamic response of consumption and investment to these shocks. The graphs in Appendix 2 show that in a floating exchange rate regime the relatively modest increase in short-term interest rates is sufficient for achieving considerably smaller inflation than in the fixed exchange rate regime. This is accomplished through nominal exchange rate by reducing import price inflation. At the same time, within the IT framework the real exchange rate channel eliminates the positive impact of the shocks on net exports faster compared with the fixed exchange rate regime. To sum up, the simultaneous effect of the falling contribution of net exports to GDP caused by real appreciation, the gradually more restrictive macroeconomic environment in terms of growing real interest rates and the fact that the shocks are anticipated by forward-looking agents are the main explanations for the gradual fall and subsequent return to equilibrium in both consumption and investment. The fact, that the shock is temporary and anticipated explains the almost negligible impact of the shocks on real GDP. Employment, since it is determined by inverted production function, follows very much the pattern of GDP (conditional on the capital stock). Finally, the stabilising role of fiscal policy in a fixed exchange rate regime can be well understood by noticing that the applied fiscal rule generates considerably larger fall in government debt in order to stabilise the economy after the shock compared with the situation when monetary policy is active.

4.2 Policy experiment 3: an unanticipated 100 basis point shock to the policy rate for the period of 8 quarters

The impulse response results depicted in Appendix 3 imply a standard transmission mechanism of a small open economy. The unanticipated series of shocks to the nominal interest rates result in a fall of output below the baseline for a period of 8 quarters. Consumption falls even deeper than output. It is worth noting that the dynamic response of consumption understandably closely follows the path of short-term real interest rates. Investment falls mildly below the baseline during the first year followed by strong rise in investment activity in approximately the next 8 quarters. Exports decline initially mirroring closely the real exchange rate development. Imports, in addition to the real exchange rate appreciation, reflect domestic demand conditions as well. The initial fall in GDP results in a decrease in demand for labour of a comparable magnitude, again, explained by labour demand being derived from the inverted production function. Fiscal policy judged by the initial build-up of the government debt, similarly as in the case of monetary policy, acts as an economic stabiliser. Inflation expressed by the GDP deflator falls below inflation target as a result of employment being below baseline. CPI inflation, in addition to the demand effect, incorporates the impact of the appreciating nominal exchange rate.

4.3 Policy experiment 4: an 1% depreciation in the targeted level of the nominal exchange rate

Assessing the 1 percentage point depreciation of the targeted level of the nominal exchange rate is one of the most interesting policy experiments directly related to the Czech Republic's EMU accession. This exercise illustrates how can the model be used for quantifying the dynamic response of main macroeconomic variables to the choice of alternative entry levels of the Czech koruna/euro exchange rate by the Czech authorities.

The model simulation results, aiming at quantifying the effects of a 1% depreciation in the target level of the nominal exchange rate, are included into Appendix 4. The results, again, are very intuitive and highlight the main channels of the transmission mechanism in a fixed exchange rate regime compared with the previous results obtained for a model with a floating exchange rate regime. The immediate impact of the 1% depreciation in the target level of the nominal exchange rate is real depreciation of the real exchange rate and fall in the real interest rate. Since the level of the real exchange is weaker than that of the baseline, exports increase. Imports increase initially as well since the positive demand effect of the real depreciation more than eliminates its negative impact on price competitiveness. Using analogous reasoning as in the previous case the below-the-baseline level of real interest rates boost both consumption and investment and the jump in employment reflects solely output being above long-term equilibrium. The stimulating effect of the depreciation is accompanied by a jump in CPI inflation and inflation measured by the GDP deflator. The former is of course slightly higher given the additional direct import price effect on consumer price inflation. Government reduces its debt in order to mitigate the boost phase of the economic cycle caused by the depreciation. All in all, the model simulations illustrate that the presented model framework is suitable for assessing the impact of any misalignment of the of alternative entry levels of the Czech koruna/euro exchange rate prior to fixing the exchange rate. Moreover, the exercise can be repeated for alternative calibrations of the model to take into account the parameter uncertainty resulting from very short time series available for calibration of the model.

5 Summary

The main goal of this paper has been to calibrate a micro-optimisation based model for the Czech economy based on an euro area -wide model (EDGE), formerly developed at the Research Department of the Bank of Finland. The theoretical structure of the model has been slightly changed in terms of including a micro-optimisation based trade and price block. The structure of the paper and the theory that it is based on has been described in Section 2. In order to calibrate the model on the Czech economy, a database necessary for this exercise has been collected. The data set and main data sources have been described in Section 3 of the paper. The calibration of the presented model, given the very short time series available, has been achieved on the basis of evaluating two criteria. First, the calibration relied on basic characteristics of the Czech economy (labour and capital shares, basic national accounts characteristics, price information, etc.) Second, it aimed at obtaining a broadly 'reasonable' baseline when the model is solved on real data. Third, impulse response results were evaluated to assess whether the magnitudes of dynamic response of the main model variables to selected shocks are in line with the small open economy assumption and basic intuition regarding the Czech economy. In order to be able to present that the model is already developed enough to address both issues related to the Czech Republic's pre-EMU accession phase and the period after that, two alternative versions of the model – based on fixed and floating exchange rate regimes – have been developed. Two impulse response analyses related to the shocks to foreign demand and the policy rate served as an example of a policy analysis carried out within an inflation-targeting framework. The former impulse response for a foreign demand shock has been repeated for the fixed exchange rate regime version of the model as well, in order to be able to compare the differences between the dynamic response of the main policy variables in the two alternative policy regimes. The last policy experiment aimed at quantifying the impact of a change in the target level of the nominal exchange rate within a fixed exchange rate framework in order to illustrate how the model can be used for the analysis of the introduction of the euro in the Czech Republic. The impulse response results presented in Section 5 confirm that the model exhibits realistic dynamic properties that are consistent with the small open economy assumption. As such, the model is expected to serve as an important policy analysis tool for quantifying both inflation targeting and EMU accession related questions in the Czech Republic in the near future.

