# Should the National Bank of Romania use a dynamic stochastic general equilibrium model for Romania in its monetary policy decision process?*


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**Abstract**

Dynamic stochastic general equilibrium (DSGE) models are currently the most important tool of macroeconomic modeling, being used or under development in most policy making and academic institutions. Nevertheless, the National Bank of Romania (NBR) has not yet developed such a model for the Romanian economy. Thus, through this paper[1], it will be shown the advantages of using a DSGE model in the monetary policy of Romania, a developing country which is trying to fulfill the economic convergence criteria as an Euro-area candidate, arguments which will be further used in order to formulate the appropriate recommendation for the NBR.


*This model is the result of a research done by the author at the National Bank of Romania - Macroeconomic Modeling Department in July 2011 and has been introduced in the author's Master Thesis - "*Analysis of the relationship between price inflation and wages in the Romanian economy. The role of nominal and real rigidities in an estimated small open economy model*" which was presented in February 2012 to the representatives of the Universities of Bern and Basel. However, the views presented in this paper are of the author and no responsibility for them should be attributed to the National Bank of Romania, the University of Bern or the University of Basel.


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[1] This paper consists of 29 pages, including first page and bibliography.

# 1 Introduction

Although starting from the nineteenth century researchers studied business cycles (see Cass (1965)and Brock and Mirman (1972)), it was not until the late 1980s and early 1990s that macroeconomists learned to handle microfounded frictionless dynamic macroeconomic models. The Real Business Cycle (RBC) model has its origins in the seminal papers of Kydland and Prescott (1982) and Prescott (1986)and is the core of new Keynesian monetary model.

Common features of the two approaches are: optimizing behavior of agents (households maximize their utility subject to the budget contraint while firms maximize their profits subject to the resource constraint), reliance on the rational expectations hypothesis and clearing of all markets.

However, the new Keynesian model has also elements of the classical monetary models developed during the 1960s and 1970s such as monopolistic competition and nominal rigidities which determine the short-term non-neutrality of monetary policy, opposed to the RBC models which have a general tendency to abstract from monetary factors.

After developing the new Keynesian models, researchers were faced with the challenge of matching these models with the empirical evidence. Using traditional econometric tools like Vector Autoregressions (VAR), Vector Error Correction Models (VECM), Bayesian Vector Autoregressions (BVAR), and the most promising of them all, the Bayesian techniques, they were able to prove that the new Keynesian DSGE models have data explanatory power.

Starting with closed economy studies such as Smets and Wouters (2003), Christiano et. al. (2005), An and Schorfheide (2006)andFernàndez-Villaverde (2009), and continuing with new open economy models (NOEM) like those presented in Adolfson et. al. (2005),Andrle et. al. (2008), and others, the importance of new Keynesian DSGE models has grown due to their possibility of combining macroeconomics theory with empirical evidence and has transformed them in the most attractive tool for macroeconomic modelling.

This is the reason why these models are not only used for academic research, but also by central banks and other institutions as a tool in conducting monetary policy. Some of these institutions are the European Central Bank, the European Comission, the Bank of England, the Bank of Spain, the Federal Reserve Board, the Bank of Canada, the Swiss National Bank, the Bank of Sweden, and the Bank of Finland.

Despite the fact that these topics are the essence of modern macroeconomics, few attempts had been made to apply them for the Romanian economy (see Caraiani (2008),Caraiani (2009),Leonte (2010),Grigoras (2010)), which makes this paper a pioneering study, hopefully one of the first steps in this direction, not only for me but also for many other Romanian researchers.

The model used in this paper is inspired from Christiano et. al. (2005), Adolfson et. al.

(2005), Gali and Monacelli (2005), and Andrle et. al. (2008). It is a small open economy model, since Romania can be considered a small economy vis-a-vis the Euro area or the rest of the world, featuring four types of economic agents namely households, firms, aggregators and the Euro area. In this case, the Romanian economy's size is negligible, relative to that of the Euro area, and therefore its specific economic fluctuations have no influence on the macroeconomic aggregates and monetary policy of the Euro area. Moreover, the model includes shocks and frictions in order to better match the short-run properties of the data. Furthermore, for simplification, it is assumed that all trade (importing and exporting activities) is performed with countries belonging to the Euro area, which implies that the nominal exchange rate is RON/EUR, and that there is no fiscal authority (government) but only a monetary authority (the central bank) which sets the nominal interest rate according to a Taylor rule.

The model is estimated using Bayesian methods and it is not linearized because, as it is stated in Amisano and Tristani (2007), nonlinear models are more suited to characterize macroeconomic dynamics in presence of large deviations from the steady state and have been argued to provide sharper estimates of the structural parameters than their linearized counterparts. I will not go into details about the Bayesian estimation techniques because this goes beyond the purpose of the paper, but discussions concerning this subject can be found in Fernàndez-Villaverde (2009)and An and Schorfheide (2006).

This paper is structured in four main sections as it follows: the first section introduces the model, which is then estimated in the next section. In this section it is also presented the data used for doing the estimation and some methodological considerations, along with the estimation results. The following section introduces the analysis of the empirical properties of the model. Firstly, it is made a comparison of the model with the real world. Secondly, using impulse response functions, it is possible to analyze whether the model replicates the historical path of major variables, and finally, the forecasting potential of the model on the short to medium term is investigated. In the last section, it becomes clear whether the NBR should use a DSGE in the formulation of the appropriate monetary policy reactions to hypothetical or expected future events.

## 2 The model

The small open economy DSGE model which will be further described in this paper is following mainly Christiano et. al. (2005), Adolfson et. al. (2005), Andrle et. al. (2008), and Gali and Monacelli (2005).

Although, in the small open economy (SOE) literature it is often assumed that the economy which is analyzed is part of a continuum of small open economies that form the world economy, because Romania has most of its commercial activities with the Euro area (57.7% of its exports going to the Euro area, out of 74.3% of its exports to EU, while 53.2% of its imports come from the Euro area, out of the 73.3% imports from EU[2]) I consider it to be a small open economy with respect to the Euro area and not to the world economy. In the model, Romania will be refered to as the home country and the Euro area as the foreign country. In this context, the policy decisions of the home country have no impact on the foreign country's economy, and thus, the variables assigned to the foreign country are exogenously given.

The home economy is represented by households, firms and monetary authority. The model abstracts from capital accumulation and ignores the existence of a government, their presence in the model not being mandatory for the purpose of the paper.

Households maximize their utility function which consists of consumption and leisure. They consume a finished good which, since they are part of an open economy, is made out of two types of intermediate goods, domestically produced and imported. As in Galí and Blanchard (2005), the goods are non - storable, so they must be sold and consumed in the period they are produced such that in each period output equals consumption. Moreover, households' preferences are subject to habit formation, that introduces a real rigidity in the model.

Nominal rigidities are further introduced through wage and price setting decisions staggered à la Calvo (1983). When they are not reoptimized, prices and wages are partially indexed to past inflation rates. Households set their own wages because each of them is a monopoly supplier of a specialized type of labor. Households are not allowed to hold cash in this model, so they can only use their wages for acquiring consumption goods or for saving in domestic and foreign bonds.

The firms (intermediate goods domestic producers, intermediate goods importers, consumption final goods producers and final goods exporters), all produce differentiated goods and set prices. As in Adolfson et. al. (2005), the model features incomplete pass-through associated with the local currency pricing which is applied by exporters and importers.

In the following subchapters, the model is described in details by presenting the optimization problems of households and firms along with the activity of the monetary authority, namely the central bank of the home country. Finally, there will be introduced some processes that show how the foreign economy evolves.

## 2.1 Households

The small open economy is populated by a continuum of identical households and, since they are all alike, I will further consider the case of a representative household.

