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Economic Development of Visegrad Countries: Macroeconomic DSGE Models

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ECONOMIC DEVELOPMENT OF VISEGRAD COUNTRIES: MACROECONOMIC DSGE MODELS

Abstract:

The Working Paper deals with estimations of cash-in-advance dynamic stochastic general equilibrium model for the Visegrad countries and the Euro area. The CIA approach stresses the medium-of-exchange function of money. Money is directly used to purchase consumption goods. This model framework is used for estimations on the quarterly time series. The estimation is realized by Bayesian technique. More concretely, we used the Metropolis-Hastings algorithm to Markov Chain Monte Carlo. The values of estimated parameters for all countries are analyzed. The behavior which is represented by impulse response functions is discussed.

Abstrakt:

Studie se zabývá odhady cash-in-advance dynamického stochastického modelu všeobecné rovnováhy pro visegrádské země a Euro zónu. CIA přístup zdůrazňuje funkci peněz jako směnného prostředku. Peníze jsou přímo použity na nákup spotřebního zboží. Tento modelový rámec je použit k estimaci na čtvrtletních časových řadách. Odhady jsou provedeny pomocí bayesovské techniky. Konkrétně jde o Monte Carlo Metropolis-Hastings algoritmus. Hodnoty odhadnutých parametrů pro všechny země jsou analyzovány. Chování, které je představováno funkcemi impulsních odezev, je diskutováno.

Reviewer:
Mgr. Jan Vlček, PhD.

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1. INTRODUCTION

The interest in structural macroeconomic modeling issues has been rising rapidly since 1970s. There are many factors which underlie this dynamic development. The advancement of computer science has enabled estimations or simulations of linear as well as nonlinear macroeconomic models with “complicated” interdependent relations. The gradual abandonment of Keynesian[1] macroeconomics after the Lucas Critique in the late 1970s contributed to the increased interest in macroeconomic modeling in order to find suitable models for the macroeconomic analysis etc. Today, the structural dynamic stochastic general equilibrium (DSGE) macroeconomic models are the most used tools for the macroeconomic analysis, business cycle analysis or monetary policy evaluation.[2] These models are judged according their ability to replicate realistic patterns of co-movement among key macroeconomic variables and impulse responses to structural shocks as the total factor productivity shock or the unexpected change in the growth rate of money supply.

The neoclassical growth models are the backbone of modern business cycle theory. In fact, real business cycle theory (RBC) is simply a Ramsey neoclassical growth model with stochastic technology shocks. A typical RBC model posits real side shocks as the sources of business cycles, and these shocks are propagated over time as they interact with production technologies and houses preferences. But the standard neoclassical growth model represents the non-monetary economy. Critics may argue that the absence of monetary factors is an important weakness of RBC models. If we want to study real and monetary sectors simultaneously, we must incorporate the monetary sector into the model framework. Within this model framework, we are studying the economy in the long run. Thus, the prices and wages are flexible. In order to incorporate monetary sector, the role for money must be specified so that the agents will wish to hold positive quantities of money. In this paper, we use the cash-in-advance approach where the medium-of-exchange role of money is stressed. Money is used to purchase consumption goods.

The objective of this Working Paper is to present results of the estimations of monetary CIA DSGE model on time series of Visegrad countries and the Euro area. The estimation is realized by Bayesian technique. We used the Metropolis-Hastings algorithm to Markov Chain Monte Carlo (MCMC). The analysis of estimation results, for example estimated values of model parameters, can help us to know

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[1] Today, the term “New Keynesian” is widely used in many papers. It is adopted from some papers, such as from Clarida, Gertler and Galí (1999). Nonetheless, a more convenient term should be “New Neoclassical Synthesis”.

[2] The brief history of structural macroeconomic models can be found in Polanský (2006).

more about long-run development of these countries. Moreover, the estimation results might be used for future estimations and analyses of more sophisticated models that contain nominal rigidities, exchange rates, adjustment costs etc.

This paper is structured as follows: section 2 briefly describes ways that can be used to introduce money in macro models. It clears up the MIU approach, shopping-time models and the CIA approach. The third section of the paper demonstrates the CIA approach in detail. The fourth section describes the CIA framework which is used for the estimations. Section 5 presents the solution of the model. Next part deals with estimations for the Czech Republic. It clears out the data of the model, the Bayesian technique for the estimation, the choice of priors for the estimation and the estimation results. The estimated values of the model and impulse responses are discussed. Section 6 then presents estimation results for other Visegrad countries and the Euro area. The final part concludes the paper.

2. WAYS TO INTRODUCE MONEY IN MACRO MODELS

There are three general approaches to incorporating the monetary sector into the general equilibrium (GE) models. The first one is the money-in-the-utility (MIU) approach. It claims that real money balances directly enter the agents' utility functions. In this case, the household solves optimization problem where the utility function has the form

$$\max \sum_{t=0}^{\infty} \beta^t u(C_t, M_t / P_t) ,$$

where β the discount factor, u is the utility function with some characteristics, C denotes the real consumption and M / P denotes real money balances. One motivation for having real money balances in the utility function is that having cash may save time in transactions. In other words, time for shopping is a decreasing function of real money balances. Disadvantage of this approach is that it simply assumes the problem of positive value for money away. The postulating that money yields direct utility guarantees that money will be valued.[3]

The second approach which lies between MIU approach and cash-in-advance models (which are the macroeconomic framework within this paper) deals with the shopping time.[4] In these models, time and money are used to produce transaction services that are required to purchase consumption goods. Higher levels of money holdings reduce the time needed for shopping, thereby increasing the individual agent's leisure. When the total time is normalized to equal 1, the utility function of the representative household becomes

$$\sum_{t=0}^{\infty} \beta^t u(C_t, 1 - l_t - l_t^s) ,$$

where l denotes time spent in market employment and l^s denotes time spent in shopping, which is an increasing function of consumption and a decreasing function of real money holdings. Subsequently, we can rewrite the utility as a function of consumption, labour supply and money holdings.

On the other hand, we often think of money as yielding utility indirectly. The third approach, the cash-in-advance theory, stresses the medium of exchange function of money. Money is held in order to facilitate transactions. This approach will be demonstrated in the next parts of this paper.

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[3] See Walsh (2003) for more details.

[4] Some authors do not classify shopping-time models into a separate category.

3. CASH-IN-ADVANCE APPROACH

The cash-in-advance approach to macroeconomic modeling stresses the medium-of-exchange function of money. Money is used to purchase consumption goods. In these models, households face at least two constraints – besides the standard budget constraint it is a cash-in-advance constraint.

