Estimation of the Basic New Keynesian Model for the Economy of Romania

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2014

THE BUCHAREST ACADEMY OF ECONOMIC STUDIES

ESTIMATION OF THE BASIC NEW KEYNESIAN MODEL FOR THE ECONOMY OF ROMANIA

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Abstract

In this paper a simple New-Keynesian DSGE model is derived and then estimated for the Romanian economy. Some parameters are calibrated and others are estimated on Romania's data using Bayesian techniques. The model fit is evaluated and the effects of different types of shock are presented.

I) Introduction

Dynamic Stochastic General Equilibrium (DSGE) models have become over years the workhorse of modern macroeconomics. Most central banks around the world adopted this DSGE framework for policy analysis and forecasts.

Before the revolution of Kydland and Prescott (1982), macroeconomic models were criticized for their lack of microeconomic foundations. At the root of DSGE models stands the *Real Business Cycle* (RBC) model which derives aggregate relations for the economy from the optimizing decisions of the individual agents. The term *Real* in RBC theory derives from the fact that only real shocks can affect the economy (e.g. technological shock) wile monetary shocks doesn't influence the economy. Thus, the advantage of DSGE models lies in the ability to model individual agents' behavior, fact that doesn't make them subject to Lucas' critique. The problem with RBC models was that they proved to be an empirical failure: it implies that monetary disturbances do not have real effects; it rests on large aggregate technology shocks for which there is little evidence; and its predictions about the effects of technology shocks and about business-cycle dynamics appear to be far from what is observed[1]. As a result, new features were added to the RBC model. One such feature is incomplete price flexibility which is incorporated as Calvo type pricing. The resulting model, on which more complex DSGE models are build, is known as the *Basic New Keynesian* (NK) model or the *Canonical New Keynesian* model.

Given the importance of the NK model, I intend to estimate a NK model for the economy of Romania and to study the effects of different type of shocks on the macroeconomic variables. Bayesian tools will be used in order to estimate structural parameters and to study the effects of frictions, namely the price adjustment frequency.

The rest of the paper is organized as follows: section 2 is a review of DSGE literature, section 3 presents the model, section 4 describes the econometric methodology and the data, section 5 the results and the final section describes the conclusions of the paper.

II) Literature review

As previous noted, DSGE models have their roots in the seminal paper of Kydland and Prescott (1982). However, RBC models assume all aggregate fluctuations are due to technological shocks, thus omitting monetary and fiscal policy.

Over the years the classical RBC model also incorporated other extensions: monopolistic competition was added to the classical RBC model (which implied price rigidity a la Calvo (1983)); wage stickiness was introduced by Erceg *et al*. (2000).

Smets and Wouters (2003) estimated the first DSGE model for the euro area featuring real and nominal rigidities as well as habit formation. Christiano *et al*. (2005)

[1] See Romer (2012)

studied the effects of monetary shocks in a DSGE model with variable capital utilization and investment adjustment costs.

Adolfson *et al*. (2005) incorporates open economy characteristics to the model of Christiano *et al*. (2005). After the recent crisis, the interest turned towards building DSGE models with financial sector, although the effects of financial frictions on business cycle can be found in Bernake and Gertler (1999). Curdia and Woodford (2009) developed a stylized model with a banking sector and heterogeneous households who can change their type. The paper main implication is that including the credit channel in the standard New-Keynesian (NK) model does not fundamentally alter optimal monetary policy. Christiano *et al*. (2010) develops a model with financial frictions on the credit channel in order to explain the stylized facts of the global economic crisis. They found that liquidity constraints and changing risk perception are the main ingredients of economic fluctuations. Recent advancements in DSGE modeling with financial frictions include Gertler and Karadi (2011) who focus on explaining the motivation of banks to take excessive risk.

As regards the area of DSGE estimation, two methods were advanced. The first method focuses on matching the impulse response of a shock to monetary policy of DSGE and a VAR (Monacelli (2003)). The second involves using bayesian techniques to retrive the posterior distributions of the parameters.

III) The New Keynesian Model

A simple New-Keynesian model is considered to analyse the Romanian economy. The model presented in this paper closely follows the solution path of Gali (2008) or Walsh (2010). The notation are from Gali (2008).

The basic New Keynesian model ignores capital stock due to the weak relationship with output at business cycle frequencies. Furthermore, the economy is populated by 3 types of agents: households who maximize their lifetime utility of consumption and leisure (in line with Friedmans' Permanent Income Hypothesis), firms and a central bank who follows a Taylor-type rule.

1) Households

Households maximize their discounted lifetime utility of consumption and labor

$$E_o = \sum_{t=0}^{\infty} \beta^t U(C_t, N_t) \tag{3.1.1}$$

subject to the budget constrain

$$\int_0^1 P_t(i) C_t(i) di + Q_t B_t \leq B_{t-1} + W_t N_t + T_t \tag{3.1.2}$$

where $C_t = (\int_0^1 C_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di)^{\frac{\varepsilon}{\varepsilon-1}}, Q_t$ the price of bonds, B_t the quantity of bonds purchased, $P_t(i)$ the price of the good i, W_t the wage received for labor, T_t lump-sum transfers and has been assumed that there are a continuum of goods in the economy. Furthermore, households solve the following optimization problem:

$$\max_{C_t(i)} C_t$$
$$s.t \int_0^1 P_t(i)C_t(i)di = Z_t \tag{3.1.3}$$

where Z_t is the total nominal expenditure on consumption goods. Setting up the lagrangean of the system given by (3.1.3) and solving for the first order condition:

$$L = \left[\int_0^1 C_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}} - \lambda\left[\int_0^1 P_t(i)C_t(i)di - Z_t\right]$$

$$\frac{\partial L}{\partial C_t(i)} \Rightarrow \left[\int_0^1 C_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{1}{\varepsilon-1}} C_t(i)^{-\frac{1}{\varepsilon}} = \lambda P_t(i) \ \| C_t(i)$$

$$\left[\int_0^1 C_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{1}{\varepsilon-1}} C_t(i)^{\frac{\varepsilon-1}{\varepsilon}} = \lambda P_t(i)C_t(i) \Big\| \int_0^1$$

$$\left[\int_0^1 C_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{1}{\varepsilon-1}} \int_0^1 C_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di = \lambda \int_0^1 P_t(i)C_t(i)di \equiv C_t = \lambda Z_t .$$

Letting P_t be a price index associated with C_t, then $P_t C_t = Z_t$, and note that $\lambda = \frac{1}{P_t}$.

