Analyzing the interactions of monetary and fiscal policy in a small open economy using a DSGE model

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Abstract. The principal aim of this paper is to estimate a small open economy dynamic stochastic general equilibrium (DSGE) model with monetary and fiscal policy and analyze the interaction of these policies in Hungary. In the paper we present the model in a log-linearized form. We combine both calibration and Bayesian estimation to obtain parameter values of the model. We find that the model is suitable for impulse response analysis, so we estimate the impulse response functions of the model. We examine how five endogenous variables – namely output, inflation, the nominal interest rate, government spending and government revenue – react to non-systematic shocks to the nominal interest rate, government spending and government revenue. The plotted impulse response functions allow us to study how monetary and fiscal policy interacts in a small open economy. In some cases we find that restrictive fiscal policy is accompanied by expansive monetary policy, while in other cases the policy responses to shocks are coordinated. We conclude that our results are in accordance with economic theory.

Keywords: DSGE model, Fiscal policy, Monetary policy

JEL classification: *B 23, C 01, E 60*

1 Introduction

Standard New Keynesian dynamic stochastic general equilibrium (DSGE) models lack an active fiscal sector. Usually, fiscal policy is only represented in the model in the form of government expenditures. Based on the assumption that fiscal policy only plays a passive role, government expenditure is usually an exogenous process in these models. As a result of this, the possible interactions between monetary and fiscal policy are ignored. However, Ratto et al. (2012) recently published a model of the Eurozone which includes a comprehensive fiscal sector. Because active fiscal policy is becoming increasingly popular, we include an active fiscal sector in our model. This way we can study the interactions of monetary and fiscal policy in Hungary similarly to Algozhina (2012). We, however, not only calibrate parameter values, but also employ Bayesian estimation techniques to estimate impulse response functions using data available for the period after the Great recession. We also include a backward looking price setting mechanism in the New Keynesian Phillips curve, which is uncommon in the literature. Despite this, we find that a substantial portion of firms sets their prices based on historical information.

In the next chapter we present our model. Then we calibrate and estimate the parameter values. In the fourth chapter we present and analyze the impulse response functions. The last section concludes.

2 The model

In this subchapter we present the log-linearized model equations. For a full model description please refer to Galí and Monacelli (2005, 2008), Çebi (2013) and Galí and Gertler (2000). The method of log-linearization is characterized in Uhlig (1995). The steady state value of each variable below is zero, because they are defined as deviations from their respective steady state values.

To begin with, the representative household of a small open economy is infinitely lived and allocates resources between consumption and investment to maximize its discounted utility function. It has access to international financial markets. Because of this, it can invest in both domestic and foreign bonds with a one-period maturity. To finance consumption and investment, it offers labor and receives wages. The log-linearized IS curve is given as

$$y_t = E_t\{y_{t+1}\} - E_t\{\Delta g_{t+1}\} + \alpha(\omega - 1)(\rho_{c^*} - 1)c_t^* - \frac{1}{\sigma_\alpha}\left(r_t - E_t\{\pi_{H,t+1}\}\right) \quad (1)$$

where α is the degree of openness, c_t^* is an exogenous AR(1) process representing world output with ρ_{c^*} being the autoregressive parameter., while ω and σ_α are parameters defined as

$$\omega = \sigma\gamma + (1 - \alpha)(\sigma\eta - 1) \quad (2)$$

$$\sigma_\alpha = \frac{\sigma}{(1-\alpha)+\alpha\omega} \quad (3)$$

where γ is the elasticity of substitution between domestic and foreign goods, η is the elasticity of substitution between foreign goods from different countries, while σ represents the inverse elasticity of substitution in consumption. Besides these parameters it is also important to define the endogenous variables. Firstly, output y_t is defined as $y_t - \bar{y}$, where $\bar{y}$ represents the steady state value of output. Secondly, government spending is given as $g_t = -ln\left(1 - \frac{G_t}{Y_t}\right)$. Thirdly, the nominal interest rate is given by r_t. Fourthly, domestic inflation is represented as $\pi_{H,t} = ln\left(\frac{P_{H,t}}{P_{H,t-1}}\right)$, where $P_{H,t}$ is the CPI.