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Appendix 1

The model equations

E1: Output

$$\mathrm{DYN}: Y_t = C_t + CG_t + I_t + X_t - M_t + \Delta KI_t$$

$$\mathrm{SS}: Y_t = T_t \cdot K_t^{\beta} \cdot L_t^{1-\beta}$$

E2: Technological progress

$$\mathrm{DYN}: T_t = T_{t-1} \cdot (1 + g \cdot (1+\beta))$$

$$\mathrm{SS}: T_t = T_{t-1} \cdot (1 + g \cdot (1+\beta))$$

E3: Labour Demand

$$\mathrm{DYN}: L_t = \frac{\rho}{1+b+\rho} \cdot E_t(L_{t+1}) + \frac{1}{1+b+\rho} \cdot L_{t-1} + \frac{b}{1+b+\rho} \cdot \left(\frac{Y_t}{T \cdot K_t^{\beta}} \right)^{\frac{1}{1-\beta}}$$

$$\mathrm{SS}: L_t = N_t \cdot (1 - U_t)$$

E4: Capital Accumulation

$$\begin{aligned}\mathrm{DYN}: \Delta \log K_t = {} & \frac{-\rho^2 \cdot b_1}{(\rho \cdot b_1 \cdot (1+b_1)+1)} \cdot E_t \Delta \log K_{t+2} \\ & + \frac{(\rho^2 \cdot b_1^2 + \rho \cdot (1+b_1))}{(\rho \cdot b_1 \cdot (1+b_1)+1)} \cdot E_t \Delta \log K_{t+1} \\ & + \frac{b_1}{(\rho \cdot b_1 \cdot (1+b_1)+1)} \cdot \Delta \log K_{t-1} + \frac{1}{a_1 \cdot (\rho \cdot b_1 \cdot (1+b_1)+1)} \cdot \\ & \left(\frac{PF_t}{PC_t} \cdot \left(\frac{\beta \cdot Y_t}{K_t} \right) - \left(\frac{(1+r_t) \cdot (1+\chi) \cdot (1+\delta) - 1}{(1+r_t) \cdot (1+\chi)} \right) \cdot \frac{PI_t}{PC_t} \right)\end{aligned}$$

$$
\begin{aligned}
\mathrm{SS}: \mathrm{const}_K = {} & \frac{-\rho^2 \cdot b_1}{(\rho \cdot b_1 \cdot (1+b_1)+1)} \cdot \mathrm{const}_K + \frac{(\rho^2 \cdot b_1^2 + \rho \cdot (1+b_1))}{(\rho \cdot b_1 \cdot (1+b_1)+1)} \cdot \mathrm{const}_K \\
& + \frac{b_1}{(\rho \cdot b_1 \cdot (1+b_1)+1)} \cdot \mathrm{const}_K + \frac{1}{a_1 \cdot (\rho \cdot b_1 \cdot (1+b_1)+1)} \cdot \\
& \left(\frac{PF_t}{PC_t} \cdot \left(\frac{\beta \cdot Y_t}{K_t} \right) - \left(\frac{(1+r_t) \cdot (1+\chi) \cdot (1+\delta) - 1}{(1+r_t) \cdot (1+\chi)} \right) \cdot \frac{PI_t}{PC_t} \right)
\end{aligned}
$$

where $\mathrm{const}_K = \log(1+g)$

E5: Nominal wages

$$
\begin{aligned}
\mathrm{DYN}: \frac{WINR_t}{L_t} = {} & \frac{1-q}{1+(1-q) \cdot (1-q) \cdot \tilde{\rho}} \cdot \frac{WINR_{t-1}}{L_{t-1}} \cdot (1+\pi_{t+1}^d) \\
& + \frac{(1-q) \cdot \tilde{\rho}}{1+(1-q) \cdot (1-q) \cdot \tilde{\rho}} \cdot E_t \frac{WINR_{t+1}}{L_{t+1} \cdot (1+\pi_t^d))} \\
& + \frac{q \cdot (1-(1-q) \cdot \tilde{\rho})}{1+(1-q) \cdot (1-q) \cdot \tilde{\rho}} \cdot \left[PF_t \frac{(1-\beta) \cdot Y_t}{N_t} \cdot (1-\eta \cdot (U_t - \overline{U}_t)) \right]
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{SS}: \frac{WINR_t}{L_t} = {} & \frac{1-q}{1+(1-q) \cdot (1-q) \cdot \tilde{\rho}} \cdot \frac{WINR_t}{L_t \cdot (1+g)} \cdot (1+\overline{\pi}) \\
& + \frac{(1-q) \cdot \tilde{\rho}}{1+(1-q) \cdot (1-q) \cdot \tilde{\rho}} \cdot E_t \frac{WINR_t \cdot (1+g)}{L_t \cdot (1+\overline{\pi}))} \\
& + \frac{q \cdot (1-(1-q) \cdot \tilde{\rho})}{1+(1-q) \cdot (1-q) \cdot \tilde{\rho}} \cdot \left[PF_t \frac{(1-\beta) \cdot Y_t}{N_t} \right]
\end{aligned}
$$

E6: Inflation measured in terms of the GDP deflator

$$
\begin{aligned}
\mathrm{DYN}: \pi_t^d = {} & \frac{1}{1+a+\tilde{\rho}} + \frac{\tilde{\rho}}{1+a+\tilde{\rho}} \cdot (1+E_t \pi_{t+1}^d) \cdot (1+\pi_t^d) \\
& + \frac{a}{1+a+\tilde{\rho}} \cdot \frac{WN_t \cdot L_t}{(1-\tau_t^{\mathrm{indirect}}) \cdot (1-\beta) \cdot Y_t} \cdot \frac{1}{P_t} \cdot (1+\pi_t^d)
\end{aligned}
$$

$$
\mathrm{SS}: \pi_t^d = \frac{P_t}{P_{t-1}} - 1
$$

E7: Consumption

$$
\begin{aligned}
\mathrm{DYN}:C_t = {} & \frac{1-p}{1-(1-p)\cdot(1-\theta\cdot(1-p))}\cdot\frac{E_t C_{t+1}}{(1+r_t)\cdot(1+\chi)} \\
& +\frac{p\cdot(1-\theta\cdot(1-p))}{1-(1-p)\cdot(1-\theta\cdot(1-p))}\cdot\left(\frac{A_{t-1}}{PC_t}+\frac{YDN_t}{PC_t}\right)
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{SS}:C_t = {} & \frac{(1-p)\cdot(1+g)}{1-(1-p)\cdot(1-\theta\cdot(1-p))}\cdot\frac{C_t}{(1+r_t)\cdot(1+\chi)}+\frac{p\cdot(1-\theta\cdot(1-p))}{1-(1-p)\cdot(1-\theta\cdot(1-p))} \\
& \cdot\left(\frac{A_t\cdot(1+g)\cdot(1+\bar{\pi})}{PC_t}+\frac{YDN_t}{PC_t}\right)
\end{aligned}
$$