Inserting into the first order conditions:

$$\left[\int_0^1 C_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{1}{\varepsilon-1}} C_t(i)^{-\frac{1}{\varepsilon}} = \frac{P_t(i)}{P_t}$$
$$C_t^{\frac{1}{\varepsilon}} C_t(i) = \frac{P_t(i)}{P_t} \tag{3.1.4}$$
$$C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} C_t$$

where the last equation is the demand for good i. The price index can be derived in the following manner:

$$P_t C_t = \int_0^1 P_t(i) C_t(i) di$$

$$P_t C_t = \int_0^1 P_t(i) \left(\frac{P_t(i)}{P_t} \right)^{-\varepsilon} C_t di \tag{3.1.5}$$

$$P_t = \left[\int_0^1 P_t(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}}$$

Taking into account the above considerations, the optimization problem of the household becomes:

$$\max_{C_t, B_t, N_t} \sum_{t=0}^{\infty} \beta^t U(C_t, N_t)$$
$$s.t \quad P_t C_t + Q_t B_t \leq B_{t-1} + W_t N_t + T_t \ .$$

Under the following form of the utility function, $U(C_t, N_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\varphi}}{1+\varphi}$, the consumer optimal behavior is given by:

$$\frac{W_t}{P_t} = C_t^{\sigma} N_t^{\varphi} \tag{3.1.6}$$

$$Q_t = \beta E_t \left\{ \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t}{P_{t+1}} \right\} \tag{3.1.7}$$

or in log-linear form, where lower case variables denote logarithms

$$w_t - p_t = \sigma c_t + \varphi n_t \tag{3.1.8}$$

$$c_t = E_t(c_{t+1}) - \frac{1}{\sigma}(i_t - E_t(\pi_{t+1}) - \rho) \tag{3.1.9}$$

where $i_t = -\ln Q_t$ is the nominal interest rate, $\rho = -\ln \beta$ and π_{t+1} is the rate of inflation between t and $t+1$. The demand for money is set to have the following log-linear form:

$$m_t - p_t = y_t - \eta i_t \tag{3.1.10}$$

2) Firms

Each firm produces a differentiated good and has the following production function:

$$Y_t(i) = A_t N_t(i)^{1-\alpha} \tag{3.2.1}$$

where A_t represents the level of technology exogenously determined.

Following Calvo(1983) each firm can reset its price only with probability $(1-\theta)$ in a given period thus the average duration of a price is $(1-\theta)^{-1}$.

In this case, the aggregate price index can be rewritten as:

$$P_t = \left[\theta(P_{t-1})^{1-\varepsilon} + (1-\theta)(P_t^*)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$$

where P_t^* is the price chosen by the reoptimizing firms. Dividing both terms by P_{t-1} and log-linearizing:

$$\pi_t = (1-\theta)(p_t^* - p_{t-1}) \tag{3.2.2}$$

which makes it clear that inflation depends critically on pricing decisions of the firms. The reoptimizing firm solves the following optimization problem:

$$\max_{P_t^*} \sum_{k=0}^{\infty} \theta^k E_t \left\{Q_{t,t+k}(P_t^* Y_{t+k/t} - \psi_{t+k}(Y_{t+k/t})\right\}$$

$$s.t \quad Y_{t+k/t} = \left(\frac{P_t^*}{P_{t+k}}\right)^{-\varepsilon} C_{t+k}$$

where $Q_{t,t+k}$ the stochastic discount factor and $\psi_{t+k}(Y_{t+k/t})$ a cost function. The first order condition for the above problem is

$$\sum_{k=0}^{\infty} \theta^k E_t \left\{Q_{t,t+k} Y_{t+k/t}(P_t^* - M\psi_{t+k}{'}(Y_{t+k/t})\right\} = 0 \tag{3.2.3}$$

where $M = \dfrac{\varepsilon}{\varepsilon - 1}$ is the desired markup for the firm. Dividing (3.2.3) by P_{t-1} and log-linearizing it around a zero steady state inflation:

$$p_t^* - p_{t-1} = (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k E_t(\hat{mc}_{t+k/t} + p_{t+k}) \tag{3.2.4}$$

where $\hat{mc}_{t+k/t} = mc_{t+k/t} - (-\log M)$ is log-deviation of the marginal cost from its steady-state value.

3) Equilibrium

Market equilibrium implies that $Y_t(i) = C_t(i)$. Taking into account that $Y_t = \left(\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}}$ it follows that:

$$\begin{aligned} Y_t &= C_t \\ y_t &= E_t(y_{t+1}) - \frac{1}{\sigma}(i_t - E_t(\pi_{t+1}) - \rho). \end{aligned} \tag{3.3.1}$$

Also, in equilibrium

$$y_t = a_t + (1-\alpha)n_t . \tag{3.3.2}$$

The marginal cost for the firm that reoptimized in period t is given by:

$$mc_{t+k/t} = mc_{t+k} - \frac{\alpha\varepsilon}{1-\alpha}(p_t^* - p_{t+k}) . \tag{3.3.3}$$

Substituing (3.3.3) in (3.2.4), rearranging and combinig the result with (3.2.2) (see Gali (2008)) the following equation for inflation is obtained:

$$\pi_t = \beta E_t(\pi_{t+1}) + \lambda \hat{m}c_t \tag{3.3.4}$$

where

$$\lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta}\Theta, \quad \Theta = \frac{1-\alpha}{1-\alpha+\alpha\varepsilon} .$$

Let y_t^n be output from flexible price equilibrium, interpreted as natural level of output, which has the following form:

$$y_t^n = \psi_{ya}^n a_t + \upsilon_y^n \quad \text{where}$$

$$\psi_{ya}^n = \frac{1+\varphi}{\sigma(1-\alpha)+\varphi+\alpha}, \upsilon_y^n = -\frac{(1-\alpha)(\log\frac{\varepsilon}{\varepsilon-1} - \log(1-\alpha))}{\sigma(1-\alpha)+\varphi+\alpha} . \tag{3.3.5}$$

Under this conditions the inflation equation (3.3.4) can be rewritten in terms of the output-gap, $\tilde{y}_t = y_t - y_t^n$:

$$\pi_t = \beta E_t(\pi_{t+1}) + \kappa\tilde{y}_t + q_t \tag{3.3.6}$$

where $\kappa = \lambda\left(\sigma + \frac{\varphi+\alpha}{1-\alpha}\right)$ .The resulting equation is referred to as *New Keynesian Phillips Curve* (NKPC) . It is "new" in the sense that is forward-looking unlike the classical view which treated inflation as a backward-looking variable. Also it depends positively on output-gap. I have added the exogenous process q_t to capture shocks to the inflation rate which are not explained by the model.