[2]for details see ECB Convergence Report of May 2010

### 2.1.1 Preferences

The infinitely lived representative household of the small open economy seeks to maximize its intertemporal utility function (with time separable preferences) by deciding upon the expected labor supply and consumption:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[ \frac{(C_t - \chi * H_t)^{(1-\sigma)}}{(1-\sigma)} - \frac{N_t^{(1+\varphi)}}{1+\varphi)} \right] \tag{1}$$

The parameters used in this equation are discount factor $\beta$, constant of relative risk aversion $\sigma$, habit persistence $\chi$ and elasticity of labor supply $\frac{1}{\varphi}$. The model allows for habit persistence in consumption which is externally determined (*keeping up with the Joneses*):

$$H_t = C_{t-1} * exp(\Delta A_{ss}) * exp(shk_H) \tag{2}$$

Thus, the habit evolves depending on the aggregate consumption from the previous period, adjusted with the steady state value of the growth rate of technology and an i.i.d. shock which can be a change in preferences.

### 2.1.2 Budget constraint

The maximization of the utility function is subject to a sequence of flow budget constraints such as:

$$\Pi_t + W_{j,t} * N_{j,t} + exp(R^*_{t-1} + PREM_{t-1}) * S_t * B^*_{j,t} + exp(R_{t-1}) * B_{j,t} + TR_t + D_t = S_t * B^*_{j,t+1} + P_t^C * C_{j,t} + B_{j,t+1} \tag{3}$$

Household j has in period t the following earnings: profits $\Pi_t$ received from firms since it is assumed that the households own the firms; wages $W_{j,t}$ for the labor supplied $N_{j,t}$; revenues from owning domestic bonds $exp(R_{t-1}) * B_{j,t}$; revenues from owning foreign bonds $exp(R^*_{t-1} + PREM_{t-1}) * S_t * B^*_{j,t}$; dividend payments $D_t$; transfers from the government $TR_t$.

These earnings are used not only for acquiring new domestic and foreign bonds but also for purchasing consumption goods.

By maximizing the utility function subject to the budget constraint, we get the first order conditions which combined determine the following equations:

- Intertemporal condition (Euler equation)

$$E_t \left[ \frac{(C_{t+1} - \chi * H_{t+1})^{-\sigma}}{(P^C_{t+1})} \right] * exp(R_t) * \beta = \frac{(C_t - \chi * H_t)^{-\sigma}}{(P^C_t)} \tag{4}$$

- Intratemporal condition (equates the marginal rate of substitution between consumption and leisure to the real wage)

$$N_{j,t}^{\varphi} = \frac{(C_t - \chi * H_t)^{-\sigma}}{(P_t^C)} * W_t \tag{5}$$

- Uncovered interest parity (UIP)

$$\triangle S_{t+1} = R_t - R_t^* - PREM_t(+shk_{uip}) \tag{6}$$

### 2.1.3 Wage setting

The labor market has monopolistic power, which means that each household supplies its labor to an agent also known as labor union which aggregates the labor of all households and offers it in a competitive way to the intermediate goods producers.Wage rigidity is modeled in Calvo style. Thus, the function of aggregation is of Dixit – Stiglitz type:

$$N_t = \left( \int_0^1 (N_{j,t})^{\frac{1}{\lambda_W}} d_j \right)^{\lambda_W}, 1 < \lambda_w < \infty \tag{7}$$

,where $N_t$ is the aggregate labor, $N_{j,t}$ is the labor provided by household j at time t and $\lambda_W$ is the mark-up over the marginal cost, the relationship between this mark-up and the elasticity of substitution of different types of labor provided by the households being $\lambda_W = \frac{\theta_W}{\theta_W - 1}$.

The aggregating agent faces the following optimization problem, having the individual wages $W_{j,t}$ as given and considering as a constraint the function (7):

$$min \int_0^1 W_{j,t} * N_{j,t} dj \tag{8}$$

The first order condition that results from the optimization problem is the demand for labor of the aggregating agent from household j:

$$N_{j,t} = N_t * \left( \frac{W_{j,t}}{W_t} \right)^{\frac{\lambda_w}{1-\lambda_w}} \tag{9}$$

Moreover, the aggregate index of wages is given by the following expression:

$$W_t = \left( \int_0^1 (W_{j,t})^{\frac{1}{1-\lambda_w}} dj \right)^{1-\lambda_w} \tag{10}$$

The process of wage setting is done in several steps. The wages of the households which do not receive the signal to optimize are adjusted with the wage inflation of the previous period:

$W_{j,t+1} = \pi^W * W_{j,t}$. In each period, a household can receive the signal to optimize with probability $1 - \xi_W$. Some of the households are randomly selected to optimize their wages and they choose the value that maximizes their present value utility function, taking into account the probability that they may not receive the signal again for some periods and also considering the budget constraint, the demand for labor of the aggregating agent and the indexation of wages to past inflation in case the signal is not received. Therefore, a household that receives the optimization signal in period t but does not receive it for the next s periods, will set the wage as it follows:

$$W_{j,t+s} = \pi_t^W * \ldots * \pi_{t+s-1}^W * W_{j,t}^{new} \tag{11}$$

Using this equation, we can write the optimization problem that the household faces at time t when it received the signal to optimize as:

$$\max_{W_{j,t}^{new}} E_t \sum_{s=0}^{\infty} (\beta * \xi_W)^s * \left[ \frac{N_{j,t+s}^{1+\varphi}}{1+\varphi} + \Lambda_{t+s} * (\pi_t^W * \ldots * \pi_{t+s-1}^W) * W_{j,t}^{new} * N_{j,t+s} \right] \tag{12}$$

Introducing the constraint given by equation (9) in the previous formula and doing the first order condition and log-linearization, we get the Phillips Curve for wage inflation:

$$\pi_t^W = \frac{\beta}{1+\beta} * \pi_{t+1}^W + \frac{1}{1+\beta} * \pi_{t-1}^W + \frac{(1-\beta*\xi_W)*(1-\xi_W)}{(1+\beta)*\xi_W} * log\left(\frac{Wflex_t}{W_t} * \lambda^W\right) (+shk_W) \tag{13}$$

,where

$$Wflex_t = P_t^C * (C_t - \chi * H_t) \tag{14}$$

and $\pi_t^W = log(W_t/W_{t-1})$. The last variable in the equation, $shk_W$, represents any shock that can influence the evolution of wages and can be attributed to the variation of mark-up, $\lambda^W$, but it can also have other causes.

## 2.2 Firms

There are four types of firms operating in the home country: intermediate goods domestic producers, intermediate goods importers, consumption final goods producers and fnal goods exporters. The intermediate goods domestic firms produce a differentiated good, using labor as input, which they sell to an aggregating agent. The intermediate goods importing firms transform a homogenous good, bought from the foreign market, into a differentiated imported good, which they also sell to an aggregating agent. The consumption goods producers use the intermediate domestic and imported goods sold by a continuum of agents to produce a homogenous consumption final good. The exporting firms pursue a similar scheme. The exporting firms produce an exporting final good and differentiate it by brand naming. Each exporting firm is thus a monopoly supplier of its specific product in the foreign market.

### 2.2.1 Intermediate goods domestic producers

Since in this model we are abstracting from capital accumulation, the only production factor that the firms have at their disposal is labor which is provided by the aggregating agent, namely the labor union. Therefore the firms are producing using a linear Cobb - Douglas technology:

$$Y_{i,t} = A_t * N_{i,t} * exp(shk_Y) \tag{15}$$

,where $Y_{i,t}$is the output produced by firm i at time t, $N_{i,t}$is the demand for labor of firm i at time t, $A_t$is the technological progress at time t, and $shk_Y$ is a temporary shock in the production process which has to explain any variation in output that is not determined by the other variables in the equation.

As it can be seen in the previous formula, the amount of intermediate goods produced does not depend entirely on the labor supplied but also on the technological progress, $A_t$, which is the main trend in the model.

These firms are operating on a competitive market so, having the prices of the production factors and the final output given, they can only decide upon the amount of production factors they need for their activity, while minimizing costs:

$$\min_{N_{i,t}} W_t * N_{i,t} \tag{16}$$

subject to the constraint given by equation (15).

By doing the optimization, the demand for labor is determined:

$$N_{i,t} = \frac{Pyflex_t}{W_t} * Y_{i,t} \tag{17}$$

,where $W_t$is the wage paid by the firms in order to use the production factor needed, labor, and $Pyflex_t$is the nominal marginal cost and is defined as:

$$Pyflex_t = \frac{W_t}{A_t} * \frac{1}{exp(shk_Y)} \tag{18}$$

The firms have monopolistic power, each of them being the only supplier of a certain intermediate good, and are competitive on the market. They deliver these products to an aggregating agent which transformes them into a homogenous good that is further used as input in the final goods production.