To continue with, equation (4) represents the log-linearized open economy hybrid New-Keynesian Phillips curve which includes both forward- and backward-looking price setting mechanisms of firms

$$\pi_{H,t} = \lambda^b \pi_{H,t-1} + \lambda^f E_t\{\pi_{H,t+1}\} + \kappa mc_t \tag{4}$$

where τ is the log-linearized government revenue equation, mc_t represents real marginal cost, κ is the slope coefficient and λ^b and λ^f are parameters defined as

$$mc_t = (\sigma_\alpha + \varphi)(y_t - y_t^n) - \sigma_\alpha g_t + \tau \tag{5}$$

$$\lambda^b = \frac{\xi}{\theta + \xi(1 - \theta(1 - \beta))} \tag{6}$$

$$\lambda^f = \frac{\beta\theta}{\theta + \xi(1 - \theta(1 - \beta))} \tag{7}$$

$$\kappa = \frac{(1 - \beta\theta)(1 - \theta)(1 - \xi)}{\theta + \xi(1 - \theta(1 - \beta))} \tag{8}$$

In equation (4) the output gap $(y_t - y_t^n)$, government spending (g_t) and taxation (τ) indirectly affects inflation via the real marginal cost. The sensitivity of inflation to real marginal cost is represented by the slope coefficient κ. Secondly, κ and the remaining two structural form parameters of the Phillips curve are represented by three deep model parameters, namely the discount factor(β), the Calvo parameter (θ) and the parameter representing backward looking firms (ξ). If $\xi = 0$ then we have a forward looking New-Keynesian Phillips curve, otherwise the Phillips curve is hybrid. If $\beta = 1$, the sum of the parameters of forward and backward looking inflation equals to 1. What is more, the value of λ^b and λ^f falls between β (if $\xi = 0$) and 1 (if $\xi = 1$). Because β is always close to 1, λ^b and λ^f represent the relative weights given to past and expected inflation. From this we can conclude that if the number of backward looking firms increases and price stickiness is high then current inflation is less sensitive to current real marginal cost.

The third agent in the model is the central bank, which is represented by the monetary policy rule formulated by Taylor (1993) as

$$r_t = \rho_r(r_{t-1} - r_t^n) + (1 - \rho_r)\left[r_\pi \pi_{H,t} + r_y(y_t - y_t^n)\right] + r_t^n + \epsilon_t^r \tag{9}$$

where ρ_r represents the degree of interest rate smoothing, r_π represents the monetary authority's reaction to inflation, r_π represents the monetary authority's reaction to the output gap and ϵ_t^r is an i.i.d non-systematic policy rate shock. y_t^n represents potential output while r_t^n is the natural interest rate, so we can write that

$$y_t^n = \frac{(1+\varphi)}{(\sigma_\alpha + \varphi)} a_t - \frac{(\sigma - \sigma_\alpha)}{(\sigma_\alpha + \varphi)} c_t^* \tag{10}$$

$$r_t^n = \sigma_\alpha(E_t\{y_{t+1}^n\} - y_t^n) + \sigma_\alpha \alpha(\omega - 1)(\rho_{c^*} - 1)c_t^*$$
(11)

where φ is the inverse elasticity of labor supply and a_t represents the AR(1) technology process.

The last part of the model is the fiscal block. Government spending is given as

$$g_t = \rho_g g_{t-1} + (1 - \rho_g)[g_y(y_{t-1} - y_{t-1}^n) + g_b b_t] + \epsilon_t^g$$
(12)

and taxes are represented as

$$\tau_t = \rho_\tau \tau_{t-1} + (1 - \rho_\tau)[\tau_y(y_{t-1} - y_{t-1}^n) + \tau_b b_t] + \epsilon_t^\tau$$
(13)

In this paragraph we characterize the parameters of equations (12) and (13). Firstly, parameters ρ_g and ρ_τ represent the fiscal spending smoothing and tax smoothing parameters, respectively. Secondly, parameters g_y and τ_y represent the reaction of government spending and the lump sum tax to changes in the lagged output gap. Thirdly, parameters g_b and τ_b represent the reaction of government spending and the lump sum tax to changes in the debt stock. Lastly, we have the exogenous i.i.d fiscal shocks, namely ϵ_t^g and ϵ_t^τ, which represent the non-systematic changes in government spending and the lump sum tax. From these equations we can see that in the presence of a high degree of fiscal smoothing the reactions of government spending and tax to lagged output gap and debt are smaller.