The other building block of the New Keynesian Model, is the *Dynamic IS curve* which is obtain by rewriting the second equation of (3.3.1) in terms of output-gap:

$$\tilde{y}_t = -\frac{1}{\sigma}\left(i_t - E_t(\pi_{t+1}) - r_t^n\right) + E_t(\tilde{y}_{t+1}) \tag{3.3.7}$$

where r_t^n is the natural rate of interest given by:

$$r_t^n = \rho + \sigma\psi_{ya}^n E_t(\Delta a_{t+1}).$$

In this present framework real variables cannot be determined independently of monetary policy thus the model is analyzed under a simple Taylor rule of the form:

$$i_t = \rho + \phi_\pi \pi_t + \phi_y \tilde{y}_t + v_t. \tag{3.3.8}$$

To exogenous variables all follow an AR(1) process:

$$\begin{aligned} a_t &= \rho_a a_{t-1} + \varepsilon_a \\ v_t &= \rho_v v_{t-1} + \varepsilon_v \\ q_t &= \rho_q q_{t-1} + \varepsilon_q . \end{aligned} \tag{3.3.9}$$

where $\varepsilon_a, \varepsilon_v, \varepsilon_q$ are i.i.d normal random variables with mean zero and standard deviation σ_a, σ_v and σ_q.

IV) Methodology

For the estimation procedure I collected quarterly data from 2000Q1 to 2013Q4 for the following variables:

- Real GDP (2005=100)
- Consumer Price index (2005=100)
- Short term interest rate.

All the data were obtained from IMF Financial Statistics database. In order to fit the model variables the series were transformed in the following manner[2]:

$$\begin{aligned} \pi_t^{data} &= \log(\frac{CPI_t}{CPI_{t-1}}) - \log(mean(\frac{CPI_t}{CPI_{t-1}})) = \pi_t \\ i_t^{data} &= \log(1 + \frac{i_t^{data}}{400}) - mean(\log(1 + \frac{i_t^{data}}{400})) = i_t \\ y_t^{data} &= \log(y_t^{data}) - \log(y_t^{trend}) = \tilde{y}_t \end{aligned}$$

The cyclical component for real GDP was extracted using the Hodrick-Prescott filter using a value of λ of 1600, standard for quarterly data.

Due to small sample size some parameters were calibrated in the following manner: discount factor β was set to 0.99, elasticity of substitution ε was set to 6, labor elasticity φ was set to 1, capital share α was set to 0.33, σ was set to 1, implying a log utility function and the elasticity of money demand η was set to 4.

[2] The data for real GDP was first deseasonalized using the Census X12 procedure with the additive option (the program used for estimation was Eviews).

For sticky price parameter (θ) I selected a Beta distribution with mean 0.67 and standard deviation 0.1. For the standard deviations of exogenous processes I selected Inverse Gamma distribution with mean 0.05 and standard deviation 4. For the inflation parameter in the monetary policy rule (ϕ_π) I selected a normal distribution with mean 1.5 and standard deviation 0.5 while for the output-gap parameter (ϕ_y), a Beta distribution with mean 0.12 and standard deviation 0.01 was chosen. As regards the autoregressive parameters, Beta distribution were selected with mean 0.75 and standard deviation 0.1, with the exception of the parameter for interest rate, ρ_v, for which a mean of 0.25 was set.

For the Bayesian estimation procedure I used DYNARE toolbox with MATLAB R2012a. A detailed treatment of Bayesian estimation of DSGE models can be found in Fernandez-Villaverde (2009).

For posterior distributions' simulation I used two MH chains with 20.000 draws each and set the scale parameter to 0.8 in order to obtain a recommended acceptance ratio of 25% (Griffoli (2010)).

V) Results

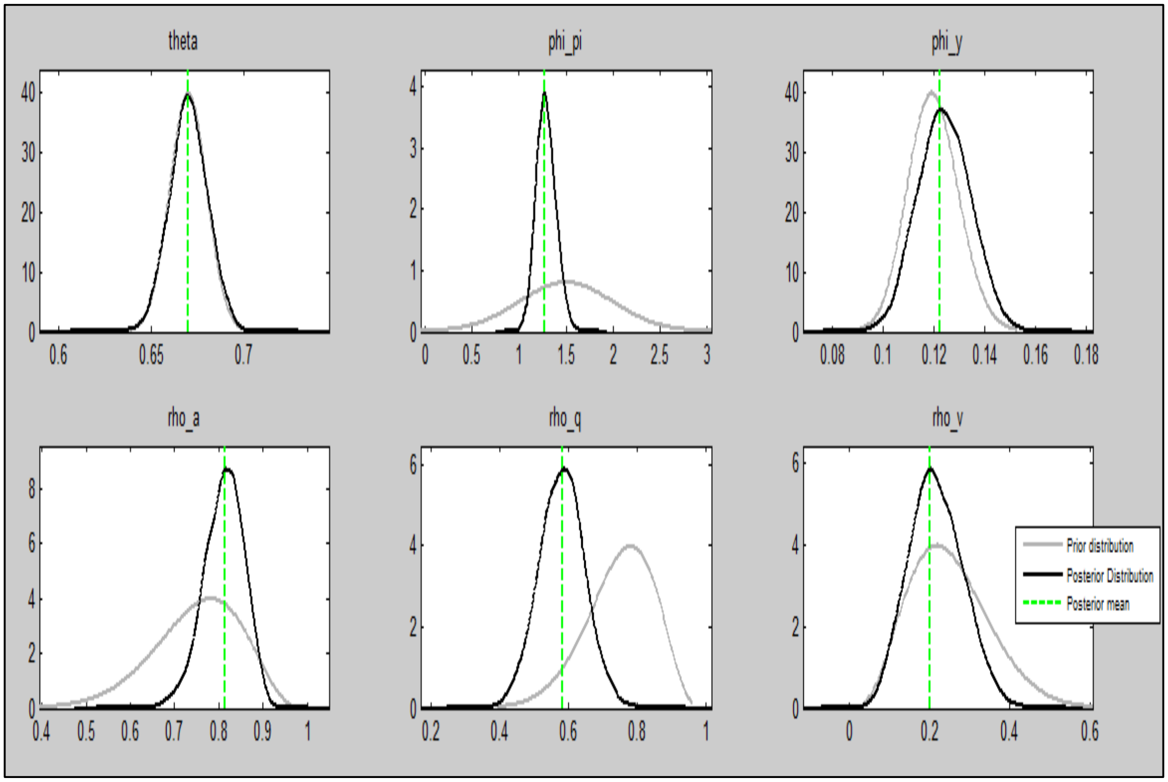
In this section the results arising from the estimation of the model are presented. First, the parameters posterior distributions are analyzed and secondly, an impulse-response analysis is conducted.