The production function of the aggregating agent is:

$$Y_t = \left( \int_0^1 (Y_{j,t})^{1/\lambda_Y} dj \right)^{\lambda_Y}, 1 < \lambda_Y < \infty \tag{19}$$

,where $Y_t$is the aggregated intermediate output, $Y_{j,t}$is the intermediate output offered by firm j, and $\lambda_Y$is the mark-up of the intermediate goods producers over the marginal cost, the relationship between this mark-up and the elasticity of substitution of different types of intermediate goods is $\lambda_t = \frac{\theta_Y}{\theta_Y - 1}$.

The purpose of the aggregating agent is to minimize the costs:

$$\min \int_0^1 P^Y_{j,t} * Y_{j,t} dj \tag{20}$$

, subject to the constraint given by equation (19).

The resulting first order condition shows the demand of the aggregating agent for the intermediate good produced by firm j:

$$Y_{j,t} = Y_t * \left( \frac{P^Y_{j,t}}{P^Y_t} \right)^{\frac{\lambda_Y}{1-\lambda_Y}} \tag{21}$$

Moreover, the aggregated price index is given by the following expression:

$$P^Y_t = \left( \int_0^1 (P^Y_{j,t})^{\frac{1}{1-\lambda_Y}} dj \right)^{1-\lambda_Y} \tag{22}$$

As in the case of wage setting, the price rigidity of intermediate goods is set á la Calvo. The steps are the same and, after following them, we get the Phillips Curve for intermediate goods price inflation:

$$\pi^Y_t = \frac{\beta}{1+\beta} * \pi^Y_{t+1} + \frac{1}{1+\beta} * \pi^Y_{t-1} + \frac{(1-\beta * \xi_Y) * (1-\xi_Y)}{(1+\beta) * \xi_Y} * log \left( \frac{Pyflex_t}{P^Y_t} * \lambda^Y \right) (+shk_{P^Y_t}) \tag{23}$$

,where $\pi^Y_t = log(P^Y_t / P^Y_{t-1})$. The last variable in the equation, $shk_{P^Y_t}$, represents a shock given by the evolution of the mark-up, $\lambda^Y$.

### 2.2.2 Intermediate goods importers

The intermediate goods are either produced by domestic firms or imported from abroad. While the domestic goods are produced in the home country, as it has been seen in the previous section, there is also an infinite number of importing firms which acquire intermediate goods from other countries. These goods are further transformed by an aggregating agent into a homogenous imported intermediate good that is used for the production of final consumption or exporting goods.

Each importer is facing an optimization problem, to minimize its costs, having as given the amount and price of foreign exports and being constrained by the aggregating procedure which is adding up the exports of several countries into its imported intermediate goods.

$$\min_{\widetilde{X}^l_{i,t}} \int_0^1 S_t * \widetilde{P}^{M,l}_t * \widetilde{X}^l_{i,t} dl \tag{24}$$

subject to:

$$M_{i,t} = \left( \int_0^1 (\widetilde{X}^l_{i,t})^{\frac{\gamma-1}{\gamma}} dl \right)^{\frac{\gamma}{\gamma-1}} \tag{25}$$

,where $S_t$ is the exchange rate at time t, $\widetilde{P}^{M,l}_t$is the price of exporting goods of country l, $\widetilde{X}^l_{i,t}$is the amount of exports of country l to agent i, $M_{i,t}$stands for the imports of agent i from all the countries, and$\gamma$ represents the elasticity of substitution between the exports of foreign countries.

By doing the first order conditions, we get the following relations:

$$\widetilde{X}^l_{i,t} = \left( \frac{\widetilde{P}^{M,l}_t}{\widetilde{P}^M_t} \right)^{-\gamma} * M_{i,t} \tag{26}$$

,which is the demand of the importing firm i for the exports of country l and

$$\widetilde{P}^M_t = \left( \int_0^1 (\widetilde{P}^{M,l}_t)^{1-\gamma} dl \right)^{\frac{1}{1-\gamma}} \tag{27}$$

,which is the aggregated price index of all exports towards the home country.

Once the imports have been done, they are aggregated by a representative competitive firm to form a composite intermediate import good which is further used by final goods producers to make consumption and export goods.

The composite imported good, $M_t$, is produced using a CES technology with a continuum of imported intermediate goods, $M_{i,t}$, as inputs:

$$M_t = \left( \int_0^1 (M_{i,t})^{\frac{1}{\lambda_M}} di^{\lambda_M} \right)^{\lambda_M}, 1 < \lambda_M < \infty \tag{28}$$

,where $\lambda_M$is the importers' mark-up over the nominal marginal cost, the relationship between this mark-up and the elasticity of substitution of different types of imports offered by the importing agents being the following: $\lambda_M = \frac{\theta_M}{\theta_{M-1}}$.

As in the case of domestic intermediate goods, the demand of the aggregating agent for the intermediate imported good brought by the importing firm j is:

$$M_{j,t} = M_t * \left( \frac{P_{j,t}^M}{P_t^M} \right)^{\frac{\lambda_M}{1-\lambda_M}} \tag{29}$$

, and the aggregated price index given by the following expression:

$$P_t^M = \left( \int_0^1 (P_{j,t}^M)^{\frac{1}{1-\lambda_M}} dj \right)^{1-\lambda_M} \tag{30}$$

As in has been seen in the previous cases, following Calvo's method, and doing the math, we get the Phillips Curve for intermediate imported goods price inflation:

$$\pi_t^M = \frac{\beta}{1+\beta} * \pi_{t+1}^M + \frac{1}{1+\beta} * \pi_{t-1}^M + \frac{(1-\beta*\xi_M)*(1-\xi_M)}{(1+\beta)*\xi_M} * log\left( \frac{Pmflex_t}{P_t^M} * \lambda^M \right) (+shk_{P_t^M}) \tag{31}$$

,where $\pi_t^M = log(P_t^M / P_{t-1}^M)$. The last variable in the equation, $shk_{P_t^M}$, represents a shock given by the evolution of the mark-up, $\lambda^M$and $Pmflex_t = S_t * \tilde{P_t^M}$is the marginal nominal cost.

### 2.2.3 Consumption final goods producers

The final good that is used for domestic consumption, $C_t$, is produced in the home country using, as inputs, intermediate domestic and imported goods. Each competitive firm is facing an optimization problem, having to minimize its production costs:

$$\min_{Y_{i,j}^C, M_{i,j}^C} [P_t^Y * Y_{i,t}^C + P_t^M * M_{i,t}^C] \tag{32}$$

, subject to the following production function:

$$C_{i,t} = \left[ (1-\omega_c)^{1/\eta_C} * (Y_{i,t}^C)^{(\eta_C-1)/\eta_C} + (\omega_c)^{1/\eta_C} * (M_{i,t}^C)^{(\eta_C-1)/\eta_C} \right]^{\eta_C/(\eta_C-1)} \tag{33}$$

By doing the first order conditions, it results the demand for the production factors:

$$Y_{i,t}^{C} = (1-\omega_c) * \left(\frac{Pflex_t}{P_t^Y}\right)^{\eta_C} * C_{i,t} \quad (34)$$

$$M_{i,t}^{C} = (\omega_c) * \left(\frac{Pflex_t}{P_t^M}\right)^{\eta_C} * C_{i,t} \quad (35)$$

, where $C_{i,t}$is the consumption good produced by agent i, $Y_{i,t}^{C}$ and $M_{i,t}^{C}$ are the intermediate domestic and imported goods of agent i, while $P_t^Y$ and $P_t^M$ are their prices, $\omega_c$is the share of imports in consumption, $\eta_C$is the elasticity of substitution across consumption goods and $Pflex_t = \left[(1-\omega_c) * (P_t^Y)^{1-\eta_C} + (\omega_c) * (P_t^M)^{1-\eta_C}\right]^{\frac{1}{1-\eta_C}}$is the nominal marginal cost, equivalent to the Lagrange multiplier from the optimization problem.