The exact form of the CIA constraint depends on the two model properties. The first feature of the CIA constraint is determined by the types of purchases that are subjected to the CIA constraint. We may restrict purchasing of all consumption and investment goods, consumption goods only, some subset of consumption goods etc. The second characteristic is model timing, more concretely opening time of goods and credit markets.[5] If the asset market opens first and then the goods market opens, agents are able to allocate their portfolio between cash and other assets at the start of the period, after observing any current shocks but prior to purchasing goods. This implies that if there is a positive opportunity cost of holding money and the asset market opens first, agents will only hold an amount of money that is just sufficient to finance their desired level of consumption. Whenever the nominal interest rate is positive, the opportunity cost of holding money is positive as well. In other words, no one would accumulate more cash than strictly needed for consumption purposes since there are better investment opportunities. The result is that the CIA constraint will always hold with equality.[6] The example of simply CIA constrained economy where the credit market open first is

$$P_t C_t \leq M_{t-1} - b_t \,,$$

where b denotes nominal bonds.

The second possibility is that the goods market opens first. In this case, the agents have only the cash carried over from the previous period for their spending available. This implies that the cash balances must be chosen before agents know how much spending they will wish to undertake. In nominal terms, the most simplified CIA constraint with this timing schedule has the form

$$P_t C_t \leq M_{t-1} \,.$$

[5] See the timing of the model in the beginning of the next section.

[6] This conclusion is true for the certainty case. See Walsh (2003) for more details.

4. THE CIA MODEL

This section presents the monetary business cycle dynamic stochastic general equilibrium (DSGE) model.[7] The model economy consists of a representative household, a firm, and a financial intermediary. The financial intermediary and the representative firm are owned by households. The firm owns the capital stock, but hires labour services from the household.

As was noted, the model timing is very important in cash-in-advance approach. Within this model, the representative household inherits the entire stock of money of the economy at the beginning of period t. Then the representative household observes current shocks in the economy. In other words, the portfolio decisions completely reflect current shocks. Because the model contains monetary sector as well as the non-monetary one, there are two shocks. The first one is the technology shock; the second one reflects current period surprise change in money growth. Both shocks are modeled as exogenous.

After the observation, the household determines the amount of deposits at the financial intermediary. These deposits earn interest and are denoted by D_t. The financial intermediary receives these deposits from the representative household and in addition, it receives a monetary injection from the central bank. The financial intermediary lends these funds to the representative firm.

The representative firm hires labour services from the households. After the firm produces its output, it uses money borrowed from the financial intermediary to pay wages to the household. Thus, the household's cash balances are

$$M_t - D_t + W_t H_t ,$$

where W denotes the nominal hourly wage and the H denotes hours worked. This specification of the model timing implies that all consumption purchases must be paid for with the accumulated cash balance.[8] The firm pays dividends from its net cash inflow to the household. Moreover, the household receives its deposits back at the financial intermediary and dividends from the net cash inflow of the bank.

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[7] This model is often called as standard CIA model in the sense that date *t* exogenous disturbances occur before date *t* decisions are made. Naturally, this model serves as the initial model for many extensions. See Schorfheide (2000), Nason and Cogley (1994), Walsh (2003) and citations therein for more details about this model.

[8] The CIA constraint deals with all consumption goods. The household is not restricted within its purchases.

4.1. Exogenous Disturbances

The model economy is perturbated by exogenous shocks. As was noted earlier, the CIA model contains real and nominal sectors, so we need to introduce at least two disturbances. The first is the technology shock which is denoted by A. This shock evolves according to

$$\ln A_t = \gamma + \ln A_{t-1} + \varepsilon_t^A, \quad (1)$$

where $\varepsilon_t^A \sim N(0, \sigma_A^2)$.

In addition, the model includes an exogenous stochastic process for the growth rate of the monetary injection from the central bank which has the form

$$\ln m_t = (1-\rho)\ln m^* + \rho \ln m_{t-1} + \varepsilon_t^m, \quad (2)$$

where the parameter ρ lies between zero and one, i.e. $0 < \rho < 1$ and $\varepsilon_t^m \sim N(0, \sigma_m^2)$. The unconditional mean of monetary injection growth is denoted with m^*. This equation can be interpreted as a simple monetary policy rule without feedbacks, where the monetary injection growth is defined as

$$m_t = M_{t+1} / M_t,$$

where M_t denotes the stock of money base at the end of date $t-1$. The innovations ε_t^m capture unexpected changes of the money growth rate due to "normal" policy. Changes in m^* or ρ correspond to rare regime shifts. Innovations to the technology and monetary injection growth shocks are uncorrelated to all leads and lags.

4.2. The Representative Household

An infinitely lived representative household chooses consumption C_t, hours worked H_t, and non-negative deposits D_t in order to maximize the expected utility function of the form

$$E_0[\sum_{t=0}^{\infty} \beta^t ((1-\psi)\ln C_t + \psi \ln(1-H_t))], \quad (3)$$

where the parameters β and ψ lie between zero and one, $0 < \beta, \psi < 1$ and E_0 is the expectations operator conditional on date 0 information.

In CIA models, households face at least two constraints. The first is the resource constraint. It says that the income of the representative household equals or exceeds the expenditures. Within this model, dividend payments from the firm and the financial intermediary, labour income, interest income on the deposits and current cash holding are the household's resources. The household uses these resources for consumption purchases, making deposits at the financial intermediary and cashing to carry into future. This constraint has the form

$$M_{t+1} = (M_t - D_t + W_t H_t - P_t C_t) + R_t^H D_t + B_t + F_t \,, \qquad (4)$$

where D_t denotes current period nominal deposits $0 \leq D_t$, F_t denotes nominal dividends the household receives from firms, B_t denotes nominal dividends the household receives from the financial intermediary, R_t^H is the gross nominal interest rate the household faces in the market for deposits, P_t is the price level of consumption good, and W_t denotes the nominal wage rate.