1) Posterior Distributions and Implied values

Prior distributions along with posterior distributions and their mean are presented in Figure 5.1. The Calvo parameter posterior distribution (*theta*) is very close to its prior, having a mean of 0.6702, thus implying that the average duration of prices in the Romania economy is 3 months. Regarding the estimation of the monetary policy rule parameters', it follows that the central bank reacts 1.3 times greater ($\hat{\phi}_\pi = 1.29$) to a deviation of inflation from its steady state value while the respond to output-gap is limited ($\hat{\phi}_y = 0.1242$). Turning to the estimates for the shock processes, the technology shock is the most persistent with an AR (1) coefficient of 0.81. In turn, the persistence of inflation shock is 0.58 in mean, while for the interest rate shock is 0.21.

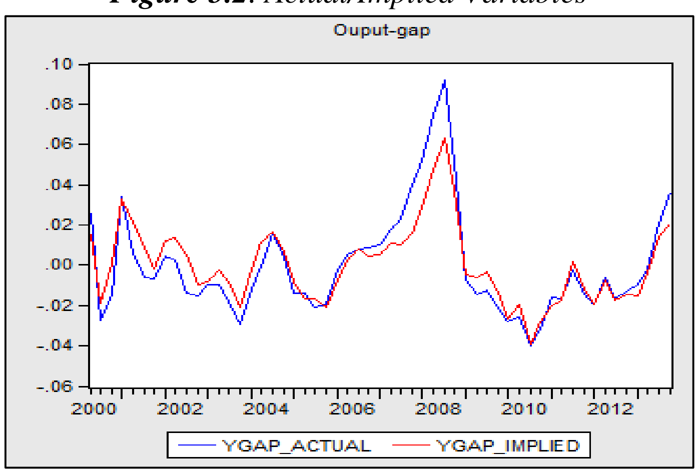
The Metropolis-Hastings Diagnosis tests proposed by Brooks and Gelman represent the overall and univariate convergence of the values estimated in the MH chains, being a measure of the stability of those results. The results indicate a satisfactory convergence of the series. The statistics for the posterior distributions and the convergence tests are summarized in Appendix A.

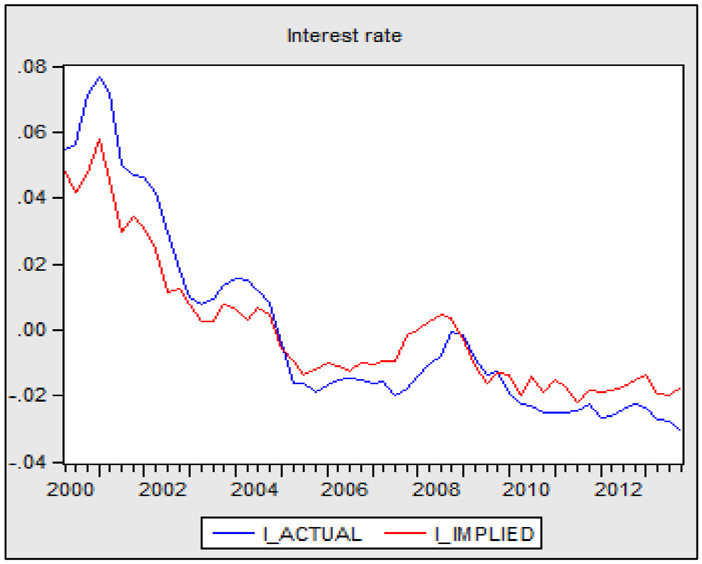
***Figure 5.1**. Posterior Distributions*

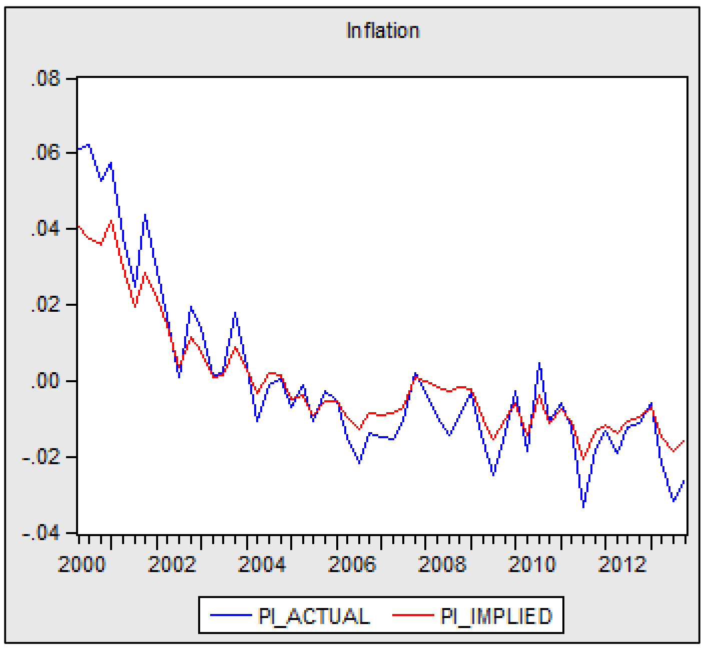


The estimated model captures relatively well the actual dynamics in the data, as can be seen from Figure 5.2 which plots the implied values by the model and the actual data for output-gap, inflation and interest rate.