The composite consumption good, $C_t$, is produced using a CES technology with a continuum of final goods, $C_{i,t}$, as inputs:

$$C_t = \left(\int_0^1 (C_{i,t})^{\frac{1}{\lambda_C}} di^{\lambda_C}\right)^{\lambda_C}, 1 < \lambda_C < \infty \quad (36)$$

,where $\lambda_C$is the final goods producers' mark-up over the nominal marginal cost, the relationship between this mark-up and the elasticity of substitution of different types of final consumption goods being the following: $\lambda_C = \frac{\theta_C}{\theta_{C-1}}$.

The demand of the aggregating agent for the final good brought by firm j:

$$C_{j,t} = C_t * \left(\frac{P_{j,t}}{P_t}\right)^{\frac{\lambda_C}{1-\lambda_C}} \quad (37)$$

, and the aggregated price index given by the following expression:

$$P_t = \left(\int_0^1 (P_{j,t})^{\frac{1}{1-\lambda_C}} dj\right)^{1-\lambda_C} \quad (38)$$

Once more, following Calvo, we get the Phillips Curve for final consumption goods price inflation:

$$\pi_t = \frac{\beta}{1+\beta} * \pi_{t+1} + \frac{1}{1+\beta} * \pi_{t-1} + \frac{(1-\beta * \xi_C) * (1-\xi_C)}{(1+\beta) * \xi_C} * log\left(\frac{Pflex_t}{P_t} * \lambda^C\right) (+shk_{P_t}) \quad (39)$$

,where $\pi_t = log(P_t/P_{t-1})$. The last variable in the equation, $shk_{P_t}$, represents a shock given by the evolution of the mark-up, $\lambda^C$.

### 2.2.4 Final goods exporters

The exporters of final goods are following the same production procedure as the consumption goods producers. They are using a CES technology:

$$X_{i,t} = \left[(1-\omega_x)^{1/\eta_x} * (Y_{i,t}^X)^{(\eta_x-1)/\eta_x} + (\omega_x)^{1/\eta_x} * (M_{i,t}^X)^{(\eta_x-1)/\eta_x}\right]^{\eta_x/(\eta_x-1)} \tag{40}$$

Their demands for production factors are:

$$Y_{i,t}^X = (1-\omega_x) * \left(\frac{Pxflex_t}{P_t^Y}\right)^{\eta_x} * X_{i,t} \tag{41}$$

$$M_{i,t}^X = (\omega_x) * \left(\frac{Pxflex_t}{P_t^M}\right)^{\eta_x} * X_{i,t} \tag{42}$$

, where $X_{i,t}$is the consumption good produced by agent i, $Y_{i,t}^X$ and $M_{i,t}^X$ are the intermediate domestic and imported goods of agent i, while $P_t^Y$ and $P_t^M$ are their prices, $\omega_x$is the share of imports used in the production of exporting goods, $\eta_x$ is the elasticity of substitution across different types of exports and $Pxflex_t = \left[(1-\omega_x) * (P_t^Y)^{1-\eta_x} + (\omega_x) * (P_t^M)^{1-\eta_x}\right]^{\frac{1}{1-\eta_x}}$is the nominal marginal cost, equivalent to the Lagrange multiplier from the optimization problem.

The output meant for export is aggregated by an agent into a composite exporting good, $X_t$, using a CES technology:

$$X_t = \left(\int_0^1 (X_{i,t})^{\frac{1}{\lambda_x}} di^{\lambda_x}\right)^{\lambda_x}, 1 < \lambda_x < \infty \tag{43}$$

,where $\lambda_x$is the exporting goods producers' mark-up over the nominal marginal cost, the relationship between this mark-up and the elasticity of substitution of different types of exporting goods being the following: $\lambda_x = \frac{\theta_x}{\theta_{x-1}}$.

As in the case of consumption goods, the demand of the aggregating agent for the exporting good made by firm j:

$$X_{j,t} = X_t * \left(\frac{\widetilde{P}_{j,t}^X}{\widetilde{P}_t^X}\right)^{\frac{\lambda_x}{1-\lambda_x}} \tag{44}$$

, and the aggregated price index given by the following expression:

$$\widetilde{P}_t^X = \left(\int_0^1 (\widetilde{P}_{j,t}^X)^{\frac{1}{1-\lambda_x}} dj\right)^{1-\lambda_x} \tag{45}$$

The prices are set à la Calvo in the currency of the importing country (LCP), and, as in the previous cases the Phillips Curve for exporting goods price inflation is:

$$\widetilde{\pi}_t^X = \frac{\beta}{1+\beta} * \widetilde{\pi}_{t+1}^X + \frac{1}{1+\beta} * \widetilde{\pi}_{t-1}^X + \frac{(1-\beta*\xi_x)*(1-\xi_x)}{(1+\beta)*\xi_x} * log\left(\frac{Pxflex_t}{P_t^X} * \lambda^x\right)(+shk_{P_t^X}) \quad (46)$$

,where $\widetilde{\pi}_t^X = log(\widetilde{P}_t^X / \widetilde{P}_{t-1}^X)$, $P_t^X = \widetilde{P}_t^X * S_t$and $shk_{P_t^X}$is a shock given by the evolution of the mark-up, $\lambda^x$.

The demand for the home country's exports is modeled similarly to the demand of the home country for imports. Thus, there is a continuum of importing companies in the foreign country which buy goods from the home country. Each of these firms is faced with an optimization problem, to minimize its costs having the exports of the home country and their prices given:

$$\min_{\tilde{X}_{i,t}^H} \int_0^1 \tilde{P}_t^{X,h} * \tilde{X}_{i,t}^h dh \quad (47)$$

subject to:

$$\tilde{M}_{i,t} = \left( \int_0^1 (\tilde{X}_{i,t}^h)^{\frac{\zeta-1}{\zeta}} dh \right)^{\frac{\zeta}{\zeta-1}} \quad (48)$$

,where $\tilde{X}_{i,t}^h$represents the exports of home country to importing agent i from the foreign country, $\tilde{M}_{i,t}$ stands for all the imports of agent i, $\tilde{P}_t^{X,h}$is the price of the exports of home country in the currency of the foreign country (LCP), and $\zeta$ is the elasticity of substitution between the exports of different countries towards the foreign country.

The results of this optimization problem are the demand of the importing agent i from the foreign country for the exporting goods of the home country:

$$\tilde{X}_{i,t}^h = \tilde{M}_{i,t} * \left( \frac{\tilde{P}_t^{X,h}}{\tilde{P}_t^{X,all}} \right)^{-\zeta} \quad (49)$$

, and the aggregated price index of the exports of all countries towards the foreign country given by the following expression:

$$\tilde{P}_t^{X,all} = \left( \int_0^1 (\tilde{P}_t^{X,h})^{1-\zeta} dh \right)^{\frac{1}{1-\zeta}} \quad (50)$$

## 2.3 Evolution of net foreign assets

The evolution of the net foreign assets (NFA) of the home country is:

$$NFA_t = exp(R^*_{t-1} + PREM_{t-1} + \Delta S_t) * NFA_{t-1} + 1 - \frac{(\widetilde{P}^X_t * S_t * M_t)}{P^X_t * X_t} \tag{51}$$

, where $PREM_t = -\rho_{NFA} * (NFA_t - NFA_{ss}) - (1-\rho_s) * (E_t(\triangle S_{t+1}) + \triangle S_t - 2 * \triangle S_{ss})$, in which the variables with subscript *ss* are at their steady state value.

## 2.4 Monetary policy

The home country's central bank is following a *domestic inflation targeting* (DIT) policy in which the nominal interest rate ($R_t$) is the monetary policy tool. The monetary policy rule is of Taylor-type, only that the central bank responds to deviations of future inflation from target.

$$R_t = \rho_T * R_{t-1} + (1-\rho_T) * (R^{neutral}_t + \varpi * (\pi^C_{t+1} - \pi^{Tar}_{t+1})) + shk_{policy} \tag{52}$$

, where $shk_{policy}$is the monetary policy shock and $R^{neutral}_t = log(1/\beta) + \pi^{Tar}_t + \Delta A_{ss}$is the neutral interest rate.