E8: (Real) asset accumulation

$$
\begin{aligned}
\mathrm{DYN}:ASTR_t = {} & \frac{1}{(1+R_t/100)^{0.25}\cdot(1+\chi)}E_t\left(ASTR_{t+1}-GDNR_{t+1}-NFAR_{t+1}\right) \\
& +Y_t-\frac{WIN_t}{PF_t}-\frac{\delta\cdot PI_t\cdot K_{t-1}}{PF_t}+GDNR_t+NFAR_t
\end{aligned}
$$

$$
\begin{aligned}
\mathrm{SS}:ASTR_t = {} & \frac{1}{(1+R_t/100)^{0.25}\cdot(1+\chi)}E_t\left(ASTR_t-GDNR_t-NFAR_t\right)+Y_t-\frac{WIN_t}{PF_t} \\
& -\frac{\delta\cdot PI_t}{PF_t}\cdot\frac{K_t}{1+g}+GDNR_t+NFAR_t
\end{aligned}
$$

E9: Inventory demand

$$
\mathrm{DYN}:KI_t = k\cdot T_t\cdot L_t^{1-\beta}\cdot K_t^{\beta}-\frac{1}{\varpi}\cdot(Y_t-T_t\cdot L_t^{1-\beta}\cdot K_t^{\beta})+\frac{\rho}{\varpi}\cdot E_t(Y_{t+1}-T_{t+1}\cdot L_{t+1}^{1-\beta}\cdot K_{t+1}^{\beta})
$$

$$
\mathrm{SS}:KI_t = k\cdot Y_t
$$

E10: Export volumes

$$
\mathrm{DYN}:\log X_t = \log Y_t^{*}-\varepsilon^{X}\cdot\log\left(\frac{P_t}{PM_t}\right)
$$

$$
\mathrm{SS}:X_t = Y_t-(C_t+CG_t+I_t-M_t+\Delta KI_t)
$$

E11: Import volumes

$$\mathrm{DYN:M_t} = (1-\gamma)\cdot\left(\frac{\mathrm{PM_t}}{\mathrm{P_t}}\right)^{-1}\cdot \mathrm{C_t} + (1-\kappa)\cdot\left(\frac{\mathrm{PM_t}}{\mathrm{P_t}}\right)^{-1}\cdot \mathrm{I_t} + (1-\theta)\cdot\left(\frac{\mathrm{PM_t}}{\mathrm{P_t}}\right)^{-1}\cdot \mathrm{X_t}$$

$$\mathrm{SS:M_t} = (1-\gamma)\cdot\left(\frac{\mathrm{PM_t}}{\mathrm{P_t}}\right)^{-1}\cdot \mathrm{C_t} + (1-\kappa)\cdot\left(\frac{\mathrm{PM_t}}{\mathrm{P_t}}\right)^{-1}\cdot \mathrm{I_t} + (1-\theta)\cdot\left(\frac{\mathrm{PM_t}}{\mathrm{P_t}}\right)^{-1}\cdot \mathrm{X_t}$$

E12: Export prices

$$\mathrm{DYN:XTD_t} = \left(\mathrm{YED_t}\right)^{\theta}\cdot\left(\mathrm{MTD_t}\right)^{1-\theta}$$

$$\mathrm{SS:XTD_t} = \left(\mathrm{YED_t}\right)^{\theta}\cdot\left(\mathrm{MTD_t}\right)^{1-\theta}$$

E13: Import prices

$$\mathrm{DYN:PM_t} = \left(\mathrm{P_t}\right)^{\gamma}\cdot\left(\mathrm{e_t}\cdot \mathrm{P_t^*}\right)^{1-\gamma}$$

$$\mathrm{SS:PM_t} = \left(\mathrm{P_t}\right)^{\gamma}\cdot\left(\mathrm{e_t}\cdot \mathrm{P_t^*}\right)^{1-\gamma}$$

E14: Consumer price deflator

$$\mathrm{DYN:CPI_t} = \left(\mathrm{YED_t}\right)^{\gamma}\cdot\left(\mathrm{MTD_t}\right)^{1-\gamma}$$

$$\mathrm{SS:CPI_t} = \mathrm{CPI_{t-1}}\cdot(1+\overline{\pi}_t)$$

E15: Investment price deflator

$$\mathrm{DYN:ITD_t} = \left(\mathrm{YED_t}\right)^{\kappa}\cdot\left(\mathrm{MTD_t}\right)^{1-\kappa}$$

$$\mathrm{SS:ITD_t} = \left(\mathrm{YED_t}\right)^{\kappa}\cdot\left(\mathrm{MTD_t}\right)^{1-\kappa}$$

E16: Uncovered interest rate parity for the real exchange rate

$$\mathrm{DYN}: \mathrm{Q}_t = \mathrm{Q}_{t+1} \cdot \frac{1 + r_t^*}{1 + r_t}$$

$$\mathrm{SS}: \log(\mathrm{Q}_t) = (\log(\mathrm{X}_t) - \log(\mathrm{Y}_t^*))/\varepsilon^{\mathrm{X}},$$

E17: Net foreign assets

$$\mathrm{DYN}: \mathrm{NFA}_t = \mathrm{NFA}_{t-1} \cdot (e_t / e_{t-1}) + \mathrm{CA}_t$$

$$\mathrm{SS}: \mathrm{NFA}_t = \mathrm{NFA}_{t-1} \cdot (e_t / e_{t-1}) + \frac{\mathrm{CA}_t}{(1+g)\cdot(1+\bar{\pi}_t)-1}$$

$$+\left(\left(\frac{1+\mathrm{R}_t/100}{1+\mathrm{R}_t^*/100}\right)^{0.25} - 1\right)\cdot\frac{1}{(1+g)\cdot(1+\bar{\pi}_t)}$$