***Figure 5.2**. Actual/Implied Variables*







2) Impulse-Response Analysis

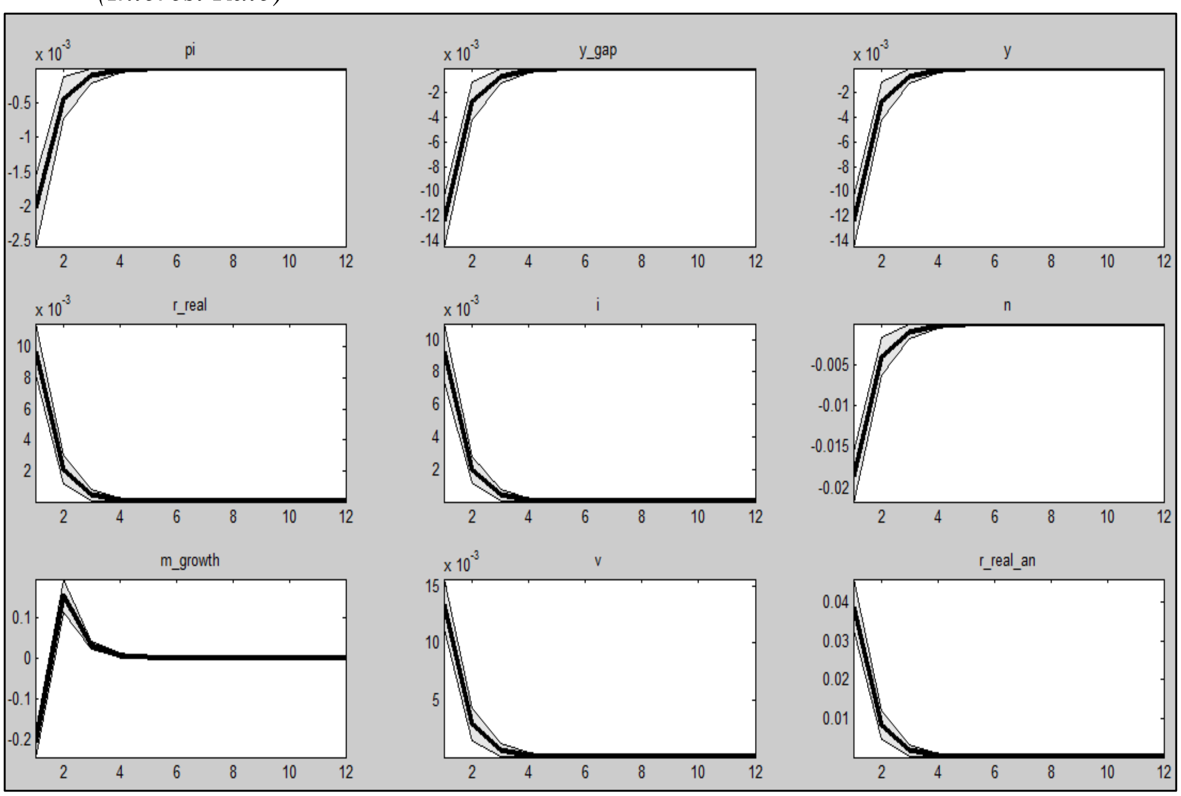
In order to understand the fluctuations of the macroeconomic variables captured in this model, three shocks will be considered:

- a technology shock;
- a monetary policy shock;
- an inflation shock.

a) Impulse Responses from a Monetary Policy Shock

Figure 5.3 presents the impulse response functions from a contractionary monetary policy shock together with the Bayesian 90% confidence intervals. The confidence bands appear to be very narrow thus indicating the statistical significance of the impulse-response functions. The shock corresponds to a 1.34 basis points increase in the interest rate. The exogenous increase in the interest rate leads to persistent decrease in inflation and output-gap. Because the natural level of output doesn't react to a monetary policy shock the decrease in output mimics the dynamics of the output-gap. The increase in nominal interest rate is due both to the direct effect of the shock and the effects of lower output-gap and inflation. In order to support the increase in interest rates the central bank must decrease the money supply, thus displaying a liquidity effect. Also, as a result of the monetary policy shock, the level of employment decreases.

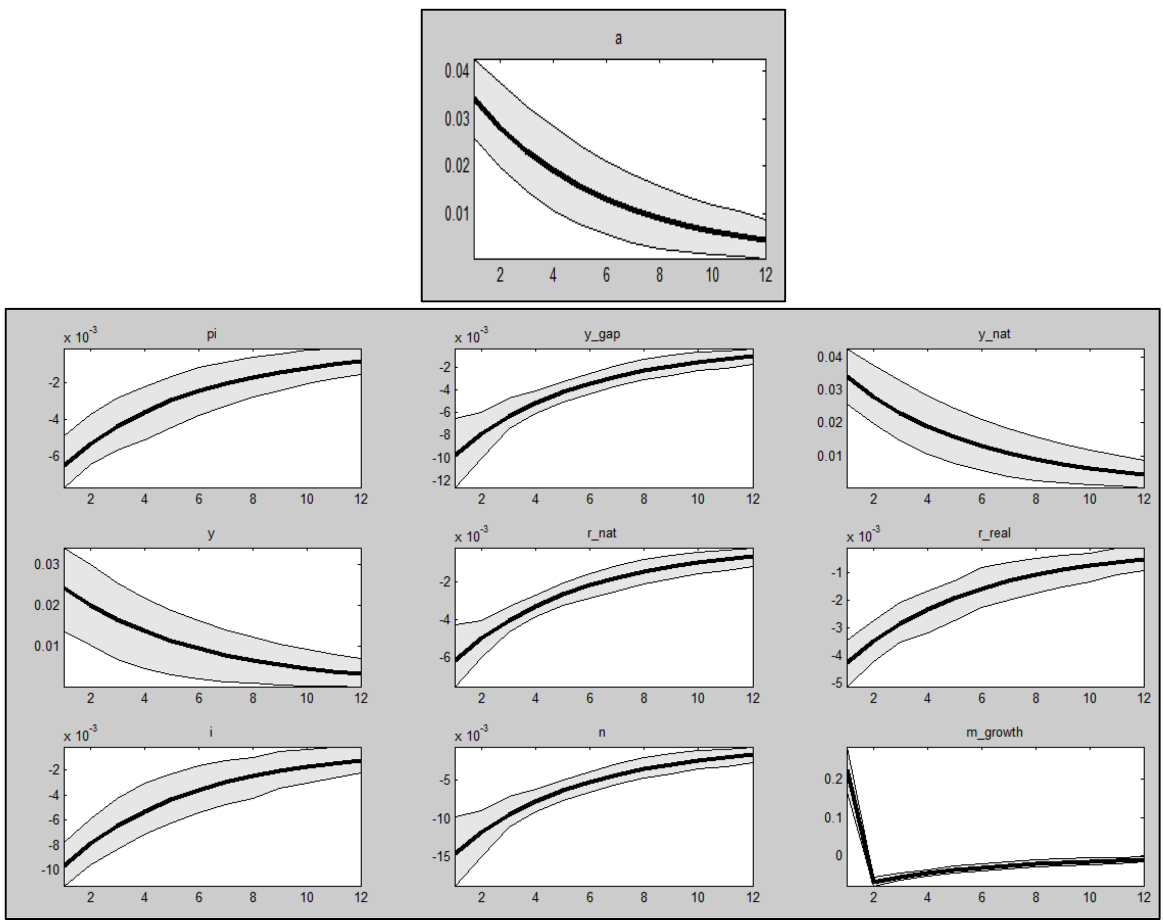
Figure 5.3. *Impulse-Response Functions from a Monetary Policy Shock (Interest Rate)*



b) Impulse Responses from a Technology Shock

The impulse response functions from a technology shock are presented in Figure 5.4. A positive a technology shock leads to a persistent decrease in inflation and output-gap. The decrease in output-gap is due to the greater increase in the natural level of output relative to its real counterpart. As a result of the negative output-gap, the central bank lowers nominal and real interest rates while at the same time increases the money supply. The technology shock also decreases the natural level of interest and employment.