## 2.5 Exogenous processes

Exogenous processes are defined for the imports of the foreign country, $\tilde{M}_{i,t}$, the worldwide technological progress, $A_t$, the aggregated price index of the exports of all countries towards the foreign country,$\tilde{P}^{X,all}_t$, aggregated price index of all exports towards the home country $\tilde{P}^M_t$, foreign interest rate $R^*_t$, the worldwide inflation target $\pi^{Tar}_t$, respectively as:

The evolution of $\tilde{M}_{i,t}$, $A_t$,$\tilde{P}^{X,all}_t$,$\tilde{P}^M_t$ is given by a first order autoregressive process:

$$\triangle Z_t = (1-\rho_Z) * \triangle Z_{ss} + \rho_Z * \triangle Z_{t-1} + shk_Z \tag{53}$$

,where $Z_t = \tilde{M}_{i,t}, A_t, \tilde{P}^{X,all}_t, \tilde{P}^M_t$, $\triangle Z_t = log(Z_t/Z_{t-1})$ is the growth rate ,$\rho_Z$shows the degree of persistence and $shk_Z$is a permanent shock for the level and has temporary effects on the growth rate.

The evolution of $R^*_t$and$\pi^{Tar}_t$ is also given by a first order autoregressive process:

$$Z_t = (1-\rho_Z) * Z_{ss} + \rho_Z * Z_{t-1} + shk_Z \tag{54}$$

,where $Z_t = R^*_t, \pi^{Tar}_t$, $\rho_Z$shows the degree of persistence and $shk_Z$is a permanent shock.

Having exogenous processes for foreign and worldwide variables, it is proven that while the small open economy is affected by foreign and worldwide activity, it has little or no influence on the rest of the world.

# 3 Estimation

## 3.1 Data

The data which was used for estimating this DSGE model is represented by 14 time series for the Romanian economy: consumption (including investment and government spending), domestic exports, domestic imports, consumption final goods prices (CPI), imported goods prices, export goods prices, nominal wages, exchange rate (RON/EUR), nominal interest rate, inflation target, foreign aggregate imports (of Euro area), foreign imports prices (of Euro area), foreign exports prices (of Euro area), and nominal interest rate of Euro area.

The reason why I have chosen to use a large number of observable variables was that, since the model is complex and contains many equations, having more observables can help identify the estimated parameters in a satisfactory way.

The data was retrieved from the databases of the National Institute of Statistics, the National Bank of Romania and EUROSTAT.

The estimation period runs from 2001Q1 to 2011Q1. The choice of the period was conditioned by the fact that most of the Romanian macroeconomic time series chosen for the estimation process have an erroneous behavior prior to year 2000, which motivated their exclusion from the sample. To perform the estimation, quarterly data was used, over these years.

The domestic and foreign prices are fixed-base indices (e.g. 100% for 2001Q1), the interest rates are expressed in percentages,wages are given in RON, the domestic consumption, exports and imports are expressed in constant prices (millions RON), and the foreign exports and imports are also in constant prices (millions Euro).

## 3.2 Calibration

In order to avoid the problem of identification that is very common to happen when dealing with DSGE models, it is recommended to calibrate some of the parameters.

The parameters I chose to calibrate are: the discount factor $\beta$ which was set to 0.9999, the parameters from the utility function $\sigma = 1$ and $\varphi = 3$ that are in accordance with Gali and Monacelli (2005) and the values for the mark-ups $\lambda_X$,$\lambda_C$,$\lambda_M$, $\lambda_W$, $\lambda_Y$ which were all set to 1.3.

Other two parameters that are calibrated are the share of imports in the domestic final consumption goods $\omega_C$ and in export goods $\omega_x$. Following Benes et. al. (2005) and Adolfson et. al. (2005), $\omega_C$was given a value of 0.25, a highly controversial figure because, while it has been shown in the Romanian literature that usually the share of imports in consumption is about 15-25%, some say that it is about 70%, mostly in the food sector (see Orgonas (2010)). Moreover, to the imports intensity of exports $\omega_x$ it was attributed a value of 0.6 because, in the production process, mostly the manufacturing industry uses imported raw materials, a good example being the Romanian automobiles producer, Dacia.

Another parameter that I chose to calibrate is $\varpi$, a parameter that is usually estimated, but for which unfortunately I could not obtain a robust estimate. This parameter was set to 1.7 which was the prior mean in Benes et. al. (2005) and Adolfson et. al. (2005), and, since the posterior estimate proved to be very close to this value, it was not necessary to use their estimate instead of the prior.

Following Adolfson et. al. (2005), I also calibrate the substitution elasticity between foreign and domestic consumption goods, $\eta_C$, to a fixed value of 5.

In what concerns the standard deviations of the shocks, some are also calibrated. I chose to calibrate first the standard deviations of the measurement errors which were set to 0.01.

Also the standard deviations of the shocks from the exogenous processes $shk_Z$, where $Z = \tilde{M}_{i,t}, \tilde{P}_t^{X,all}, \tilde{P_t^M}, R_t^*, \pi_t^{Tar}$, are set to 0.01.

In addition to the standard deviations of the shocks provided by the exogenous (pre-estimated) foreign VARs, there are also the parameters that show the degree of persistence in these equations which are kept fixed at their posterior mean estimates throughout the estimation of the DSGE model parameters. Therefore, $\rho_{\tilde{M}_{i,t}} = 0.5886$, $\rho_{\tilde{P}_t^{X,all}} = 0.5089$, $\rho_{\tilde{P_t^M}} = 0.527$, $\rho_{R_t^*} = 0.9294$, and $\rho_{\pi_t^{Tar}} = 0.9673$.

Finally, there are some steady-state variables that appear in the model and that have to be calibrated. First of all, the steady states of some price inflations such as$\tilde{\pi}_t^{\widetilde{M}}, \tilde{\pi}_t^{X,all}, \pi_t^{Tar}$are set to 2/400 in order to equal the ECB long-term inflation target of 2% per year. Secondly, the steady state of the growth rate of technological progress $\triangle A_{ss}$ is set to 3/400, which means an annual increase of 3%. Furthermore, to$\triangle S_{ss}$it is attributed a value of 0/400, which means keeping a constant nominal exchange rate per year that is in line with ECB's convergence criterion of having exchange rate stability. The last variable to be calibrated is the steady state value of net foreign assets $NFA_{ss}$which is set to 0.

## 3.3 Prior distribution

The choice of priors plays an important role in the estimation of DSGE models and is one of the hardest parts in implementing Bayesian techniques.

As it is the commonly done in the literature (see Amisano and Tristani (2007)), I chose for each of the parameters that had to be estimated a prior distribution by following these criteria: positive parameters were given an Inverse Gamma prior and the parameters constrained on the unit simplex were assumed to follow a Beta distribution.

In Appendix - Table 1 the assumptions concerning the priors are presented, which greatly benefited from insights from Fernàndez-Villaverde (2009), Adolfson et al. (2007), Smets et. al. (2007), and Ried (2009).

The prior for the habit persistence parameter $\chi$ is centered at 0.7 with a standard deviation of 0.15. The prior mode of the substitution elasticity between foreign and domestic export goods, $\eta_x$, is set to 1.5, which is a standard value used in the macro literature. Likewise, the prior mode of the substitution elasticity among imports in the foreign economy, $\zeta$ , is set to 1.5 with a standard deviation of 1.

Although in the literature it is common to assume that prices adjust at three quarters, in the case of Romania, this occurs more often (see Copaciu et. al. (2010)). Thus, for the price stickiness parameters I chose values that indicate an average length between price adjustments of 2 quarters: $\xi_Y$ and$\xi_C$are set to 0.55, $\xi_M$ is assumed to be smaller and equals 0.4 and $\xi_X$ is set to 0.6. In what concerns the wage stickiness parameter, this one was set to 0.75 because wages usually adjust in at least three quarters, which is also true for Romania. The prior standard deviation of the stickiness parameters for imports and exports are larger than those for wages and consumption prices, reflecting a greater prior uncertainty.