The fiscal block includes the fiscal constraint as well, which we can write as

$$b_{t+1} = r_t + \frac{1}{\beta}\left[b_t - \pi_{H,t} + (1 - \beta)(\tau_t - y_t) + \frac{\bar{C}}{\bar{B}}(g_t - \tau_t)\right]$$
(14)

where $b_t = ln\left(\frac{B_t}{P_{H,t-1}}\right)$ is a predetermined variable, B_t is nominal debt, $\bar{C}$ is the steady state value of private consumption to GDP ratio and $\bar{B}$ is the steady state value of the debt to GDP ratio.

3 Parameter estimation and calibration

To plot impulse response functions and reach meaningful conclusions, we first need to assign values to the parameters in the model. We do this by combining two methods. We split the parameters into two groups. The parameters in the first group are calibrated, while the parameter values in the second group are obtained using Bayesian estimation. Table 1 presents the calibrated and table 2 presents the estimated parameter values.

At first, we describe the calibrated parameters in Table 1. These parameters are calibrated because their values are almost identical in most studies. Firstly, we borrow the value of the degree of openness from a DSGE model calibrated for the Hungarian economy. We set this parameter's value at 0.69 as in Algozhina (2012). Secondly, the parameters representing the elasticity of substitution between domestic and foreign goods and the elasticity of substitution between foreign goods from different countries were set at 1.00. This value is also borrowed from another research paper Çebi (2013). Thirdly, the value of the discount factor is calibrated to 0.99 based on two previous DSGE models calibrated and estimated for the Hungarian economy by Jakab and Kónya (2016) and Jakab and Világi (2008). Finally, the last two parameters, namely the steady state values of the private consumption to GDP ratio and the debt to GDP ratio are set at 0.51 and 0.78, respectively. We obtain these values by calculating the sample means for the estimation period. To sum up, we calibrate these parameters because their values are given in most studies or can be easily calculated. The rest of the parameters are estimated using Bayesian techniques.

Table 1. Calibrated values.

Parameter	Calibrated value
$\boldsymbol{\alpha}$	0.69
$\boldsymbol{\eta}$	1.00
$\boldsymbol{\gamma}$	1.00
$\boldsymbol{\beta}$	0.99
$\bar{\boldsymbol{C}}$	0.51
$\bar{\boldsymbol{B}}$	0.78

To continue with, we describe how we selected the probability distributions, prior means and prior standard deviations of the remaining model parameters. The probability distributions, prior means and standard deviations are presented in Table 2. Firstly, we use the same probability distributions as Çebi (2013) used to estimate similar DSGE models. We use beta distributions for parameters whose value falls between zero and one. Inverse gamma distributions are used for the shocks so they cannot have negative values. Secondly, we obtain the prior means and standard deviations either by borrowing them from other studies or by running regressions in EViews. The latter, namely the OLS regressions, are used to obtain prior means and standard deviations for the autoregressive parameters of world output, government spending and taxation. The former method is used for the rest of parameters.

Table 2. Parameter estimates.

Parameter	Prior mean	Prior standard deviation	Posterior mode	Posterior standard deviation	Posterior mean	Lower 90% confidence band	Upper 90% confidence band
$\boldsymbol{\theta}$	0.93	0.02	0.97	0.006	0.97	0.956	0.977
$\boldsymbol{\varphi}$	3.00	0.20	2.98	0.20	2.98	2.659	3.304
$\boldsymbol{\sigma}$	2.50	0.20	2.55	0.19	2.52	2.214	2.844
$\boldsymbol{\rho_r}$	0.76	0.05	0.73	0.05	0.72	0.642	0.804
$\boldsymbol{r_\pi}$	1.50	0.40	1.39	0.38	1.50	0.859	2.160
$\boldsymbol{r_y}$	0.50	0.10	0.51	0.10	0.53	0.357	0.683

ρ_g	0.68	0.14	0.13	0.02	0.13	0.099	0.164
g_y	0.50	0.20	1.41	0.17	1.39	1.140	1.668
ρ_τ	0.73	0.05	0.63	0.05	0.63	0.550	0.712
τ_y	0.63	0.20	0.69	0.20	0.69	0.368	1.013
g_b	0.40	0.02	0.36	0.02	0.36	0.326	0.393
τ_b	0.40	0.02	0.40	0.02	0.40	0.371	0.433
ξ	0.75	0.05	0.74	0.05	0.74	0.657	0.819
ρ_a	0.50	0.15	0.50	0.18	0.51	0.248	0.739
ρ_{c^*}	0.80	0.05	0.84	0.03	0.84	0.787	0.899
ϵ_t^r	0.30	2.00	0.28	0.03	0.29	0.239	0.350
ϵ_t^g	3.30	4.00	3.34	0.38	3.45	2.802	4.104
ϵ_t^τ	1.80	4.00	1.67	0.19	1.72	1.382	2.032