The second one is the cash in advance constraint. The cash carried over from the previous period net of current period nominal deposits and current labour income is available only for current consumption purchases. The CIA constraint has the form

$$P_t C_t \leq W_t H_t + M_t - D_t \,. \qquad (5)$$

4.3. The Firm

The representative firm chooses the capital stock in the next period K_{t+1}, labour demand N_t, dividends F_t, and loans L_t in order to maximize the expected infinite horizon of discounted stream of dividends it pays to the household.[9] Nominal dividends are discounted by date $t+1$ marginal utility of consumption because the households value a unit of nominal dividends in terms of the consumption it enables during the next period. Thus, the firm maximizes

$$E_0 [\sum_{t=0}^{\infty} \beta^{t+1} F_t / (C_{t+1} P_{t+1})] \,, \qquad (6)$$

where nominal dividends are valued in terms of their future consumption. The firm faces the budget constraint which has the form

$$F_t \leq L_t + P_t (Y_t - I_t) - W_t N_t - L_t R_t^F \,, \qquad (7)$$

[9] This objective is very similar to the objective of the financial intermediary. See the next subsection for more details.

where N_t denotes labour demand of the firm, Y_t denotes physical output, I_t denotes the physical investment, and R_t^F denotes the interest rate at which the financial intermediary lends funds to the firm.[10] This constraint implies that the firm faces a trade-off between capital accumulation and paying larger dividends to households. The gross investment is defined by the standard law of motion

$$I_t = K_{t+1} - (1-\delta)K_t ,$$

where the depreciation rate lies between zero and one, $0 < \delta < 1$. Physical output is produced with the constant return to scale production function

$$Y_t = K_t^{\alpha}(A_t N_t)^{1-\alpha} ,$$

where $0 < \alpha < 1$. Capital stock is predetermined at the beginning of period t. After the substitution, the equation (7) becomes

$$F_t \leq L_t + P_t[K^{\alpha}(A_t N_t)^{1-\alpha} - K_{t+1} + (1-\delta)K_t] - W_t N_t - L_t R_t^F . \quad (8)$$

The last constraint says that the firm finances its current period wage bill by borrowing from the financial intermediary

$$W_t N_t \leq L_t . \quad (9)$$

4.4. The Financial Intermediary

The financial intermediary is owned by the household. As well as the firm, it maximizes the expected infinite horizon of discounted dividends which pays to the households

$$E_0[\sum_{t=0}^{\infty} \beta^{t+1} B_t /(C_{t+1} P_{t+1})] . \quad (10)$$

Nominal dividends are again valued in terms of their future consumption.

The financial intermediary faces three constraints - the budget constraint, the balance sheet constraint, and a zero profit condition. The budget constraint has the form

$$B_t = D_t + R_t^F L_t - R_t^H D_t - L_t + X_t , \quad (11)$$

[10] As was noted, the firm owns the capital stock.

where L_t is the nominal amount of loans the financial intermediary makes to firms, R_t^F denotes the gross interest rate charged on those loans, and X_t denotes the monetary injection during the date t

$$X_t = M_{t+1} - M_t .$$

The balance sheet of the financial intermediary has the form

$$L_t \leq X_t + D_t . \tag{12}$$

The final constraint is a zero profit condition along the equilibrium path. Profits on loans to firms net of the monetary injection equals the principle and interest the financial intermediary owes to households period by period. This condition has the form

$$R_t^H D_t = R_t^F (L_t - X_t) . \tag{13}$$

5. SOLVING THE MODEL[11]

5.1. Model Equilibrium

The equilibrium of dynamic stochastic general equilibrium model means that all markets are cleared simultaneously. The presented cash in advance model contain the goods market, the labor market, the credit market, and the money market. All markets are modeled as perfectly competitive.

The credit market clears when the equation (12), the balance sheet of the financial intermediary, holds with strict equality. After rearrangement and substitution into equation (13), we get

$$R_t^H = R_t^F \equiv R.$$

After substitution, this results into the equation (11), which again holds with strict equality in equilibrium, and after some rearranging, we can find that dividends the financial intermediary pays to households equal

$$B_t = R_t X_t.$$

The money market is cleared when the demand for money equals the money supply. Within this cash-in-advance model, the money demand can be described by nominal consumption demand, because money is held to purchase all consumption goods. Money supply equals the current nominal balances and monetary injections. We equal the money demand with the money supply to get the equilibrium in the money market

$$P_t C_t = M_t + X_t. \tag{14}$$

Equation (14) requires labour market equilibrium. The demand for labour must be equated to the labour supply. This can be expressed by the equation

$$N_t = H_t.$$

Moreover, credit market clearing imposed on equations (5) and (9) to hold with strict equality.

The goods market clears when output equals consumption plus investment

$$C_t + K_{t+1} - (1-\delta)K_t = K_t^{\alpha}(A_t N_t)^{1-\alpha}. \tag{15}$$

Then, we need to compute decision rules for the household, firm, and the financial intermediary. They maximize their functions with respect to the constraints. In a more detailed analysis, the representative

[11] This section is based on Nason and Cogley (1994).

household maximizes the utility function (3) with respect to equations (4) and (5). The representative firm maximizes (6) with respect to equations (7) and (9). The financial intermediary maximizes (10) with respect to equations (11) and (12). During the derivation, we assume that the representative household, the representative firm, and the financial intermediary treat the equilibrium process generating A_{t+1}, M_{t+1}, P_t, W_t, and R_t as given.

5.2. Optimality Conditions

The model has three optimality conditions which restrict equilibrium paths in the four markets. The optimality in the goods market defines the trade-off that the economy faces in moving consumption across time. Since the cash-in-advance constraint binds in equilibrium, money has a positive finite value. This implies that in terms of marginal utility, the intertemporal consumption trade-off is one period ahead weighed by the purchasing power of money. The Euler equation has the form

$$E_t\{-P_t/(C_{t+1}P_{t+1}) + \beta P_{t+1}[\alpha K_{t+1}^{\alpha-1}(A_{t+1}N_{t+1})^{1-\alpha} + \\ + (1-\delta)]/(C_{t+2}P_{t+2})\} = 0. \quad (16)$$

The intratemporal condition which restricts labour market optimality depends on the structure of the credit market. Because the firm finances its current period wage bill by borrowing from the financial intermediary, the structure of the credit market affects the representative firm's labour demand. We can rewrite the equation (9) as

$$W_t = L_t / N_t$$

in equilibrium. Then, the optimality intratemporal condition for labour market equates labour supply, the marginal rate of substitution between leisure and consumption, and labor demand and has a form

$$-[\psi/(1-\psi)][C_tP_t/(1-N_t)] + L_t/N_t = 0. \quad (17)$$

The optimality in the credit market requires that the household's loss in current consumption from increasing its deposits at the financial intermediary equals the discounted expected gain in future consumption from these deposits. The intertemporal Euler equation for this optimality condition is[12]

$$1/(C_tP_t) - \beta R_t E_t[1/(C_{t+1}P_{t+1})] = 0. \quad (18)$$

In the equilibrium, the representative firm equates the increase in its nominal revenue generated by an extra unit of labor to the nominal cost of borrowing required to pay that unit of labor. The equilibrium

[12] The optimality condition depends on date *t* information.

