J. F. Kennedy sq. 6
10000 Zagreb, Croatia
Tel +385(0)1 238 3333
www.efzg.hr/wps
wps@efzg.hr

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Vladimir Arčabić
Tomislav Globan
Ozana Nadoveza
Lucija Rogić Dumančić
Josip Tica

Macroeconomic Effects of Productivity Shocks – A VAR Model of a Small Open Economy

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Vladimir Arčabić
varcabic@efzg.hr

Tomislav Globan
tgloban@efzg.hr

Ozana Nadoveza
onadoveza@efzg.hr

Lucija Rogić Dumančić
lrogic@efzg.hr

Josip Tica
jtica@efzg.hr

Faculty of Economics and Business
University of Zagreb
Trg J. F. Kennedy 6
10 000 Zagreb, Croatia

Abstract

The paper compares theoretical impulse response functions from a DSGE model for a small open economy with an empirical five variable VAR model estimated for the Croatian economy. In the paper we analyse the impact of productivity shock on the selected macroeconomic variables: domestic output gap, nominal interest rate, CPI inflation and terms of trade. The impulse responses from the empirical VAR model do not resemble those from the theoretical one for all the variables in any proposed monetary regimes. Results of modelling simultaneous interrelationships between variables also support the results that the productivity shocks do not play a significant role in determining the variation of selected macroeconomic variables in the case of the Croatian economy.

Key words
DSGE, productivity shocks, small open economy, exchange rate, Croatia

JEL classification
D24, E32, F41

Introduction

The paper introduces the application of the DSGE framework in the case of Croatia. The goal of the paper is to compare the results of modelling Croatian economy as a small open economy DSGE model following the example of Galí and Monacelli (2005) with the empirical results of a VAR model estimated over Croatian data. In the model, Galí and Monacelli (2005) investigate the impact of a domestic productivity shock on selected macroeconomic variables in four different monetary regimes: domestic inflation targeting regime (DIT), domestic inflation-based Taylor rule regime (DITR), CPI inflation-based Taylor rule regime (CITR) and pegged exchange rate regime (PEG). In this paper the emphasis is on the productivity shock and effects on domestic output gap, nominal interest rate, CPI inflation and terms of trade in those four different monetary regimes.

Results of theoretical model imply that responses of variables to a domestic productivity shock varied depending on the monetary regime. For example, the response of the nominal interest rate is most expressed in the case of a domestic inflation-based Taylor rule regime, while in the case of a fixed exchange rate regime the nominal interest rate does not change at all in order to keep the exchange rate unchanged. From the results obtained from the empirical VAR model it can be concluded that there is no evidence that changes in productivity in Croatia significantly impact output gap, interest rate, CPI inflation and terms of trade in any proposed monetary regimes. Finally, the results of VAR modelling of simultaneous interrelationships between variables also support that conclusion.

Theoretical framework

Gali and Monacelli (2005) is a benchmark New Keynesian macroeconomic model with microeconomic foundations. In the model, the behavior of households and firms are strictly modelled. Households choose a level of employment and consumption in order to maximize utility subject to a budget constraint and firms chose a level of economic activity which will maximize its profits subject to marginal costs and demand function for their products.

The labor market is perfectly competitive with rational households which means that first order conditions of utility function $U_t = E_t\sum_{t=0}^{\infty}\beta^t U_t(C_t, N_t)$, where C_t is consumption and N_t is labor, will represent labor supply and demand for total consumption and consumption of each differentiated good j. The good's market is imperfectly competitive with a continuum of j goods that are imperfect substitute, which results in a domestic goods and foreign goods downward slopping demand curve $C_{H,t(j)} = \left(\frac{P_{H,t(j)}}{P_{H,t}}\right)^{-\varepsilon} C_{H,t}$ and $C_{i,t(j)} = \left(\frac{P_{i,t(j)}}{P_{i,t}}\right)^{-\varepsilon} C_{i,t}$, where $P_{H,t}$ is a domestic price level.

Firms maximize its profits $\max_{\bar{P}_{H,t}} \sum_{k=0}^{\infty}\theta^k E_t\{Q_{t,t+k}[Y_{t+k}(\bar{P}_{H,t} - MC^n_{t+k})]\}$ subject to sequence of domestic and foreign demand curves, where Q_t is nominal bond price, Y_t is output level, and MC_t is marginal cost. In other words, there is a monopolistic competition and firms will charge mark up $\frac{\varepsilon}{\varepsilon-1}$ over marginal costs, with ε representing demand elasticity. Having in mind that production function is Keynesian $Y_t(j) = A_t N_t(j)$, marginal cost will be equal to unit labor cost $MC_t = \frac{W_t}{P_{H,t}}\ 1/A_t$, with W_t representing nominal wage. It means that prices are set as mark up over unit labor cost and the mark up is a function of elasticity of consumption demand functions.