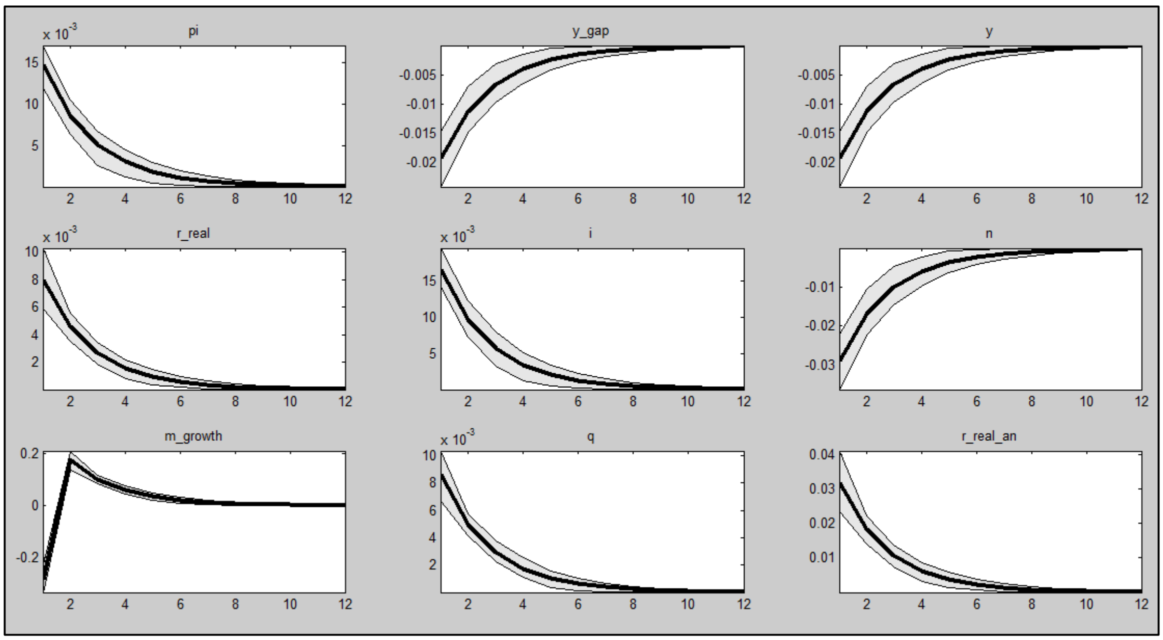
Figure 5.4. *Impulse-Response Functions from a Technology Shock*



c) Impulse Responses from an Inflation Shock

The impulse-response functions from an inflation shock are plotted in Figure 5.5. The increase in inflation determines the central bank to increase interest rates and to lower the money supply (as mentioned early the central bank cares more about inflation than it does for the output-gap). This increase in interest rates causes a negative output-gap and a decrease in employment.

Figure 5.5. *Impulse-Response Functions from an Inflation Shock*



VI. CONCLUSIONS

In this paper I have presented the *New Keynesian Model* which represents the building block of modern DSGE models. After exposing briefly the econometric methodology, the model was estimated for the Romanian economy, using Bayesian techniques. Finally, the results of different estimations and the impulse-response functions were analyzed.

Despite its simplicity, the estimated model fitted reasonably well the actual series for output-gap, inflation and interest rate. The estimation of the Calvo parameter showed an average duration of price adjustment of one quarter while the estimation of monetary rule parameters proved that the central bank reacts strongly to inflation deviations and in a limited manner to output-gap. Furthermore, the effects of a monetary shock, a technology shock and an inflation shock were analyzed. The response of macroeconomic variables to an inflation shock showed that the central bank accommodated the rise in inflation with a contractionary monetary policy at the cost of a negative output-gap.

Nevertheless, to understand the whole picture of the Romanian economy, a more complex model should be considered, a model which can capture the dynamics of consumption, investment, financial and open economy variables.

References

[1] Adolfson, M., Laseen, S., Linde, J. and Villani, M. (2005), ‘Bayesian estimation of an open economy DSGE model with incomplete pass-through’, *Sveriges Riksbank Working Paper Series* (179).

[2] Bernanke BS, Gertler M, Gilchrist S (1999): The Financial Accelerator in a Quantitative Business Cycle Framework. Handbook of Macroeconomics. In: Woodford M, Taylor JB (Eds): *Handbook of Macroeconomics.* Ed. 1, vol. 1, chapter 21 (pp. 1341‑1393). Elsevier.

[3] Calvo, G. A. (1983), ‘Staggered prices in a utility-maximizing framework’, *Journal of Monetary Economics* **12**(3), 383 – 398.

[4] Christiano, L. J., Eichenbaum, M. and Evans, C. L. (2005), ‘Nominal rigidities and the dynamic effects of a shock to monetary policy’, *The Journal of Political Economy* **113**(1), 1–45.

[5] Christiano, Lawrence & Rostagno, Massimo & Motto, Roberto, 2010. "Financial factors in economic fluctuations," Working Paper Series 1192, European Central Bank.

[7] Cúrdia V, Woodford M (2009). Credit Frictions and Optimal Monetary Policy. *BIS Working Papers*,no. 278.

[9] David Romer (2012), Advanced Macroeconomics, 4th edition, McGraw-Hill

[10] Erceg, C. J., Henderson, D. W. and Levin, A. T. (2000), ‘Optimal monetary policy with staggered wage and price contracts’, *Journal of Monetary Economics* **46**(2), 281 – 313.

[11] Fernandez-Villaverde, J. (2009), The Econometrics of DSGE Models, Working Paper 14677, National Bureau of Economic Research.

[12] Gali, J. (2008), *Monetary Policy, Inflation, and the Business Cycle*, first edition, Princeton University Press, Princeton and Oxford.

[13] Gertler M, Karadi P (2011): A Model of Unconventional Monetary Policy. *Journal of Monetary Economics*, 58(1):17‑34.

[14] Griffoli, T. M. (2010), DYNARE v4 - User Guide, Public beta version

[15] Kydland, F. E. and Prescott, E. C. (1982), ‘Time to Build and Aggregate Fluctuations’,*Econometrica* **50**(6), 1345–1370.

[15] Monacelli, T. (2003), ‘Monetary policy in a low pass-through environment’, *European Central Bank Working Paper Series* (227).

[16] Smets, F. andWouters, R. (2003), ‘An estimated stochastic dynamic general equilibrium model of the euro area’, *Journal of European Economic Association* **1**(5), 1123 – 1175.