For the standard deviations of shocks, I had no strong a-priori convictions and therefore I set priors as harmonized and loose as possible. For all the shocks, the mean was set at 0.1, while their standard deviations were set equal to Inf.

The last parameters that are considered for estimation are: $\rho_A$, $\rho_T$,$\rho_s$ and$\rho_{NFA}$. The prior mean for the autocorrelation coeffi the autocorrelation coefficient of productivity AR(1) process$\rho_A$was set to 0.85, with a standard deviation of 0.1. The interest rate smoothing coefficient $\rho_T$ was set to 0.85, having a standard deviation of 0.05. Finally, the two parameters from the risk premium's formula, $\rho_s$ and $\rho_{NFA}$ have their means set to 0.45 with a standard deviation of 0.15 for $\rho_s$, and 0.003 with a standard deviation of 0.001 for $\rho_{NFA}$.

## 3.4 Posterior estimates

As it is explained in Adolfson et. al. (2005),the joint posterior distribution of all estimated parameters is obtained in two steps. First, using standard numerical optimization routines of IRIS toolbox in MATLAB® R2010a, the posterior modes and the Hessian matrix evaluated at the mode are computed[3]. Second, with an adaptive version of the random walk Metropolis-Hastings

[3] The codes can be provided upon request

algorithm, 100,000 draws from the joint posterior are generated. The results are reported in Appendix - Table 1.

Some of the results are noteworthy. Starting with the model's rigidities, the habit formation parameter has a posterior value of 0.731 which is similar to the result of Adolfson et. al. (2005). Moreover, the high wage stickiness ($\xi_W$=0.84) shows that wage contracts are usually negotiated on a yearly basis. This is in line with Copaciu et. al. (2010), in which survey evidence indicates that about 72% of the Romanian firms change wages once per year. However, although in Copaciu et. al. (2010)it is stated that firms change prices every 5 months, the stickiness parameters for consumption goods and intermediate domestic goods indicate that price adjustments occur more rarely, at least every 2 quarters. The difference might come from the fact that, while the conclusions drawn in Copaciu et. al. (2010)are based on a survey conducted in 2006, the estimation was done using data from 2001Q1 to 2011Q1. Furthermore, imports have almost flexible prices (with a stickiness parameter of 0.33), being dependent on foreign variables such as the exchange rate, and exports' prices are more rigid than domestic prices in order to keep competitiveness at international level.

The elasticities of substitution among goods in foreign market ($\varsigma$) and among import and domestic intermediate goods in producing export goods ($\eta_x$) are quite low, the estimated value for $\varsigma$ being even less than unity, despite the fact that they had priors that allowed for large values. This problem was also identified by Justiniano and Preston (2010), who explain that estimated open economy models inference on this parameters has tended to produce either small elasticities, particularly with complete markets, or very large values, recommending for further reading Rabanal, Tuesta (2005)and Adolfson et. al. (2005) respectively.

The posterior mode of the persistence parameter in the unit-root technology process is estimated to be 0.92. This shows that there is a significant amount of persistence in the data.

The coefficient on the lagged interest rate from the Taylor rule, $\rho_T$ =0.86, which indicates that the monetary authority has a strong desire to smooth the changes on nominal interest rates over time.

The last two estimated coefficients belong to the risk premium formula, $\rho_s$ reaching a value of 0.43, while $\rho_{NFA}$ equals 0.0027.

Finally, starting from the same uninformative priors for all standard deviations of shocks, the model revealed the sources of fluctuations in the Romanian economy.

# 4 Results

## 4.1 Historical simulations

In order to decide upon the necessity of having a DSGE model for the Romanian economy, it must be firstly seen how well does the model fit the reality. Therefore, I will start the evaluation of the model by analyzing its ability to reproduce the historical pattern of the main variables. Having the solution of the model together with the realised values of the exogenous driving processes it is possible to trace out the paths of the most important variables and compare them to the actual data over the same period.

The figures below are used as exemplification. The model is capturing most turning points in the variables and reproduces well the magnitude of fluctuations.