The first four parameters in Table 2, namely the Calvo parameter, the inverse elasticity of labour supply, the inverse elasticity of substitution in consumption and the interest rate smoothing parameter are borrowed from two studies on the Hungarian economy done by Jakab and Kónya (2016) and Jakab and Világi (2008). The prior mean and standard deviation of the technology parameter are also obtained from these same studies. The Calvo parameter with its value of 0.93 is especially high compared to the literature standard, which is set between 0.5 and 0.75. The Taylor parameters are set according to the industry standard. We borrow the prior mean of the parameter representing the portion of backward looking firms from Çebi (2013) and set it 0.05 higher at 0.75. The prior means of the parameters representing the fiscal responses to the output gap are borrowed from Algozhina (2012), who estimates a DSGE model for the Hungarian economy. Lastly, we obtain the prior means and standard deviations of the errors from the studies referenced in this paragraph. We slightly modify these priors, so they better fit the underlying data. After calibrating the selected parameters and selecting priors for the remainder we proceeded to estimate the model.

Table 2 also presents the parameter estimation results, namely the estimated posterior mode, standard deviation, posterior mean and the 90% confidence bands. We use seasonally adjusted real GDP, CPI inflation, the three-month T-bill rate, government spending to GDP ratio and tax to GDP ratio as observable variables. We obtained the data for Hungary from the International Financial Statistics database of the

International Monetary Fund. The data covers the period of 2010Q1:2018Q4. We detrend the data if needed, either by taking differences or using the Hodrick-Prescott filter. We estimate the parameters and the impulse response functions using Dynare for Matlab.

4 Impulse response functions

In this subchapter we present the Bayesian impulse response functions with 90% confidence bands. There are three shocks in the model, namely the government spending shock, the tax shock, and the interest rate shock. Five endogenous variables react to these shocks. These endogenous variables are output, inflation, the nominal interest rate, government spending and tax. We begin with analyzing the effects of the government spending shock on the economy.

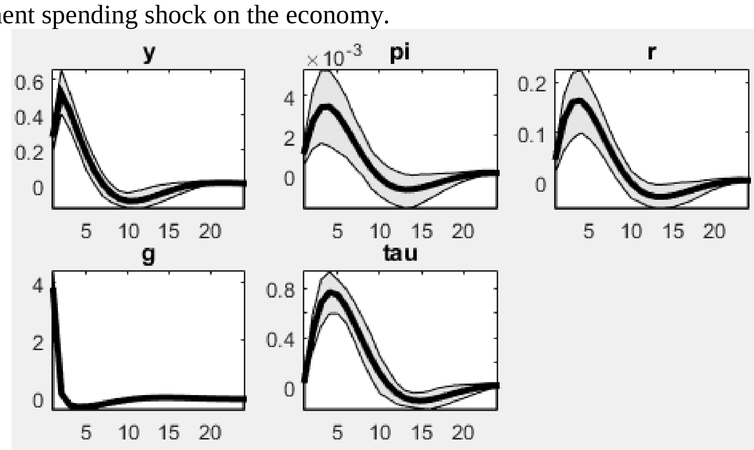

Fig. 1. Government spending shock

Firstly, the effects of an unexpected increase in government spending on the economy are presented on figure 11. As a result of an unexpected increase in government spending both output and inflation rise. The rise in output is expected, but at first glance the rise in inflation might seem contradictory. Government spending should result in a decrease in inflation via marginal cost. In our case, however, the increase in output is higher than government spending's effect on the marginal cost of firms. This explains why inflation rises. Because inflation is higher, the monetary authority reacts to it by raising the interest rate. Debt also reacts to these factors and increases, because interest rates are higher and government spending is increased. Because of this the government needs to stabilize debt levels. It raises taxes to do so. This results in a unique situation, when the expansionary fiscal policy – which means increased government spending – is accompanied by restrictive monetary policy and increased taxation. Based on figure 11 we can conclude that the effects of the shocks are statistically significant, and the variables return to their respective steady states.