E18: Net factor income from abroad

$$\mathrm{DYN}: \mathrm{NFN}_t = \left(\left(1 + \frac{\mathrm{R}_t^*}{100}\right)^{0.25} - 1\right)\cdot \mathrm{NFA}_{t-1}$$

$$\mathrm{SS}: \mathrm{NFN}_t = \left(\left(1 + \frac{\mathrm{R}_t^*}{100}\right)^{0.25} - 1\right)\cdot \frac{\mathrm{NFA}_t}{(1+g)\cdot(1+\bar{\pi}_t)}$$

E19: Public interest outlays

$$\mathrm{DYN}: \mathrm{INN}_t = \left(\left(1 + \frac{\mathrm{R}_t}{100}\right)^{0.25} - 1\right)\cdot \mathrm{GDN}_{t-1}$$

$$\mathrm{SS}: \mathrm{INN}_t = \left(\left(1 + \frac{\mathrm{R}_t}{100}\right)^{0.25} - 1\right)\cdot \frac{\mathrm{GDN}_t}{(1+g)\cdot(1+\bar{\pi}_t)}$$

E20: Fiscal policy rule

$$\mathrm{DYN}:\tau_t^{\mathrm{direct}}=\tau_{t-1}^{\mathrm{direct}}+\alpha^{\mathrm{GDN/YEN}}\cdot(\mathrm{GDN}_t/\mathrm{YEN}_t-\psi)-\beta^{\mathrm{GLN/YEN}}\cdot$$
$$(\mathrm{GLN}_t/\mathrm{YEN}_t+\psi\cdot(\pi_{t-1}+g))$$

$$\mathrm{SS}:\tau_t^{\mathrm{direct}}=\mathrm{TAX}_t/\mathrm{YEN}_t$$

E21: Real public investment

$$\mathrm{DYN}:\mathrm{GIR}_t=\mu_1\cdot\mathrm{YEN}_t$$

$$\mathrm{SS}:\mathrm{GIR}_t=\mu_1\cdot\mathrm{YEN}_t$$

E22: Real public consumption

$$\mathrm{DYN}:\mathrm{CG}_t=\mu_2\cdot\mathrm{YER}_t$$

$$\mathrm{SS}:\mathrm{CG}_t=\mu_2\cdot\mathrm{YER}_t$$

E23: Public other income

$$\mathrm{DYN}:\mathrm{GOY}_t=\mu_3\cdot\mathrm{YEN}_t$$

$$\mathrm{SS}:\mathrm{GOY}_t=\mu_3\cdot\mathrm{YEN}_t$$

E24: Public transfers

$$\mathrm{DYN}:\mathrm{TRF}_t=(\mu_4\cdot\mathrm{U}_t+\mu_5)\cdot\mathrm{YEN}_t$$

$$\mathrm{SS}:\mathrm{TRF}_t=(\mu_4\cdot\mathrm{U}_t+\mu_5)\cdot\mathrm{YEN}_t$$

E25: Direct taxes

$$\mathrm{DYN}: \mathrm{TAX}_t = \tau_t^{\mathrm{direct}} \cdot \mathrm{YEN}_t$$

$$\mathrm{SS}: \mathrm{TAX}_t = \mathrm{GYN}_t + \mathrm{TRN}_t + \mathrm{INN}_t - \mathrm{TIN}_t - \mathrm{GOY}_t$$

E26: Monetary policy rule

$$\begin{aligned}\mathrm{DYN}: \mathrm{R}_t = {} & (1-\Omega^{\mathrm{R}}) \cdot \mathrm{R}_{t-1} + \Omega^{\mathrm{R}} \cdot 100 \cdot ((1+\mathrm{r}_t^{*})^4 \cdot (1+\pi_t)^4 - 1 \\ & + \phi^{\mathrm{INF}} \cdot (\mathrm{PCD}_t / \mathrm{PCD}_{t'-4} - (1+\overline{\pi})^4) - \phi^{\mathrm{U}} \cdot (\mathrm{U}_t - \overline{\mathrm{U}}_t))\end{aligned}$$

$$\mathrm{SS}: \mathrm{R}_t = 100 \cdot (1+\mathrm{r}_t^{*})^4 \cdot (1+\overline{\pi}_t)^4$$

Identities

$$\mathrm{YDN}_t = \mathrm{YFN}_t - \mathrm{TAX}_t + \mathrm{INN}_t + \mathrm{TRF}_t - \mathrm{GOY}_t + \mathrm{NFN}_t - \delta \cdot \mathrm{PI}_t \cdot \mathrm{K}_{t-1}$$

$$\mathrm{I}_t = \mathrm{K}_t - (1-\delta) \cdot \mathrm{K}_{t-1}$$

$$\mathrm{TIN}_t = \tau_t^{\mathrm{indirect}} \cdot \mathrm{YEN}_t$$

$$\mathrm{GYN}_t = \mathrm{TAX}_t + \mathrm{TIN}_t + \mathrm{GOY}_t - \mathrm{TRF}_t - \mathrm{INN}_t$$

$$\mathrm{CA}_t = \mathrm{X}_t \cdot \mathrm{PX}_t - \mathrm{M}_t \cdot \mathrm{PM}_t + \mathrm{NFN}_t$$

$$\mathrm{GDN}_t = \mathrm{GDN}_{t-1} - \mathrm{GLN}_t$$

$$\mathrm{GLN}_t = -\mathrm{GCN}_t - \mathrm{GIN}_t + \mathrm{GYN}_t$$

$$\mathrm{DD}_t = \mathrm{C}_t + \mathrm{CG}_t + \mathrm{I}_t + \Delta\mathrm{KI}_t$$