As a result, price setting and wage setting relationship resemble WS-PS model with an exception that there is a labor supply curve instead of the wage-setting curve (no unions) and mark-up over marginal cost is derived from the slope of the demand curve for the good j.

On the demand side income is equal to the sum of consumption and trade balance $Y = NX_t + C_t$, where trade balance is implicitly defined as $nx_t \equiv 1/Y(Y_t - \frac{P_t}{P_{H,t}C_t})$ and Government consumption and investment (as well as physical capital in production function) are omitted due to simplicity. In the

same way as in intermediate macroeconomic models, PPP assumption is assumed for the exchange rate determination $P_{H,t} = P_{F,t}$ and uncovered interest parity holds as in classical Mundell-Fleming model. The only difference is that terms of trade are a function of current and anticipated real interest rate differential.

In the equilibrium, the model consist of a New Keynesian dynamic IS curve which is defined in terms of an output gap as $x_t = E_t\{x_{t+1}\} - \frac{1}{\sigma_\alpha}\left(r_t - E_t\{\pi_{H,t+1}\} - \overline{rr}_t\right)$, Phillips curve which is defined as $\pi_{H,t} = \beta E_t\{\pi_{H,t+1}\} + \mathrm{K}_{\alpha x_t}$ and natural real interest rate as $\overline{rr}_t = \rho - \sigma_{\alpha\Gamma(1-\rho_\alpha)a_t} + \alpha\sigma_{\alpha(\Theta+\Psi)E_t}\{\Delta\, Y^*_{t+1}\}$.

The model allows the comparison of the dynamic response of the economy to technological shocks and/or shock of world income based on four different designs of monetary policy in the model. Monetary policy designs are named as: domestic inflation targeting (DIT), domestic inflation-based Taylor rule (DITR), CPI inflation-based Taylor rule (CITR) and exchange rate peg (PEG). Behavior of central bank is defined with strict inflation targeting (DIT-optimal policy) $x_t = \phi_\pi \pi_{H,t} = 0$, Taylor rule for domestic inflation (DITR) $r_t = \rho + \phi_\pi \pi_{H,t}$ and Taylor rule for CPI targeting (CITR) $r_t = \rho + \phi_\pi \pi_t$ and exchange rate peg (PEG) $e = 0$.

A drawback of the model is that investment and physical capital are abstracted to make a simpler model. Productivity and technology shocks are usually considered as a major sources of business cycles in the real business cycle theory which emphasizes the role of investment and capital. Without investments and the physical capital, the model is criticized to diminish importance of productivity and technology shocks (see McGrattan, 2004 and Chari et al., 2004 for a general criticism of new Keynesian models without investment and capital).

We calibrate parameters in the model following Galí and Monacelli (2005) specification of a small open economy. They calibrate parameters for Canadian economy. For a model calibrated for Croatian economy refer to Palić (2015). Parameters used in a model are shown in the table 1.

Table 1. Calibrated parameters in estimated DSGE model

σ	ρ	τ	α	θ	β	κ	ω	ξ	ϕ_π	ρ_a	ρ_y
1.0	0.0101	1.0	0.4	0.0	0.99	0.3433	-0.1277	0.0	1.5	0.66	0.86

Methodology and data

Methodological framework for empirical research is based on theoretical assumptions of the Galí and Monacelli (2005) small open economy model. We estimate a five variable VAR model which facilitates the modelling of the impact of productivity shocks on the domestic output gap, nominal interest rate, CPI inflation and terms of trade, and enables modelling of simultaneous interrelationships between variables, which are treated endogenously. VAR model in a reduced form can be written as:

$$Y_t = B_1 Y_{t-1} + B_2 Y_{t-2} + \cdots + B_p Y_{t-p} + e_t \qquad (1)$$

where Y_t is a vector of endogenous variables, $B_i (i = 1, \ldots, p)$ are $(K \times K)$ parameter matrices, error process $e_t = (e_{1t}, \ldots, e_{Kt})$ is a K-dimensional zero mean white noise process with covariance matrix $E(e_t e_t') = \sum_e$, that is, $e_t \sim (0, \sum_e)$, and p is a number of lags in the model. The basic specification of the model is represented by the following vector of endogenous variables, with the corresponding Cholesky ordering of variables:

$$Y_t = (GAP_t, A_t, IR_t, PI_t, TOT_t)' \quad (2)$$

where GAP_t is the domestic output gap, A_t represents domestic productivity growth, IR_t is the domestic nominal interest rate, PI_t represents the inflation rate and TOT_t represents terms of trade. The ordering of variables in vector Y_t is based on economic theory and Granger causality tests, with the interest rate following the state of the economic cycle (output gap), and terms of trade following the level of the inflation rate as domestic price level directly influences the real exchange rate. The question arises to the order of the productivity growth and output gap, on which economic theory is ambiguous. Thus, Granger causality tests were employed to test which variable precedes the other. Table 2 reports that the hypothesis that output gap does not Granger-cause productivity growth is easily rejected at 1% level of significance, while the reverse hypothesis could not be rejected.

Table 2. Results of Granger causality tests

Null hypothesis	***F*-stat *(8,56)***	**Null hypothesis**	***F*-stat *(8,56)***
A does not Granger-cause *GAP*	0.500	*GAP* does not Granger-cause *A*	3.323***

Note: ***null hypothesis is rejected at the significance level of 1%
Source: authors' calculations

The analysis is carried out on quarterly data covering the period from 1995:Q1 to 2015:Q2. Domestic productivity was calculated as domestic real GDP divided by the employment. Croatian real GDP and employment data were obtained from Eurostat, Croatian statistical bureau and the IMF's International Financial Statistics (IFS) database. The time series for the output gap has been obtained by employing the Hodrick and Prescott (1997) filter on the seasonally adjusted real GDP time series for Croatia to separate the cyclical from the trend component. Domestic nominal interest rates are represented by domestic overnight money market rates, obtained from IFS and the Croatian National Bank statistical database. The time series of CPI inflation is represented by the year-on-year percentage change in the consumer price index (CPI) for Croatia, downloaded from IFS. Finally, CPI-based real effective exchange rate (REER) is proxy for the terms of trade, obtained from IFS. In order to comply with the terms of trade variable as determined in the theoretical model, the REER time series was multiplied by -1, so that an increase represents real depreciation and vice versa.

Time series indicating seasonal behaviour have been seasonally adjusted using the *Census X12* procedure. Stationarity of time series has not been tested given the requirements of the theoretical model. Specifically, in order to make the impulse responses derived from the empirical model comparable to those obtained from the theoretical model, variables needed to enter the VAR model in the form determined by theoretical equations.

Optimal number of lags in the VAR model has been determined by the minimization of the Akaike information criterion, which stated that one lag is optimal for estimation. Residuals from estimated models have been tested for autocorrelation using the multivariate serial correlation test (Hosking Q-statistics). The results, available upon request, indicate that the null hypothesis of no serial correlation cannot be rejected. Confidence intervals in impulse response functions (IRFs) have been obtained using Monte Carlo bootstrapping method with Cholesky factorization. The impulse response functions from the theoretical model were obtained using *Dynare* software in *MATLAB*.