[17] Walsh, C. E. (2010), *Monetary Theory and Policy*, third edn, The MIT Press, Cambridge, Massachusetts.38

Appendix A

Table 1. Description of posterior distributions

Parameter	Mean	Confidence interval	
θ	0.6702	0.6534	0.6868
ϕ_π	1.2912	1.1288	1.4651
ϕ_y	0.1242	0.1075	0.1410
ρ_a	0.8107	0.7410	0.8859
ρ_v	0.2154	0.1046	0.3231
ρ_q	0.5804	0.4736	0.6911
σ_a	0.0337	0.0253	0.0425
σ_v	0.0134	0.0112	0.0156
σ_q	0.0088	0.0069	0.0105

Figure A1. *MCMC Univariate convergence diagnostic*

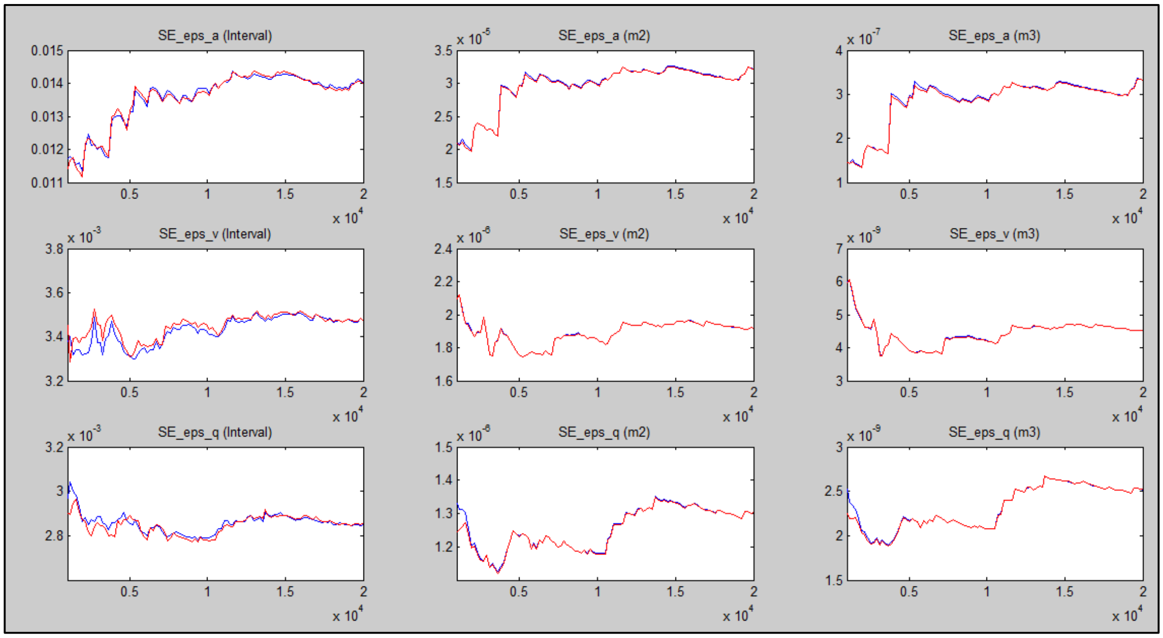


Figure A2. *MCMC Univariate convergence diagnostic*

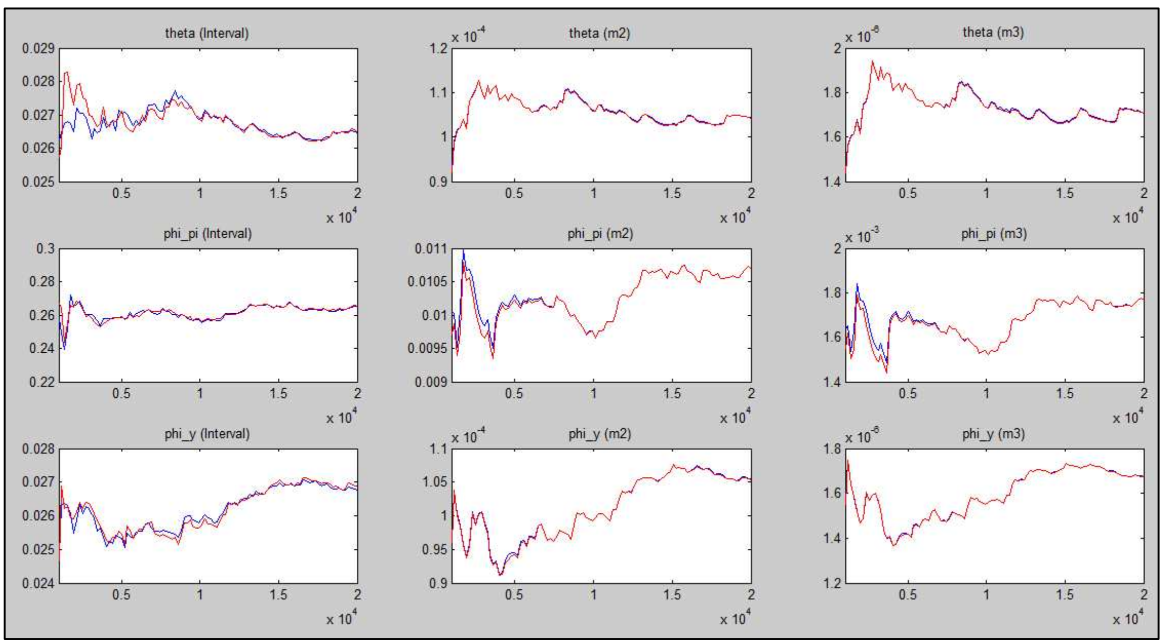


Figure A3. *MCMC Univariate convergence diagnostic*

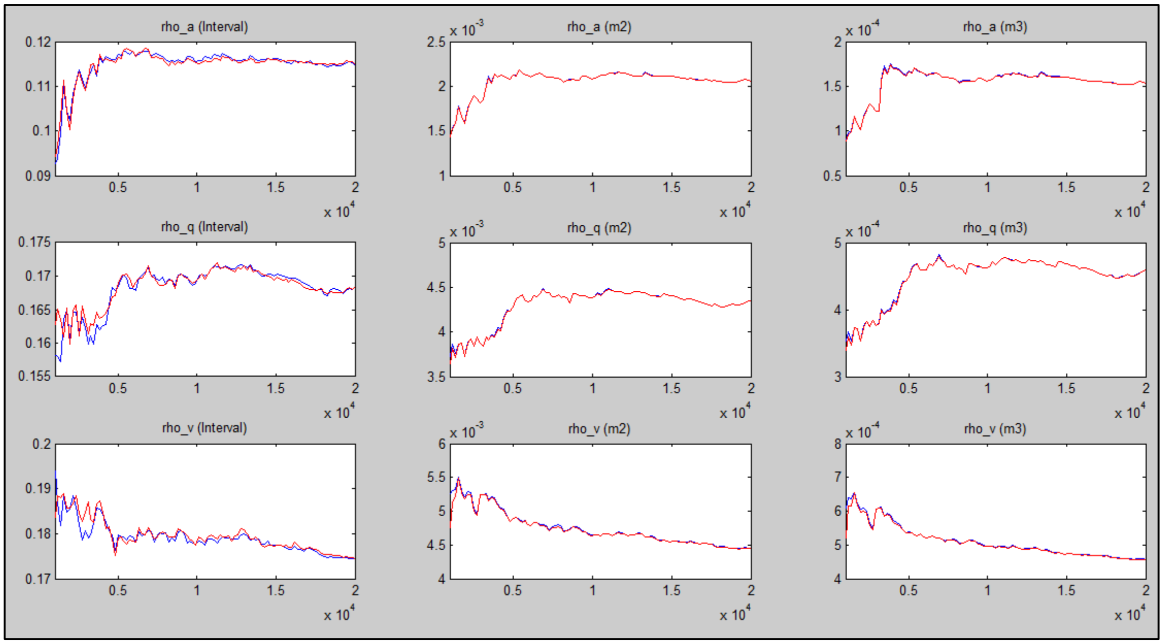
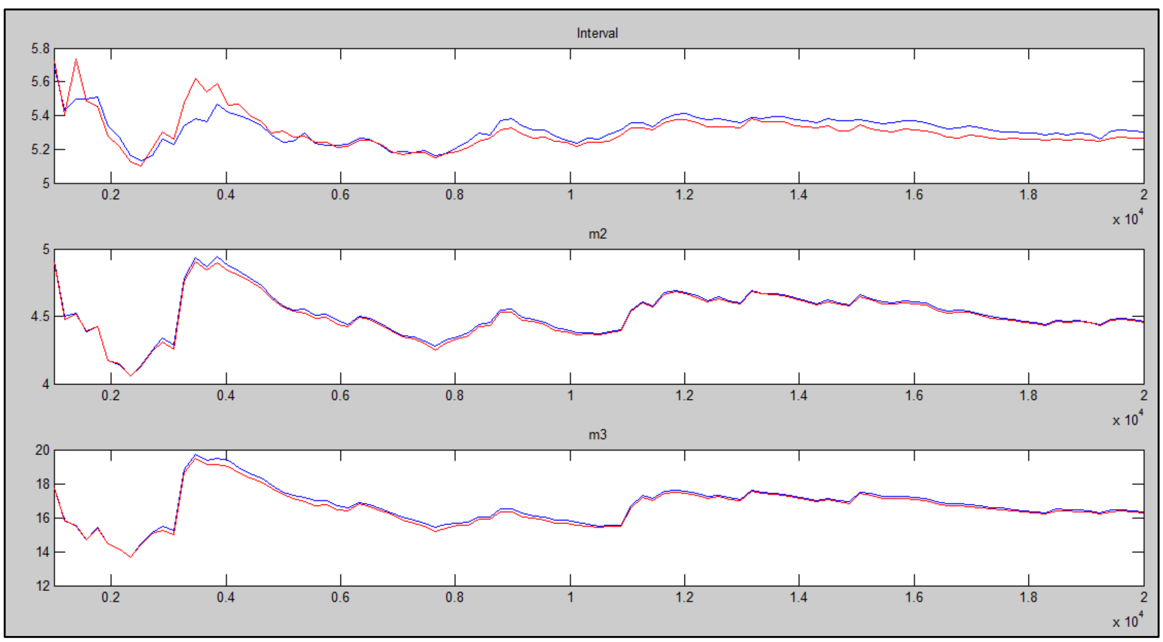


Figure A4. *MCMC Multivariate convergence diagnostic*



Appendix B

Dynare Code

```
var pi y_gap y_nat y r_nat r_real i n m_growth a v q r_real_an i_an
pi_an r_nat_an;

varexo eps_a eps_v eps_q;

parameters beta theta sigma psi_n_ya v_n_ya rho_v rho_a rho_q phi
phi_pi phi_y kappa alpha epsilon eta;

sigma = 1;      //log utility
phi=1;          //unitary Frisch elasticity
phi_pi = 1.5;   //inflation feedback Taylor Rule
phi_y  = .5/4;  //output feedback Taylor Rule
theta=2/3;      //Calvo parameter
rho_v = 0.5;   //autocorrelation monetary policy shock
rho_a  = 0.9;   //autocorrelation technology shock
beta = 0.99;    //discount factor