$$\mathrm{YFN}_t = \mathrm{Y}_t \cdot \mathrm{PF}_t$$

$$\mathrm{YEN}_t = \mathrm{Y}_t \cdot \mathrm{P}_t$$

$$\mathrm{PF}_t = \mathrm{P}_t \cdot (1-\tau_t^{\mathrm{indirect}})$$

$$r_t = \frac{\left(1 + \frac{R_t}{100}\right)^{0.25}}{1 + \pi_{t+1}} - 1$$

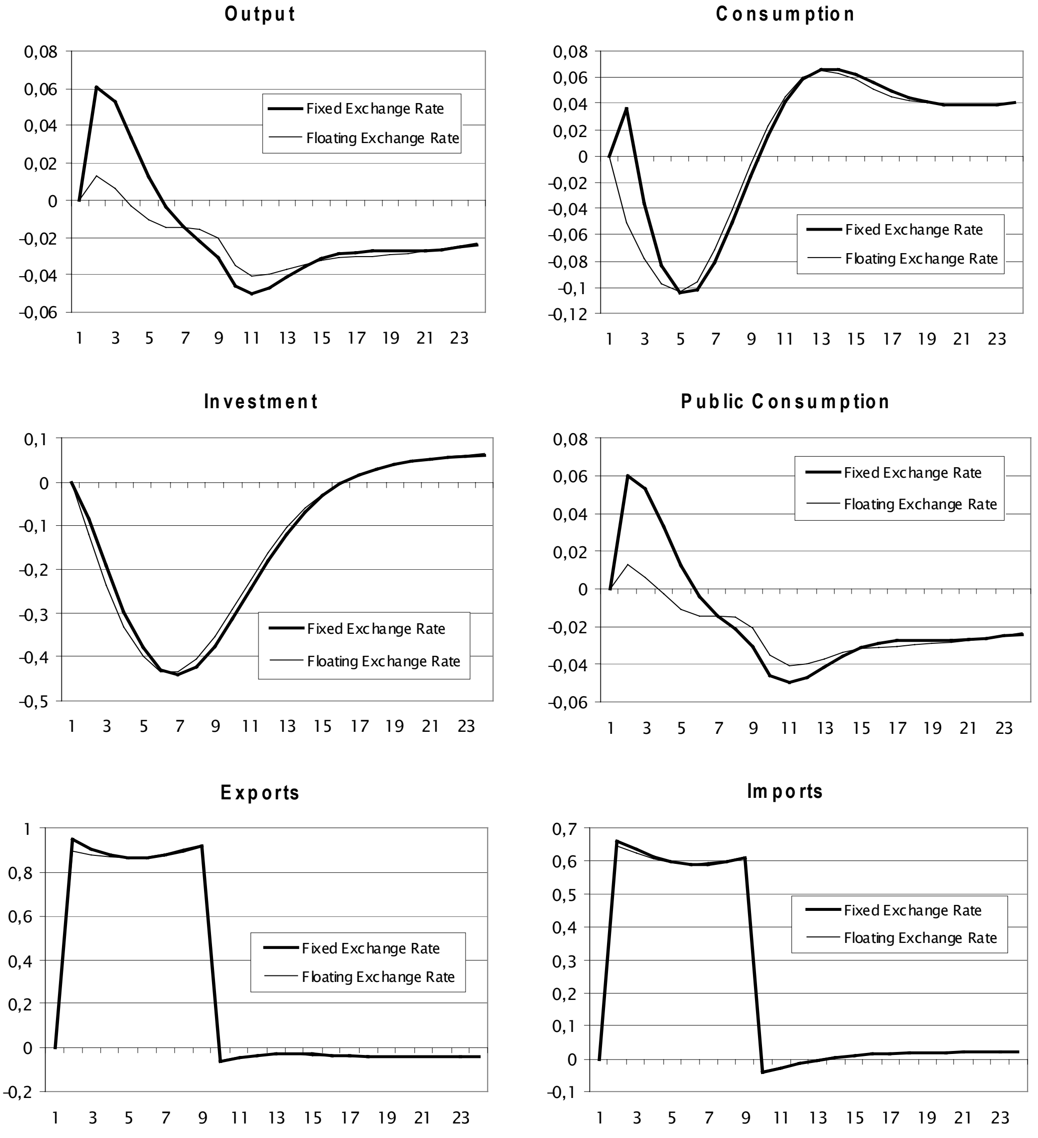
$$U_t = (N_t - L_t) / N_t$$

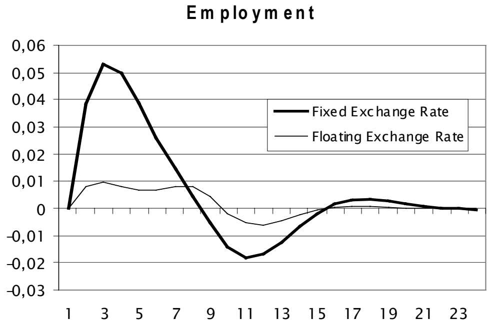
$$GCN_t = CG_t \cdot P_t$$

$$GIN_t = IG_t \cdot PI_t$$

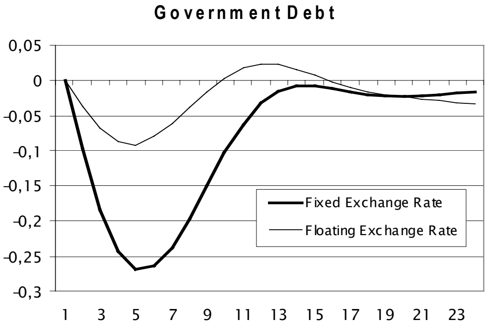
Appendix 2

Policy experiments 1 and 2: an anticipated 100 basis points shock to the level of foreign demand for the period of 8 quarters for fixed and floating exchange rate versions of the model