gross nominal interest rate equals the ratio of the marginal revenue product of labor to the nominal wage rate

$$R_t = P_t(1-\alpha)K_t^{\alpha} A_t^{1-\alpha} N_t^{-\alpha} / W_t .$$

5.3. The Numerical Solution

The next step we should take in order to solve the model is to count the numerical solution of optimization problems. We detrend the model variables. The real variables are detrended by the productivity A_t, so the detrending of real side aggregates involves

$$\hat{q}_t = q_t / A_t \text{, where } q_t = [Y_t, C_t, I_t, K_{t+1}]$$

The price level is detrended by M_t / A_t and other nominal variables are detrended by M_t. Thus, the transformed nominal variables are

$$X_t / M_t = M_{t+1} / M_t - 1,$$

$$\hat{P}_t = P_t A_t / M_t ,$$

$$\hat{Q}_t = Q_t / M_t \text{, where } Q_t = [D_t, L_{t,} W_t]$$

After detrending, we get the equilibrium conditions (next three equations). The first equation is the aggregate resource constraint (equation (19)), equation (20) is the money market condition and the last equation (21) is the credit market equilibrium condition.

$$\hat{C}_t + \hat{K}_{t+1} = \exp[-\alpha(\gamma + \varepsilon_t^A)]\hat{K}_t^{\alpha} N_t^{1-\alpha} + (1-\delta)\exp[-(\gamma + \varepsilon_t^A)]\hat{K}_t , \tag{19}$$

$$\hat{P}_t \hat{C}_t = m_t , \tag{20}$$

$$m_t - 1 + \hat{D}_t = \hat{L}_t . \tag{21}$$

The numerical solution to the cash–in-advance model ties the equilibrium conditions (equations (19)-(21)) with the detrended versions of the optimality conditions (equations (16)-(18)). Along with the exogenous stochastic processes for technology and monetary injection growth shocks, this system of six nonlinear equations determines the equilibrium distributions for the six unknowns

$$\left[\hat{K}_{t+1}, N_t, \hat{D}_t, \hat{C}_t, \hat{L}_t, \hat{P}_t\right].$$

Given these equilibrium distributions, the equilibrium distributions for output, real wages, inflation rate, and nominal interest rate can be found.[13]

[13] For more details, see technical appendix in Nason – Cogley (1994). Note that there is an initial minus sign missing in equation (A1).

6. THE EMPIRICAL ANALYSIS

6.1. The Estimation Technique[14]

The modeled CIA system contains rational expectations. The Blanchard-Kahn condition holds. This means that there are the same number of eigenvalues larger than 1 as the number of forward-looking variables.[15] This implies that a unique steady-state exists. The estimation was realized by Bayesian technique. More concretely, we used the Metropolis-Hastings algorithm to Markov Chain Monte Carlo (MCMC). The model is estimated with Dynare 3 toolbox for Matlab 7. 100000 iterations and 5 blocks were used for the model.

The Markov Chain Monte Carlo is the algorithm for sampling from probability distributions which is based on constructing a Markov chain. The chain has the desired distribution as its stationary distribution. The idea is that rather than computing a probability density denoted for example $p(\theta \mid y)$, we would be just as happy to have a large random sample from $p(\theta \mid y)$ as to know the precise form of the density. If the sample was large enough, we could approximate the form of the probability density.

There are some characteristics of the Markov chain stochastic process $(\theta_t, t \geq 0)$ unfolded over time.

- The first is that it has the same set of possible values (the same state space) as θ
- It is easy to simulate
- The equilibrium or stationary distribution (which we use to draw samples) is $p(\theta \mid y)$ after Markov chain has been run for a very large number of iterations to produce a sample of $(\theta_t, t = 1, \ldots)$ from the posterior distribution

The Metropolis-Hastings algorithm to Markov chain Monte Carlo is the most widely used approach.[16] It is based on a suggestion that given an initial value θ_0, we can construct a chain by recognizing that any Markov chain that has found its way to a state θ_t can be completely characterized by the probability distribution for time $t+1$. This algorithm relies on a proposal or candidate distribution $f(\theta \mid \theta_t)$ for

[14] This subsection is based on LeSage (1999). Notation within this subsection is different from the rest of the paper.
[15] Blanchard – Kahn (1980).
[16] Another approach is known as the Gibbs sampling.

time $t+1$, given that we have θ_t. A candidate point θ^* is sampled from the proposal distribution and:

1. This point is accepted as $\theta_{t+1} = \theta^*$ with probability

$$\alpha_H(\theta_t, \theta^*) = \min[1, \frac{p(\theta^* \mid y) f(\theta_t \mid \theta^*)}{p(\theta_t \mid y) f(\theta^* \mid \theta_t)}].$$

2. Otherwise, $\theta_{t+1} = \theta_t$, that is we stay with the current value of θ.

For example, we toss a Bernoulli (fair) coin with probability α_H of heads. Then we move to $\theta_{t+1} = \theta^*$ if we see heads, otherwise we set $\theta_{t+1} = \theta_t$. It can be demonstrated that this approach to sampling represents Markov chain with the correct equilibrium distribution capable of producing samples from the posterior $p(\theta \mid y)$ we are interested in.[17]

6.2. Data and Priors

The model for each country is estimated on the quarterly data. All time series are seasonably adjusted. These data are depicted in the Appendix 1. gy_obs is the growth coefficient of per capita real GDP and gp_obs is the growth coefficient of the CPI. For the estimations, we used time series from 1996 to 2007. For the model of Czech economy, we used data from the Czech National Bank. Other data, i.e. data of Hungarian economy, Slovak economy, Polish economy, and Euro Area, are taken from statistical offices of individual countries.

The priors were chosen in accordance with economic theory. They reflect our beliefs of the likely locations of structural. However, micro-level studies on these parameters for Visegrad states are relatively scarce. Therefore, we considered prior values from other similar estimates. [18] The choice of prior distributions reflects restrictions on the parameters. Beta distribution was chosen for parameters that are constrained on the unit interval. Inverse gamma distribution was chosen for the standard deviations of the shocks. Normal distribution

[17] LeSage (1999).

[18] For more details, see for example Schorfheide (2000), Christiano and Eichenbaum (1992) and (1995) or Nason and Cogley (1994).

was chosen for the rest of the parameters.[19] Prior distribution for the monetary business cycle model is summarized in Table 1.

Table 1: Prior distribution of model parameters

Parameter	Range	Density	Prior Mean	SE
α	[0,1]	Beta	0.360	0.0200
β	[0,1]	Beta	0.993	0.0020
γ	R	Gaussian	0.004	0.0015
m^*	R	Gaussian	1.003	0.0070
ρ	[0,1]	Beta	0.985	0.0030
ψ	[0,1]	Beta	0.602	0.0500
δ	[0,1]	Beta	0.006	0.0030
σ_A	R^+	InvGamma	0.012	inf
σ_m	R^+	InvGamma	0.005	inf

[19] Another commonly used distribution is a gamma distribution which could be chosen for parameters restricted to be positive.