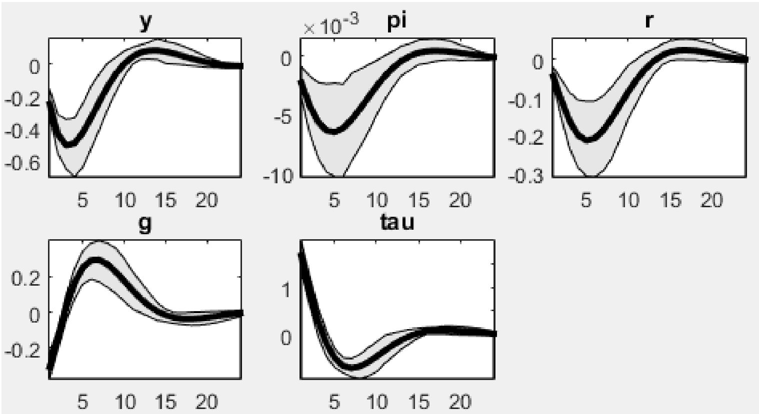

Fig. 2. Tax shock

Secondly, the effects of an unexpected increase in taxes are presented on figure 12. As a result of an unexpected increase in taxes output decreases. Taxes affect the economy via two channels. Through the first channel income taxes reduce disposable income and lead to a decrease in output. Through the second channel an increase in payroll taxes leads to an increase in the marginal cost of firms, thereby reducing aggregate supply. Furthermore, an increase in payroll taxes also increases prices, again via the marginal cost. We, however, cannot see an increase in inflation on figure 12. On the contrary, inflation decreases. At the beginning taxes increase and government spending falls, which leads to a decrease in debt. After the government debt was reduced to the appropriate level, taxes return to their steady state and government spending increases, before returning to its own steady state value. Since government spending decreases inflation via marginal cost, it seems that the effects of spending outweigh the effects of taxation. The monetary authority reacts to the decrease in inflation by conducting an expansionary monetary policy and thus it decreases the interest rate to stimulate the economy. Based on figure 12 we can conclude that the effects of the shocks are statistically significant, and the variables return to their respective steady states.

Thirdly, the effects of an unexpected increase in the nominal interest rate are presented on figure 14. As a result of an unexpected nominal interest rate shock output decreases along with inflation. The interest paid on government bonds is higher, which leads to higher levels of government indebtedness. To stabilize debt the government implements restrictive fiscal policy, resulting in government spending cuts and an increase in taxes. This kind of fiscal policy has two effects. Firstly, lower government spending further reduces output. Furthermore, larger taxes decrease the purchasing power of households, further decreasing demand. Secondly, these government measures affect the behavior of firms via marginal cost. As these firms now face increased costs, they raise prices and households need to bear the cost burden. This leads to an increase in inflation, which we can see on figure 14. It seems that the decrease in inflation was offset by the fiscal policy reaction, which results in an increase in the price level. According to these reactions both the monetary and fiscal authorities react the same way to an unexpected nominal interest rate shock. Both implement restrictive policies. Based on figure 14 we can conclude that the effects of the shocks are statistically significant, and the variables return to their respective steady states.

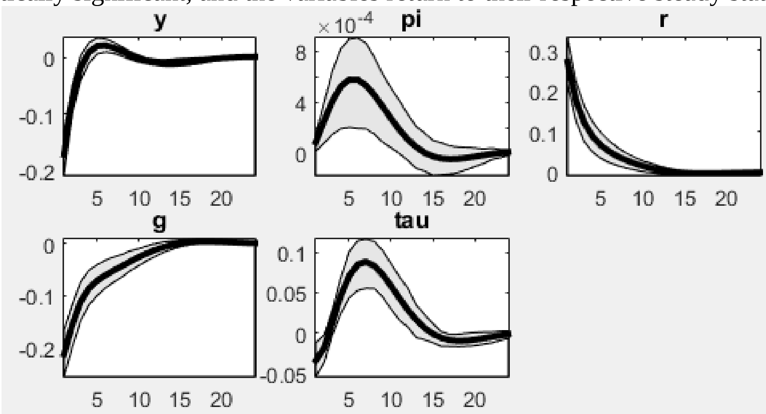

Fig. 14. Interest rate shock

5 Conclusion

In this study we calibrate and estimate the parameters of a New Keynesian small open economy dynamic stochastic general equilibrium model. We get similar results as Çebi (2013), who estimated a DSGE model for Turkey. We analyze the results using impulse response functions and focus our attention on the type of fiscal policy and monetary policy implemented by the authorities. Sometimes restrictive fiscal policy is accompanied by restrictive monetary policy. At other times the policies adopted by the fiscal and monetary authorities are different from each other. For example, in the case of the government spending shock expansionary fiscal policy is accompanied by restrictive monetary policy.

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