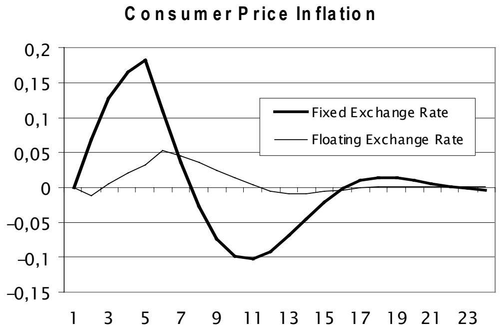




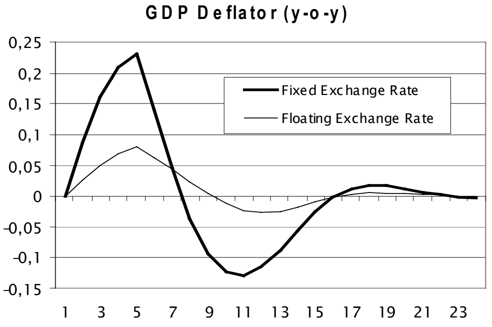
Employment



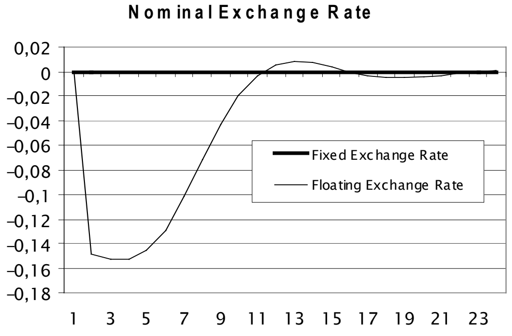
Government Debt



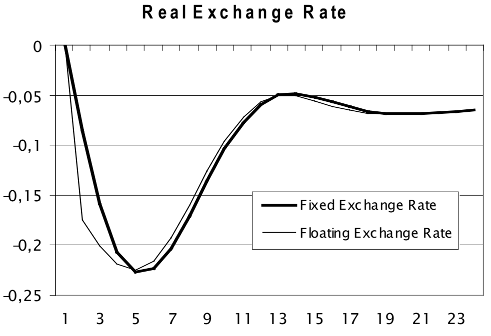
Consumer Price Inflation



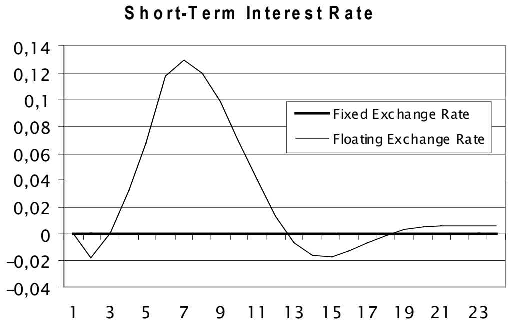
GDP Deflator (y-o-y)



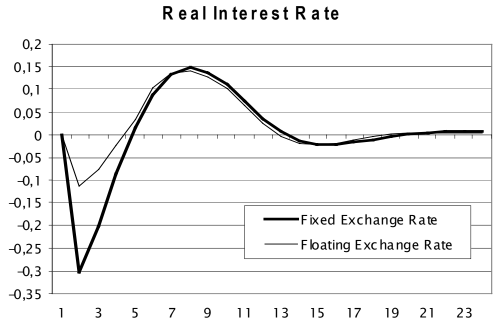
Nominal Exchange Rate



Real Exchange Rate



Short-Term Interest Rate

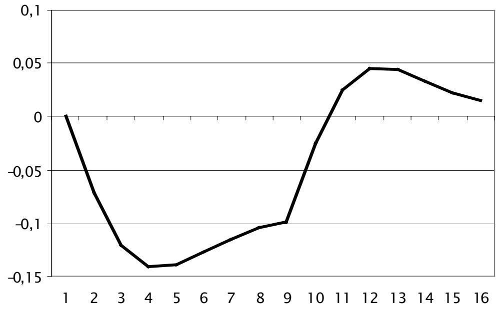


Real Interest Rate

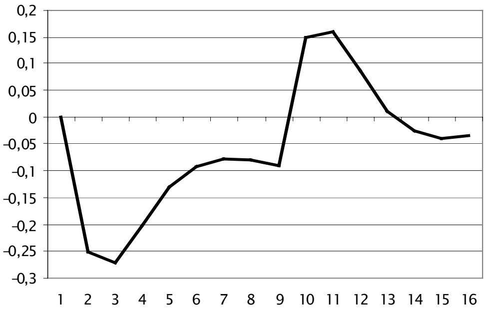
Appendix 3

Policy experiment 3: an unanticipated 100 basis point shock to the policy rate for the period of 8 quarters