7. ESTIMATION RESULTS

7.1. Posterior Parameter Estimates

Table 2 provides us with an overview of the estimation results. The posterior means and the confidence intervals are simulated by the Metropolis Hastings algorithm. The magnitudes of model parameters are in accordance with economic theory. All parameters are statistically significant.

The posterior means of the parameter for the capital share α lie between 0.3629 and 0.3769. These values are in accordance with economic theory and are often used for calibrations within many structural models. These values suggest structural similarities between economies. The highest value is for the Euro Area. It is interesting that this parameter is somewhat higher for economy of the United States, where estimations suggest the value around 0.04. We expect that in the future, this value will grow slightly to the similar value as is estimated for the US economy.

The posterior means for the discount factor β are approximately 0.992 for Czech economy, Hungarian economy and the Euro Area and 0.993 for Polish economy and Slovak economy. These estimates imply that the steady-state real interest rates are similar for all economies. The value of 0.992 suggests an annualized steady-state real interest rate slightly above 3%. The higher value of the discount parameter for Poland and the Slovak Republic implies that the real steady state rate of interest is slightly below 3%.[20] The technology growth rate is captured by the parameter γ. The values for the Czech Republic and Hungary are relatively high in comparison to other Visegrad countries or developed countries, such as the EU or the USA. These estimates speak clearly in favour of these two countries which suggests that these can be referred to as countries with dynamically developing economies. The value for the Euro Area is a bit lower than it is common for developed countries.[21]

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[20] The steady-state real interest rate is $r = (1-\beta)/\beta$.

[21] For example, Schorfheide (2000) estimated this value around 0.004 for similar two monetary models on the US data.

Table 2: Posterior means and confidence intervals for the Visegrad countries and Euro Area

	CZ	HU	SK	PO	EU
α	0.3629 (0.3297 – 0.3955)	0.3640 (0.3304 – 0.3991)	0.3737 (0.3410 – 0.4088)	0.3754 (0.3413 – 0.4067)	0.3769 (0.3443 – 0.4100)
β	0.9922 (0.9890 – 0.9957)	0.9923 (0.9891 – 0.9958)	0.9931 (0.9901 – 0.9961)	0.9931 (0.9901 – 0.9962)	0.9923 (0.9892 – 0.9956)
γ	0.0063 (0.0048 – 0.0078)	0.0074 (0.0064 – 0.0084)	0.0045 (0.0030 – 0.0060)	0.0025 (0.0009 – 0.0041)	0.0022 (0.0014 – 0.0030)
m^*	1.0053 (0.9949 – 1.0166)	1.0052 (0.9945 – 1.0165)	1.0038 (0.9919 – 1.0146)	1.0037 (0.9926 – 1.0154)	1.0045 (0.9963 – 1.0131)
ρ	0.9860 (0.9818 – 0.9910)	0.9858 (0.9816 – 0.9907)	0.9832 (0.9783 – 0.9884)	0.9830 (0.9779 – 0.9882)	0.9847 (0.9802 – 0.9896)
ψ	0.5957 (0.5158 – 0.6818)	0.5882 (0.5039 – 0.6684)	0.5880 (0.5076 – 0.6715)	0.6000 (0.5132 – 0.6754)	0.5908 (0.5065 – 0.6683)
δ	0.0063 (0.0014 – 0.0108)	0.0063 (0.0015 – 0.0109)	0.0036 (0.0010 – 0.0061)	0.0037 (0.0007 – 0.0065)	0.0044 (0.0008 – 0.0077)
σ_A	0.0085 (0.0069 – 0.0100)	0.0059 (0.0048 – 0.0071)	0.0150 (0.0121 – 0.0175)	0.0243 (0.0190 – 0.0292)	0.0044 (0.0036 – 0.0052)
σ_m	0.0039 (0.0032 – 0.0046)	0.0043 (0.0035 – 0.0050)	0.0066 (0.0054 – 0.0079)	0.0078 (0.0059 – 0.0094)	0.0015 (0.0012 – 0.0018)

This parameter ψ characterizes the utility preferences of households. The estimated posterior means are about 0.59 for all countries. This implies that the utility preferences of households are analogous. The value is smaller than estimations for the US economy. Roughly speaking, this means that by those households, consumption is more appreciated. The estimated autocorrelation of money growth is relatively high and is also similar for all countries. This can be partly caused by the nature of the model. Because prices in the model are flexible, a large ρ is needed to capture the persistence in inflation. The parameter for capital depreciation δ has similar estimation results for Czech and Hungarian economy on the one side, and for Polish and Slovak economy on the other side. The value for the Euro Area lies approximately between these two. Note that these estimated parameters have relatively large confidence intervals.

Figures 1 to 5 plot priors and posteriors for parameters of Visegrad economies and the Euro economy. The first two parameters are standard errors of the exogenous shocks. They grey line represents the prior distributions, the black line shows the posterior distributions. The dotted green line depicts the value at the posterior mode.