eta  =4;        // semi-elasticity of money demand
alpha=1/3;      //capital share
epsilon=6;      //demand elasticity
rho_q=0.8;

//composite parameters

omega=(1-alpha)/(1-alpha+alpha*epsilon);
lambda=(((1-theta)*(1-beta*theta))/theta)*omega;
kappa=lambda*(sigma+(phi+alpha)/(1-alpha));
psi_n_ya=(1+phi)/(sigma*(1-alpha)+phi+alpha);
v_n_ya=-((1-alpha)*(log(epsilon/(epsilon-1))-log(1-alpha)))/(sigma*(1-
alpha)+phi+alpha);

model(linear);
pi=beta*pi(+1)+kappa*y_gap+q;
y_gap=-1/sigma*(i-pi(+1)-r_nat)+y_gap(+1);
i=phi_pi*pi+phi_y*y_gap+v;
r_nat=sigma*psi_n_ya*(a(+1)-a);
r_real=i-pi(+1);
y_nat=psi_n_ya*a+v_n_ya;
y_gap=y-y_nat;
y=a+(1-alpha)*n;
a=rho_a*a(-1)+eps_a;
v=rho_v*v(-1)+eps_v;
q=rho_q*q(-1)+eps_q;
m_growth=4*(y-y(-1)-eta*(i-i(-1))+pi);
r_real_an=4*r_real;
i_an=4*i;
pi_an=4*pi;
r_nat_an=4*r_nat;
end;

steady;
```

```
check;


shocks;
var eps_v=0.25;
var eps_q=0.05;
var eps_a=0.05;
end;

varobs y_gap i pi;

estimated_params;
theta, beta_pdf,.67,.01;
phi_pi, normal_pdf,1.5,.5;
phi_y, beta_pdf, 0.12,.01;
stderr eps_a, inv_gamma_pdf,0.05,4;
stderr eps_v, inv_gamma_pdf,0.05,4;
stderr eps_q, inv_gamma_pdf,0.05,4;
rho_a, beta_pdf,0.75,0.1;
rho_q, beta_pdf,0.75,0.1;
rho_v, beta_pdf,0.25,0.1;

end;


estimation(datafile=date_nk,mode_compute=4,filtered_vars,forecast=4,mh_
replic=20000,mh_nblocks=2,mh_drop=0.1,mh_jscale=0.8,conf_sig=.90,bayesi
an_irf,irf=12);
```