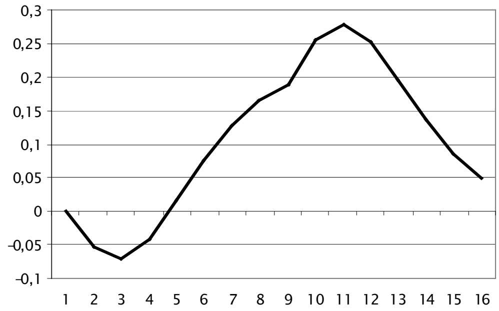
Output



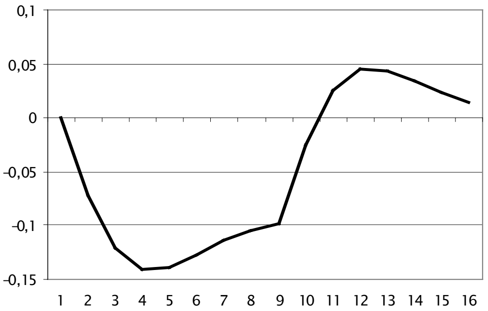
Consumption



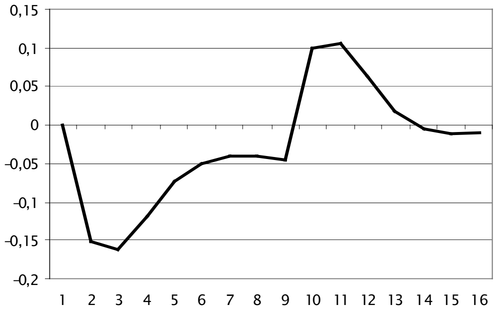
Investment



Public Consumption

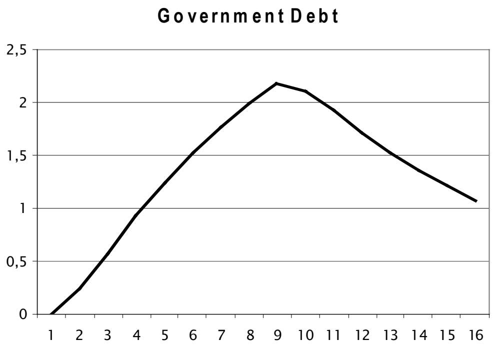


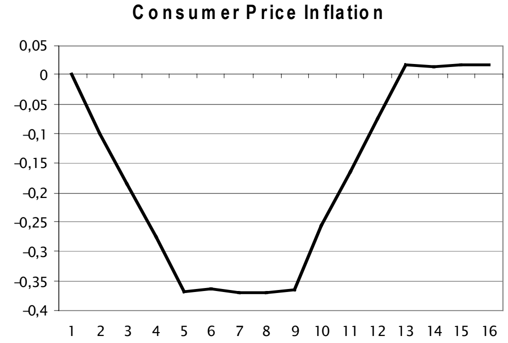
Exports

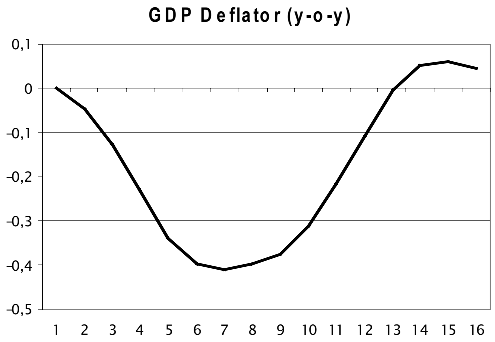


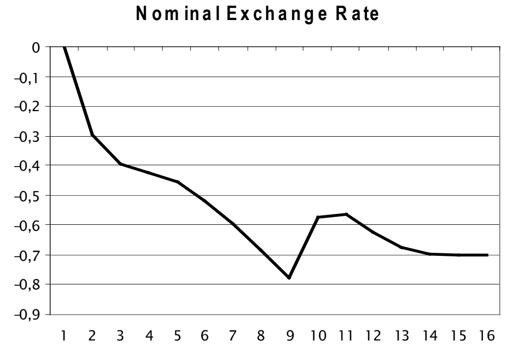
Imports

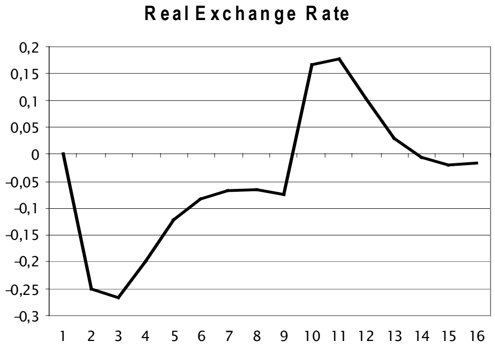

Employment

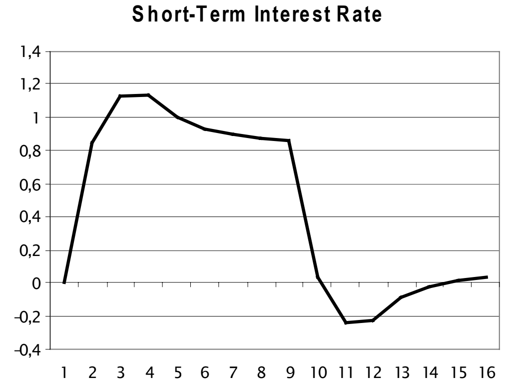

Government Debt

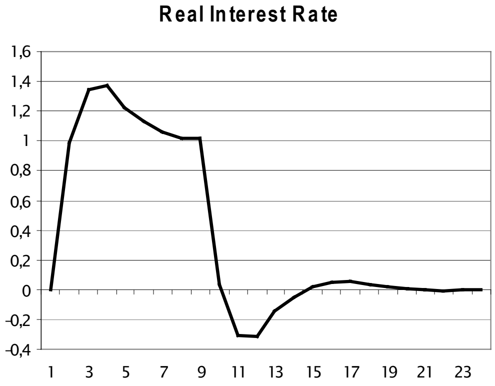

Consumer Price Inflation


GDP Deflator (y-o-y)