Figure 1: Priors and posteriors for parameters of CZ economy

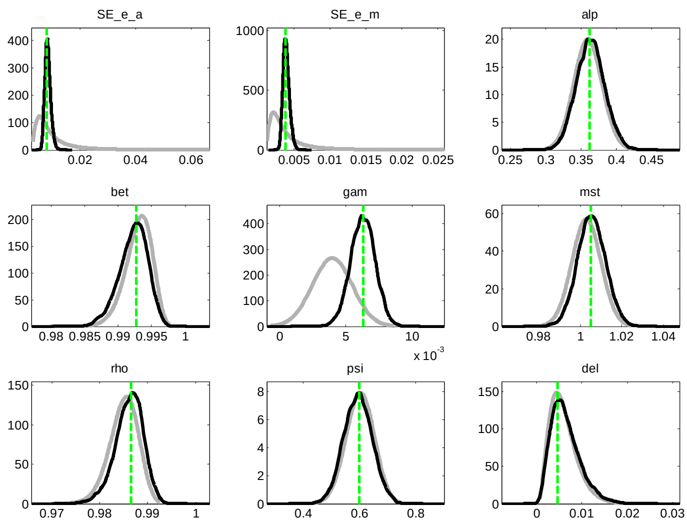


Figure 2: Priors and posteriors for parameters of HU economy

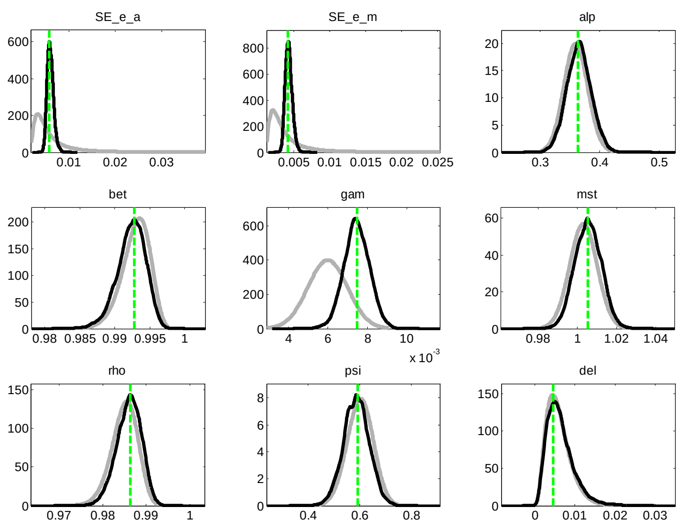


Figure 3: Priors and posteriors for parameters of PO economy

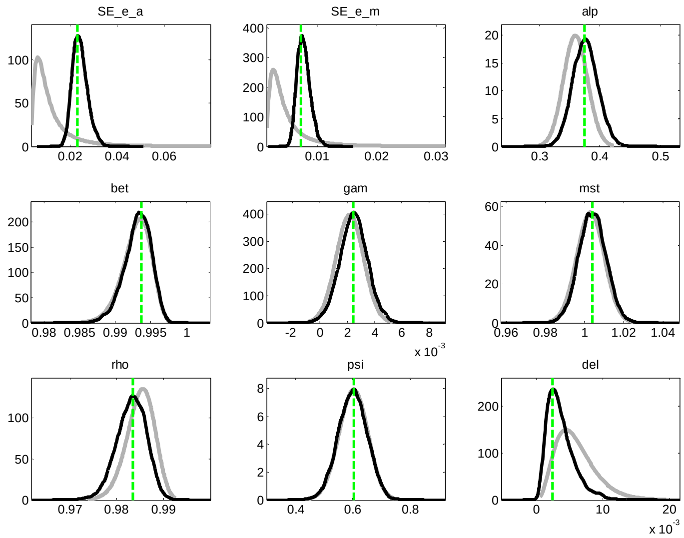


Figure 4: Priors and posteriors for parameters of SK economy

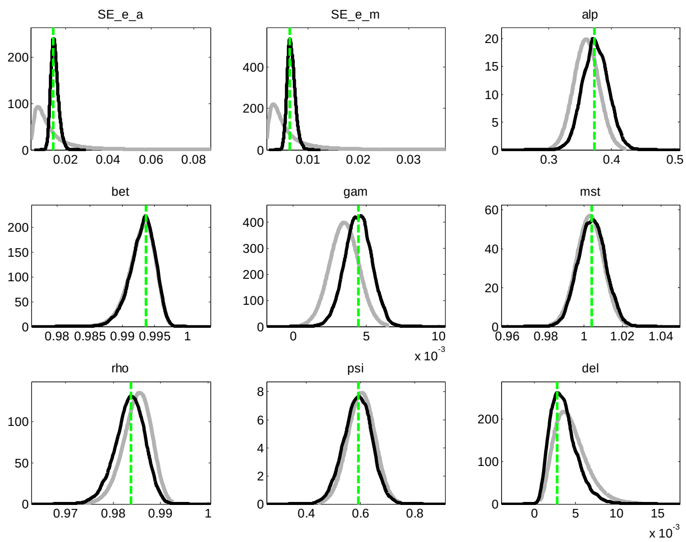
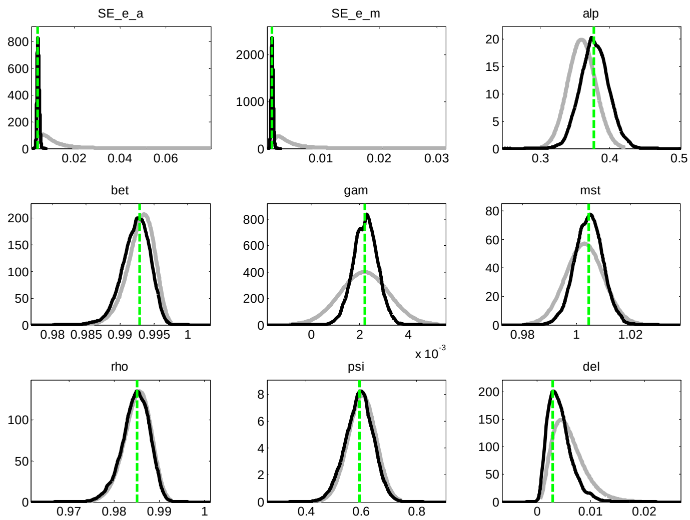


Figure 5: Priors and posteriors for parameters of Euro economy



7.2. Impulse Response Analysis

This subsection presents impulse response functions of the modeled economy and describes some features of the models. We depict only impulse responses of the Czech model and explain the behavior of the modeled economy. Impulse responses of other models are analogous.

The next figures show impulse response functions for the modeled economy. Figures 6 and 7 depict impulse response functions to the positive technology shock. Figures 8 and 9 depict impulse response functions to the positive monetary shock. gy_obs and gp_obs are observable model variables which are shown in Appendix 1. Note that in order to depict the behavior of the variable after the shock, the data are in growth coefficients. For example, Figure 7 shows that the real GDP is increasing after the positive technology shock. Other impulse responses are shown as deviations from the steady-state and are depicted in decimal notation. We can see from these impulse responses that movements of macroeconomic variables to the steady states are very gradual after the shock. Some variables return to the steady state several decades. Moreover, be careful of the scales of these figures. Some deviations are very small.

The reaction of economy to the technology shock is analogous to that published in the real business cycle literature. From the first panel of figure 8, the real GDP is rising. The second panel shows that the price level is counter-cyclical which is consistent with the RBC theory. This is in accordance with stylized facts as published by Cooley and Hansen (1995). They mention the confusion that may result from many textbooks in macroeconomics: "*which would probably lead one to suspect that the consensus view is that prices are procyclical*".[22] As was noted, the movements of macroeconomic variables to steady states are very gradual. The exception is the trajectory of the real rate of return which returns very quickly and then oscillates around its steady-state value. We simulated the behavior for more periods and recognized that the amplitude is diminishing in time. Note that the scale is very small in this case.