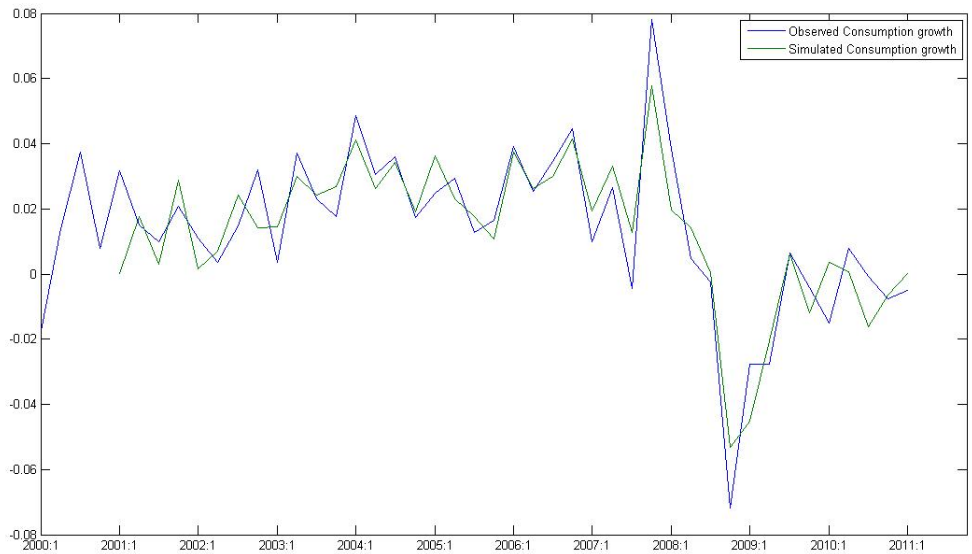


Figure 1: Historical simulation of consumption growth

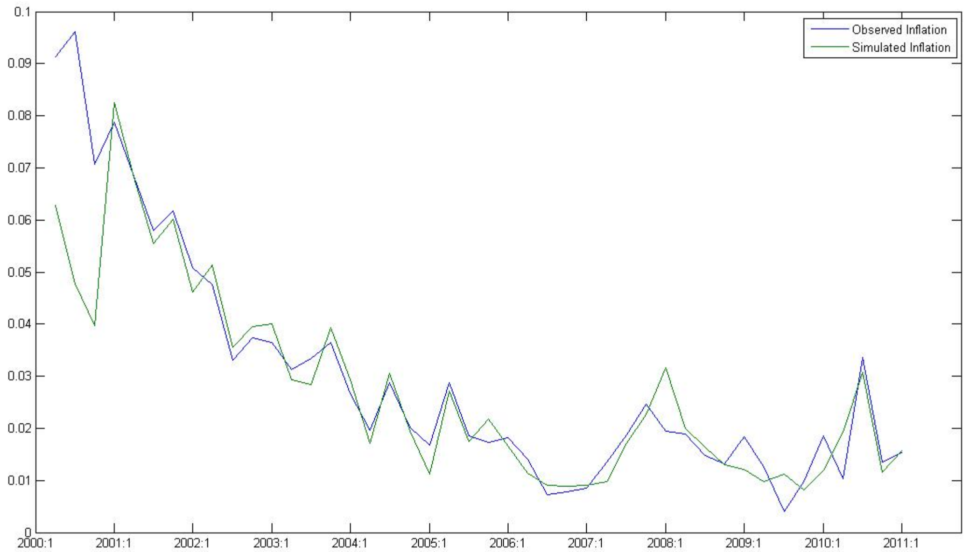


Figure 2: Historical simulation of inflation

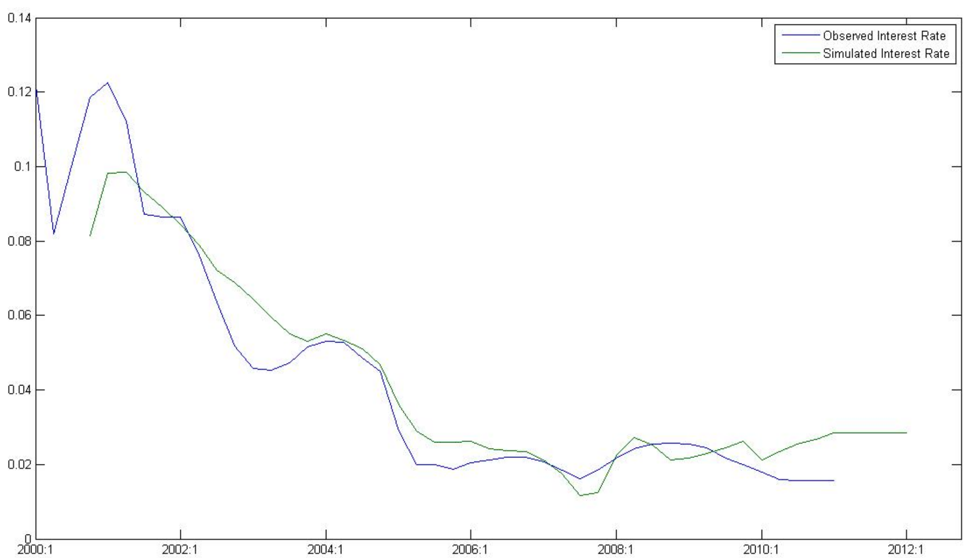


Figure 3: Historical simulation of interest rate

## 4.2 Impulse response functions

In Figure 4 it can be seen the effect of a 1% increase in productivity, a positive temporary supply shock. The economy has a temporary gain in terms of productivity due to this rise of productivity on the short term. This increase in productivity lowers real marginal costs of firms and leads to lower inflation since the firms that can adjust their prices lower them. Output and consumption increase. On impact, the increase in productivity leads to a decrease in employment. Also the domestic currency is influenced, being depreciated.

The response of the central bank to the effects of this shock is a lowering of the interest rate. Thus, the Romanian currency appreciates against the euro to the extent implied by the UIP. The decrease of the interest rate stimulates consumption and output equally. The rise in output also increases marginal costs, driving prices up. Therefore, on the long run, all the variables converge towards their equilibrium.

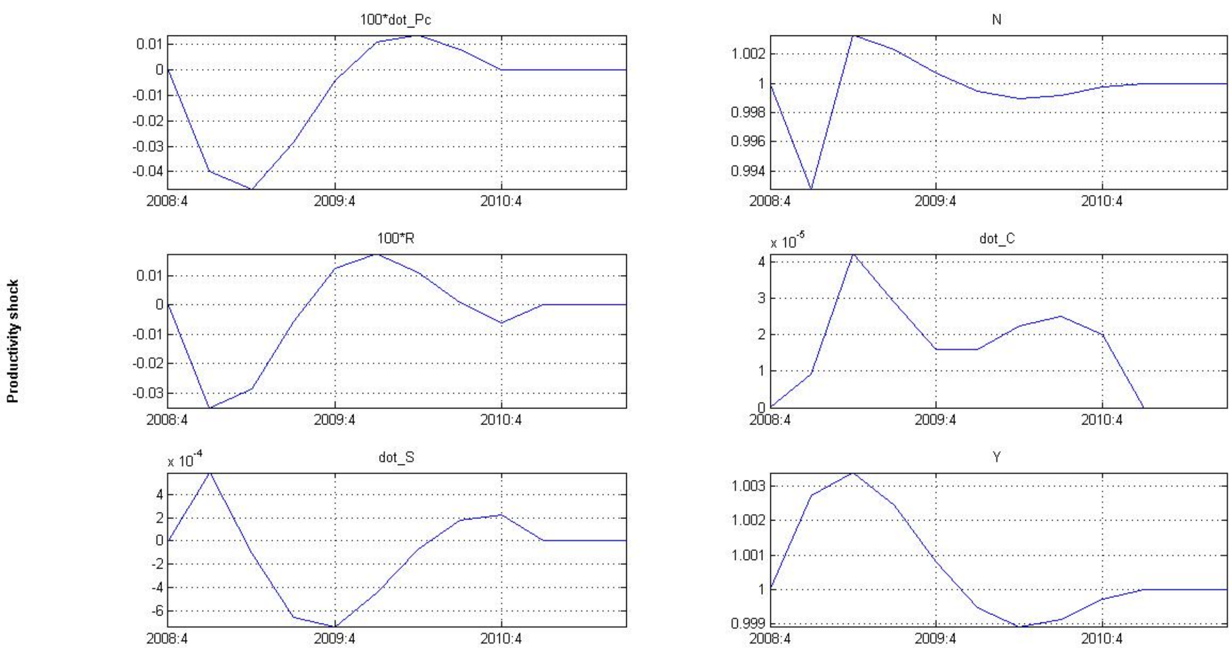


Figure 4: Impulse response function - productivity shock

Figure 5 shows the effects of a contractionary monetary policy shock, an increase in the short-term nominal interest rate. Having price rigidity, an increase, on the short run, of the nominal interest rate, implies an increase in the real interest rate. In this case, investment either domestic or foreign becomes less attractive. Thus, the Romanian currency is appreciated, which leads also to a decrease in import prices, and finally in domestic prices. Moreover, a higher real interest rate implies a drop in consumption, which is followed by a drop in production. Less production results in a reduction of employment.

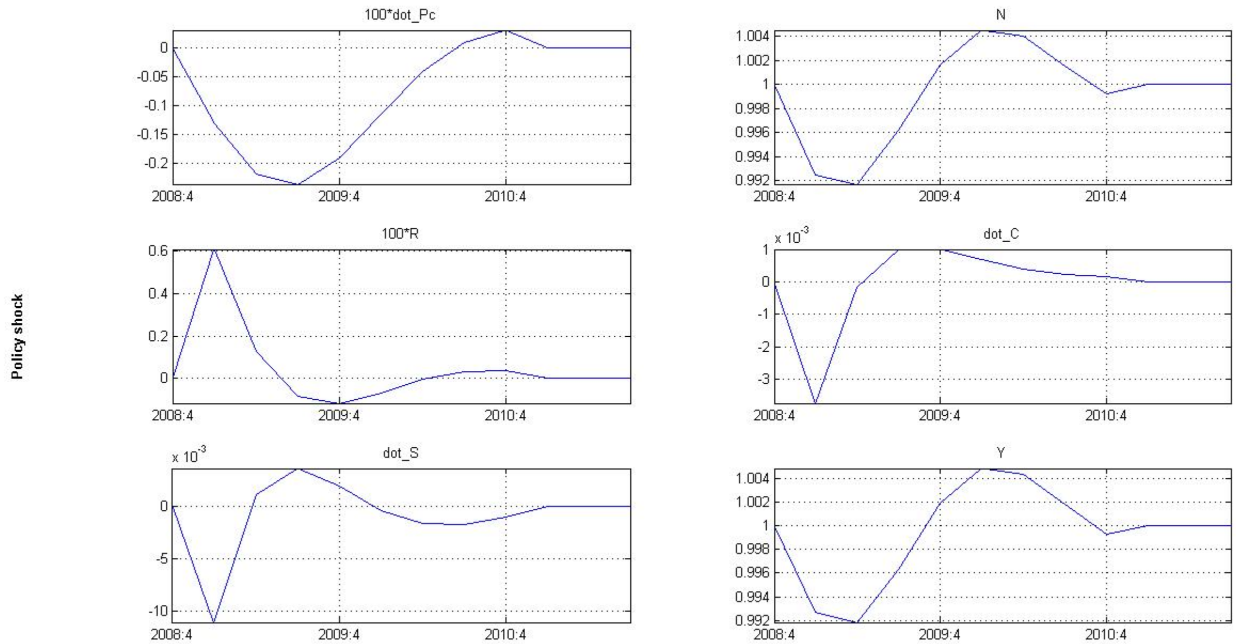


Figure 5: Impulse response function - monetary policy shock

## 4.3 Forecasts

The unconditional forecast runs from the initial condition supplied in the input database, the initial conditions consisting of the mean and the root mean square error (initial uncertainty) for each variable.