Nominal Exchange Rate

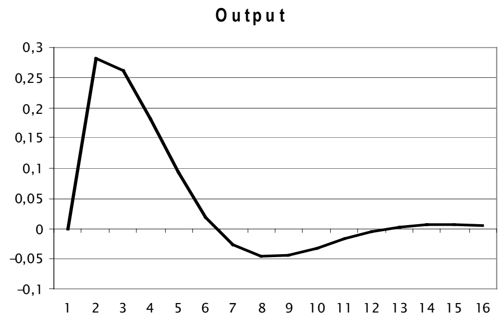

Real Exchange Rate

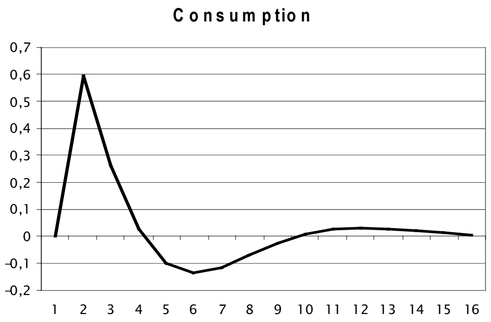

Short-Term Interest Rate

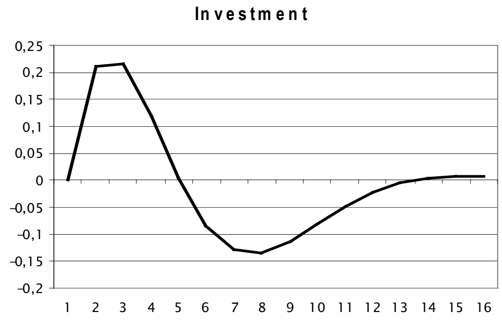

Real Interest Rate

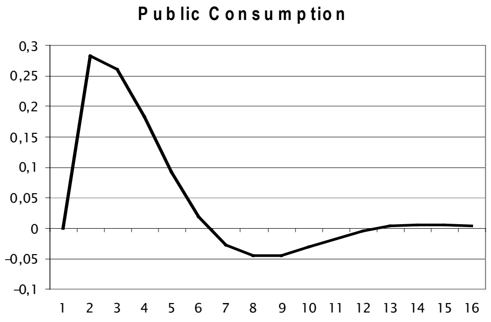
Appendix 4

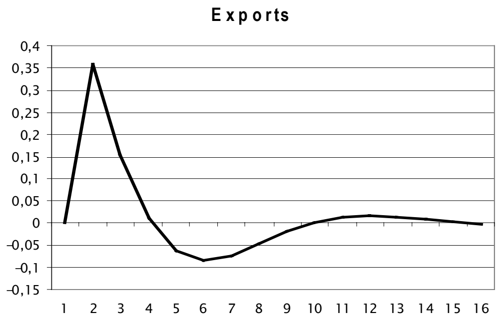
Policy experiment 4: an 1% depreciation in the targeted level of the nominal exchange rate

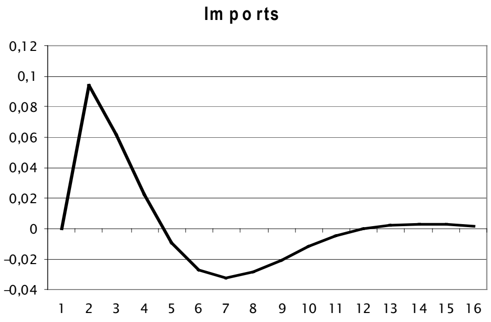


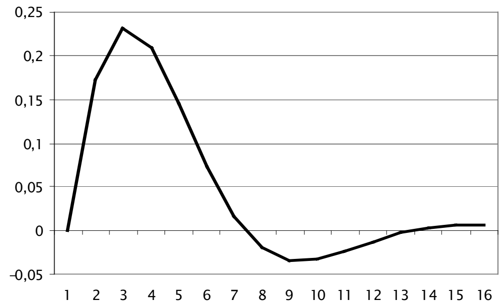




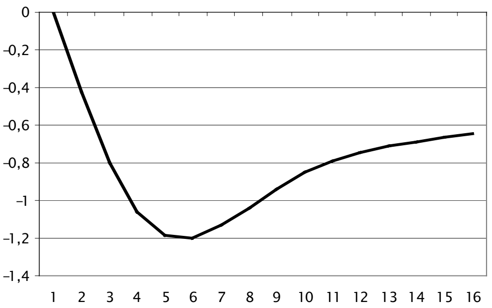




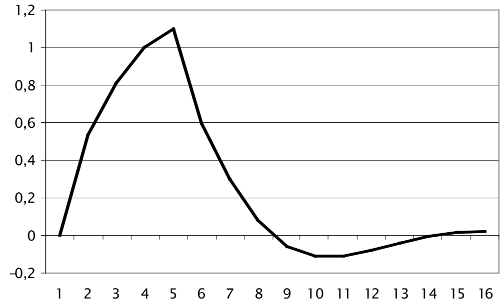




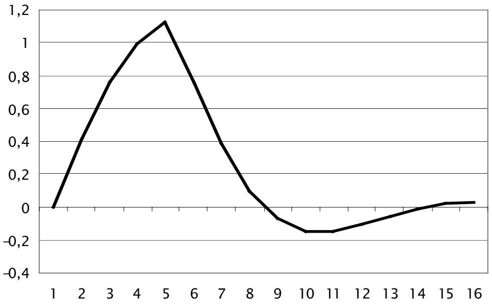
Employment



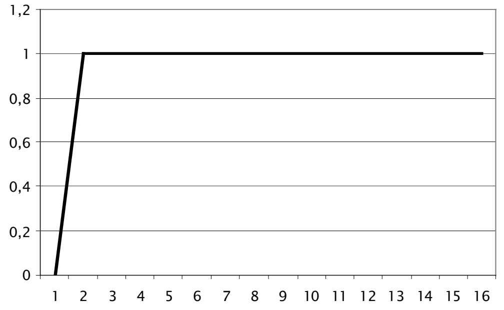
Government Debt



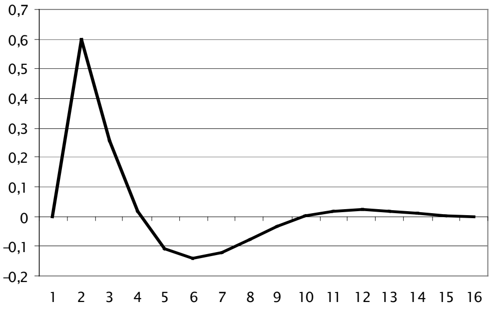
Consumer Price Inflation



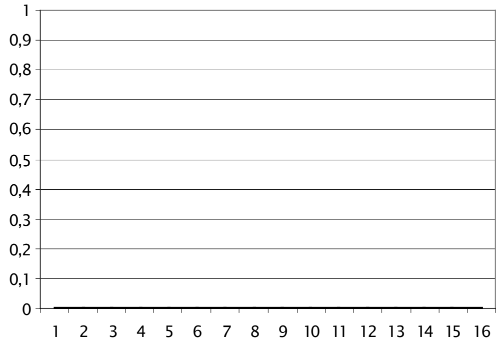
GDP Deflator (y-o-y)



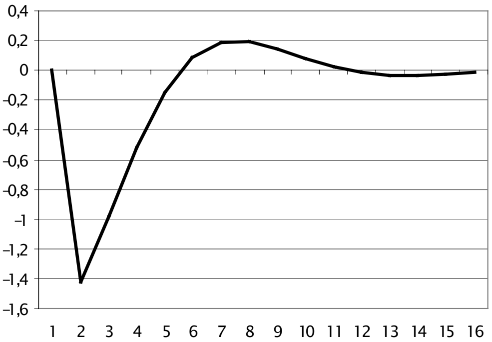
Nominal Exchange Rate



Real Exchange Rate



Short-Term Interest Rate



Real Interest Rate

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