When analyzing behavior of an economy after the monetary shock, it is important to mention some features of the model economy. The model does not generate a liquidity effect. If money growth displays positive persistence, then unanticipated shocks to the growth rate of money drive interest rates up, not down as is predicted by the liquidity effect. This is due to the fact that in these models, money shocks affect interest rates exclusively through an anticipated inflation effect.[23]

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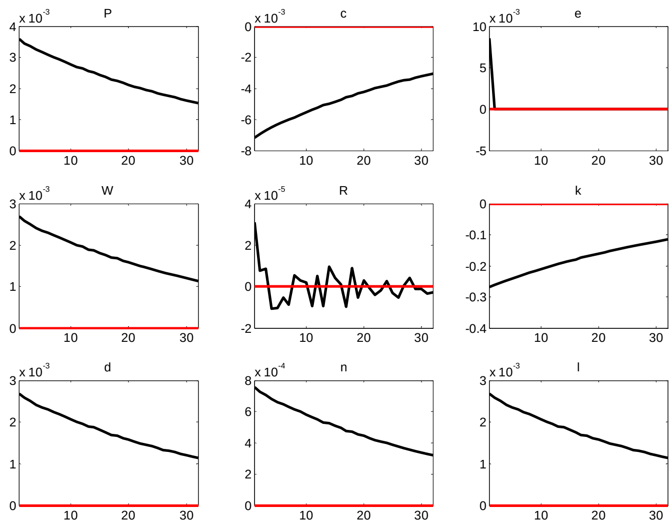
[22] Cooley and Hansen (1995), page 182.

[23] Possible way of introduction the liquidity effect into the model framework is discussed in Christiano and Eichenbaum (1992, 1995). There must be rigidity in the part of money that is allocated in consumption goods. Within this

After the money growth shock, the representative household can adjust its deposits contemporaneously. The nominal interest rate is approximately equal to the real rate of interest plus the expected inflation. The agents observe the shock to the growth rate of money and they recognize that it will cause higher inflation. The expected inflation rate will increase. This will lead to an increase of the nominal interest rate and a slight decrease of the output. This can be seen from figure 10. Hence, the model predicts sudden increase in the price level which results in the inflation in the first period.

Higher interest rate causes an increase in investment spending and a decline in the consumption. The reason is that the rise of interest rate can be viewed as a tax on the consumption goods but on the other side, a subsidy on the investment (credit) goods. The hours worked fall. Because the worked time decreased and the stock of capital is unchanged, current output falls as well. So the positive monetary shock drives the interest rate up and unemployment, consumption, and output down.

Figure 6: Impulse response functions to the CZ technology shock



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framework, a positive monetary shock increases the total percentage of the money supply available to financial intermediaries because households do not spend newly acquired money on consumption goods. Financial intermediaries lend all cash at their disposal to firms. For firms to do so voluntarily, interest rate must fall. But if the growth rate of money displays positive persistence, the expected inflation effect of a change in the growth rate of money exerts countervailing pressure on interest rates.

Figure 7: Impulse response functions to the CZ technology shock

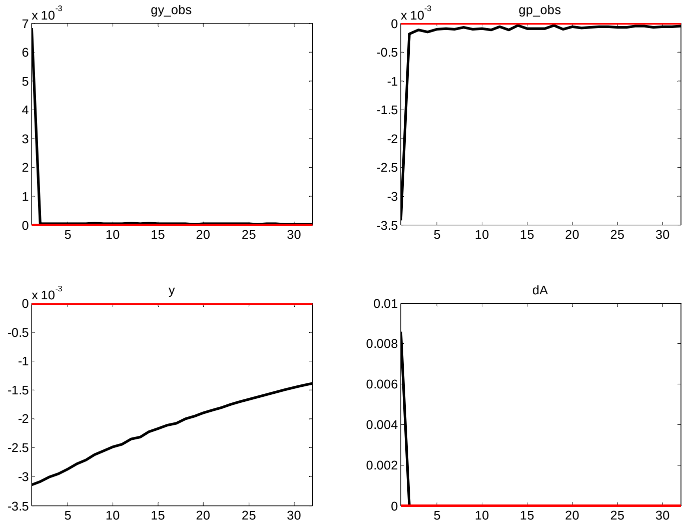


Figure 8: Impulse response functions to the CZ monetary shock

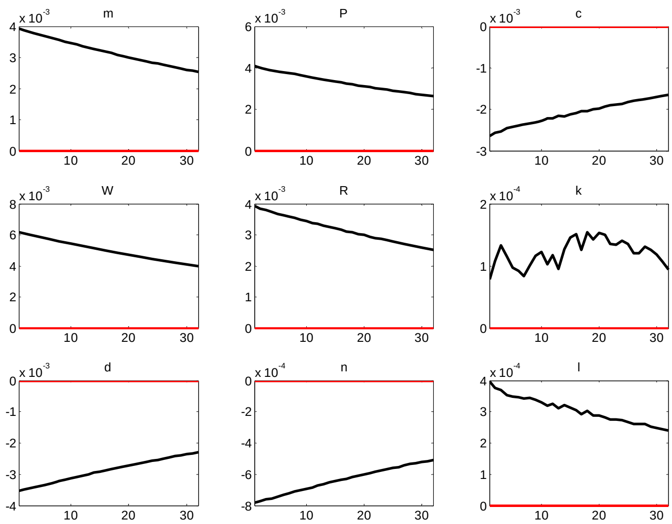
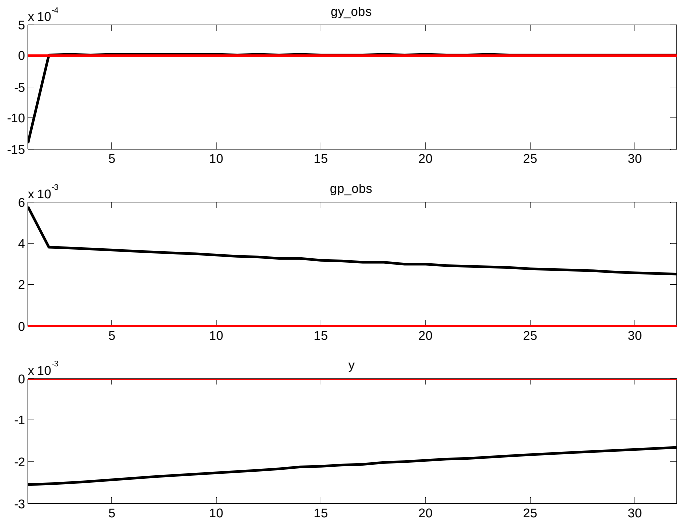


Figure 9: Impulse response functions to the CZ monetary shock



CONCLUSION

This paper presented estimations of monetary CIA model for the Visegrad countries and the Euro Area. In order to incorporate monetary sector into the model, money is incorporated into the long-run neoclassical DSGE framework through the cash-in-advance constraint. This approach stresses the function of money as that of a medium of exchange. The model is estimated on the seasonally adjusted quarterly time series of the Visegrad countries and the Euro Area. The comparison of final values is made on the basis of estimated parameters. The estimation was realized by Bayesian technique. More concretely, we used the Metropolis-Hastings algorithm to Markov Chain Monte Carlo.