In Figure 6 are pictured the unconditional forecasts for nominal interest rate, inflation, productivity, and wage inflation. The nominal interest rate is expected to decrease after 2011Q1, a forecast which until 2012Q1 proved to be wright since the nominal interest rate of the NBR's monetary policy has followed a decreasing trend[4]. Also inflation is expected to decrease, a result which goes in line with NBR's current forecasts[5]. Furthermore, productivity and wage inflation are supossed to increase after 2011Q1, which is complying with the "Projection of the Key Macroeconomic Variables for 2011-2015"[6].

[4] see http://bnr.ro/Indicatori-de-politica-monetara-1744.aspx

[5] see http://bnr.ro/Proiectii-BNR-4351.aspx

[6] http://www.cnp.ro/user/repository/prognoza_2011-2015_varianta_de_toamna_2011.pdf

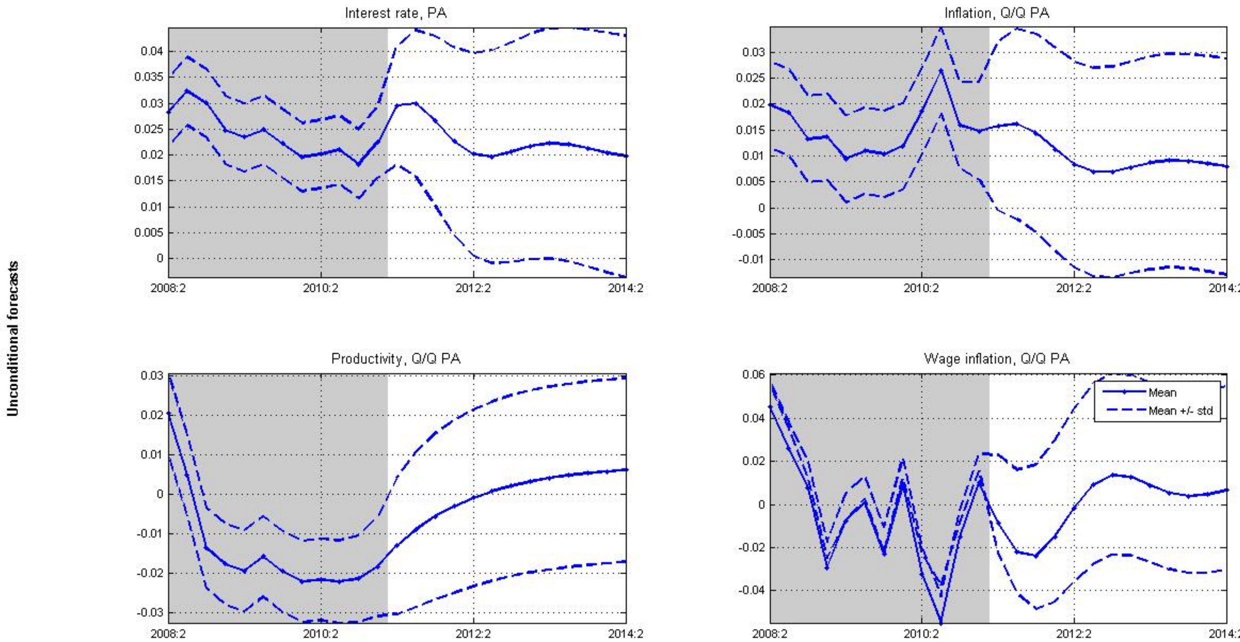


Figure 6: Unconditional forecast

# 5 Conclusions

In this paper, I chose to develop a New-Keynesian DSGE model for the Romanian economy and estimate it using Bayesian techniques in order to see whether such a model can be used in the monetary policy decision making of the NBR.

This is a medium-sized model which contains most macroeconomic variables of interest and several domestic and foreign shocks. Its estimation results are in line with the available national and international literature. Some of the estimation results are noteworthy. For example, the habit formation parameter of 0.731 is similar to the result of Adolfson et. al. (2005). Moreover, the high wage stickiness ($\xi_W$ =0.84) shows that wage contracts are usually negotiated on a yearly basis, which is in line with Copaciu et. al. (2010). The stickiness parameters for consumption goods and intermediate domestic goods indicate that price adjustments occur more rarely, at least every 2 quarters. Furthermore, imports have almost flexible prices (with a stickiness parameter of 0.33), being dependent on foreign variables such as the exchange rate, and exports' prices are more rigid than domestic prices in order to keep competitiveness at international level.

However, to estimate a model for a transition economy, as it is the case of Romania, it is not easy. The main reason is that you have at your disposal a short estimation period, in this case it runs from 2001Q1 to 2011Q1 because most of the Romanian macroeconomic time series chosen for the estimation process have an erroneous behavior prior to year 2000. In this case, it is very probable to get "prior driven" estimates, and, although for some of the parameters, mostly for those governing the persistence and volatility of shocks, the prior and posterior distributions were distinct, there were some parameters whose posterior distributions were very close to their respective priors. This is the problem of not having a long and reliable time series, and, unfortunately, there is not much to be done for the moment in this respect.

The comparison of the model to the real world indicates that the model performs rather well along standard dimensions: it can replicate the historical path of main Romanian variables quite accurately; it has sensible dynamic properties, proven by its implied IRFs, and can be used to forecast the short to medium term path of the economy.

Nevertheless, the model is not yet fully developed. For example, it can be enlarged in order to include the government as the fiscal authority and the financial/banking sector, the banking sector being very important for the Romanian economy.

In conclusion, this paper is just one of the first steps in filling out a gap and hope that it can contribute to the adoption of the DSGE in NBR's monetary policy, as it is already done by the central banks of many countries and, in particular, by the European Central Bank.

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# A Prior and posterior distribution of parameters

| Parameter | Prior | | | Posterior | |
|---|---|---|---|---|---|
| | Type | Mean | St. Dev. | Mode | St. Dev. (Hessian) |
| $\chi$ | beta | 0.7 | 0.15 | 0.731 | 0.164951 |
| $\eta_x$ | invgamma | 1.5 | 0.5 | 1.25 | 0.336935 |
| $\varsigma$ | invgamma | 1.5 | 1 | 0.9285 | 0.384286 |
| $\xi_C$ | beta | 0.55 | 0.15 | 0.5625 | 0.171518 |
| $\xi_M$ | beta | 0.4 | 0.2 | 0.3334 | 0.274851 |
| $\xi_Y$ | beta | 0.55 | 0.2 | 0.5814 | 0.279814 |
| $\xi_W$ | beta | 0.75 | 0.15 | 0.8437 | 0.165241 |
| $\xi_X$ | beta | 0.6 | 0.2 | 0.6666 | 0.275257 |
| $\rho_A$ | beta | 0.85 | 0.1 | 0.9218 | 0.0841398 |
| $\rho_T$ | beta | 0.85 | 0.05 | 0.8646 | 0.047147 |
| $\rho_s$ | beta | 0.45 | 0.15 | 0.4376 | 0.173986 |
| $\rho_{NFA}$ | beta | 0.003 | 0.001 | 0.0027 | 0.00092495 |
| $\sigma_{shk_H}$ | invgamma | 0.1 | Inf | 0.0291 | 0.00459703 |
| $\sigma_{shk_W}$ | invgamma | 0.1 | Inf | 0.0232 | 0.00381593 |
| $\sigma_{shk_Y}$ | invgamma | 0.1 | Inf | 0.0280 | 0.0120985 |
| $\sigma_{shk_{P_M}}$ | invgamma | 0.1 | Inf | 0.0255 | 0.00332353 |
| $\sigma_{shk_P}$ | invgamma | 0.1 | Inf | 0.0093 | 0.00155655 |
| $\sigma_{shk_A}$ | invgamma | 0.1 | Inf | 0.0130 | 0.00291228 |
| $\sigma_{shk_{UIP}}$ | invgamma | 0.1 | Inf | 0.0335 | 0.00613531 |
| $\sigma_{shk_{P_Y}}$ | invgamma | 0.1 | Inf | 0.0370 | 0.00563046 |
| $\sigma_{shk_{P_X}}$ | invgamma | 0.1 | Inf | 0.0246 | 0.00282979 |
| $\sigma_{shk_{policy}}$ | invgamma | 0.1 | Inf | 0.0107 | 0.00224215 |

Table 1: Prior and posterior distribution of parameters