The analysis of estimated parameters and the behavior of the model economies can help us to know more about long-run development of these countries. Estimated parameters for Visegrad countries are similar, which results in analogous impulse response functions. If we study the parameter values in more detail, we can divide the Visegrad countries into two groups. The first group consists of Hungary and the Czech Republic and the second is made up by Poland and the Slovak Republic. The former group (CZ and HU) has better characteristics than the latter. This is obvious from the parameter for the technology growth rate. The estimated values speak clearly in favour of these two countries as dynamically developing.

Moreover, the estimation results might be used for future estimations and analyses of more sophisticated models that contain nominal rigidities, exchange rates, adjustment costs etc. These models may complete the analysis and will be the object of our future research.

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APPENDIX 1: THE DATA

Figure 10: Czech data

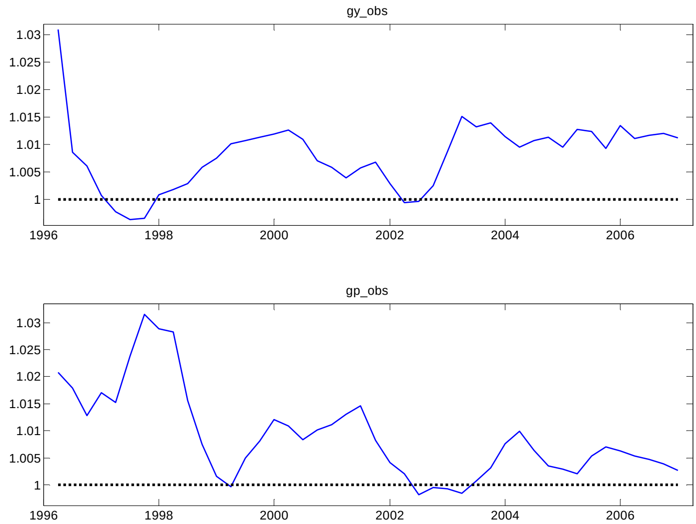


Figure 11: Hungarian data

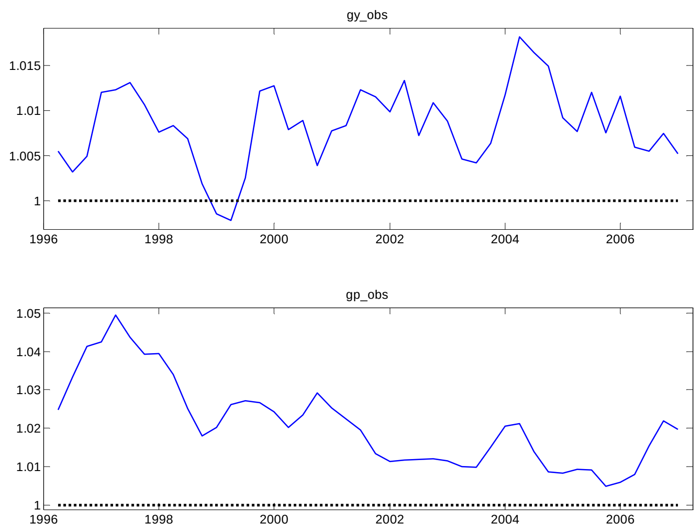


Figure 12: Slovak data

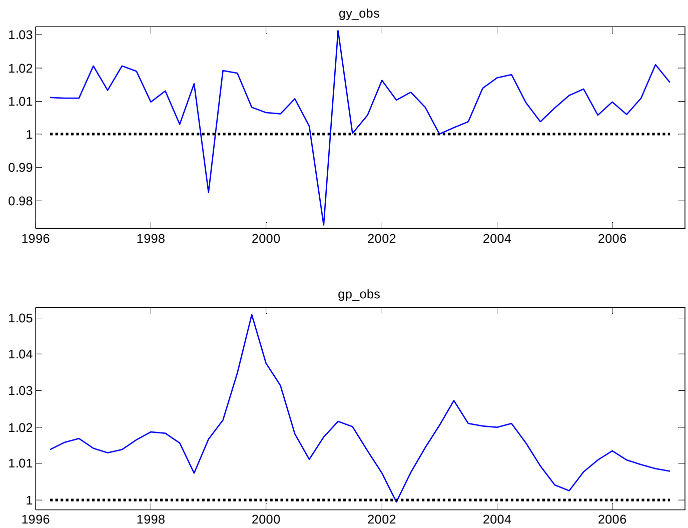


Figure 13: Polish data

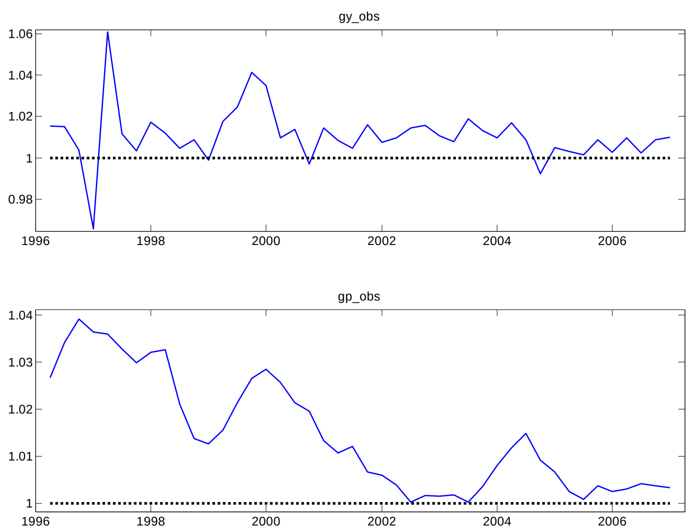
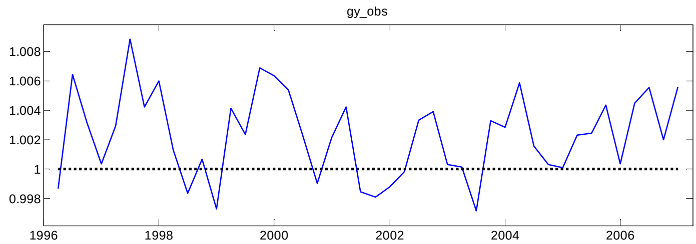
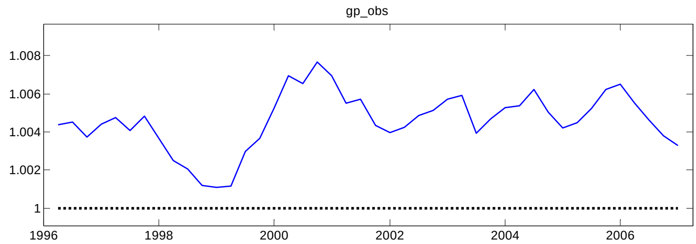


Figure 14: Data of the Euro Area





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