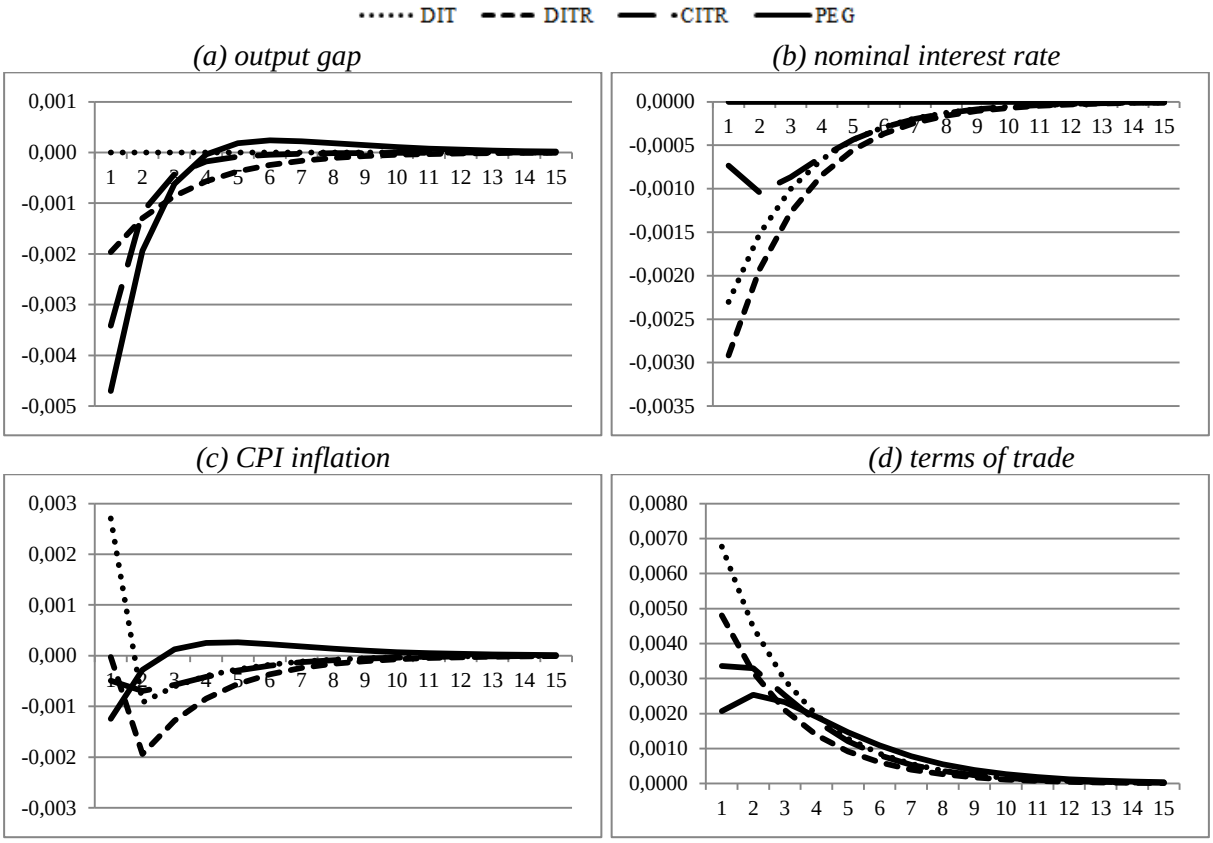
Results

In their small open economy model, Galí and Monacelli (2005) examine the impact of a domestic productivity shock on various macroeconomic variables in four different monetary regimes: domestic inflation targeting regime (DIT), domestic inflation-based Taylor rule regime (DITR), CPI inflation-based Taylor rule regime (CITR) and pegged exchange rate regime (PEG).

The quantitative and qualitative aspects of responses of variables to a domestic productivity shock varied depending on the monetary regime. Figure 1b displays how the influence of a positive shock in domestic productivity on the nominal interest rate is most pronounced in case of a domestic inflation-based Taylor rule regime, but the interest rate decreases in CITR and DIT regimes as well. The reason for this is that higher productivity leads to increased production and consumption, which must be supported by lower interest rates in case of flexible prices (Galí and Monacelli, 2005). On the other hand, in case of a fixed exchange rate regime the nominal interest rate does not change at all, given that it needs to be equal to the world interest rate in order for the exchange rate to remain unchanged.

Looking at other variables, it is evident that the productivity shock has no influence on the domestic output gap and domestic inflation in the DIT regime, but CPI inflation increases significantly and real exchange rate (terms of trade) depreciates substantially. However, in the pegged regime, prices and the real exchange rate display much less volatility, however at a cost of a significant loss in output gap due to the impossibility to decrease the nominal interest rate and depreciate the currency in order to mitigate the initial impact of a shock. However, the reaction of the output gap in PEG regime turns positive four periods after the shock.

Figure 1: Impulse response functions of selected variables to a domestic productivity shock under different monetary regimes, theoretical model



Source: authors' calculations based on Galí and Monacelli (2005)

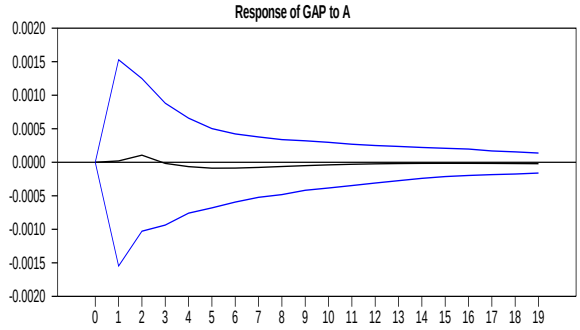
Given that Croatia operates a crawl-like regime, where the currency (kuna) is not allowed to deviate too much from the anchor (euro), it is expected that the impulse responses from the empirical VAR model should most resemble those from PEG regime in the theoretical model. However, the results did not support this hypothesis. In fact, the impulse response functions of output gap, the nominal interest rate, CPI inflation and terms of trade to a productivity shock do not resemble those in any of the four proposed monetary regimes, as defined by Galí and Monacelli (2005).

Figure 2 reveals the impulse response functions obtained by estimating a five variable VAR model on Croatian data. Although the direction and sign of impulse responses are somewhat similar to those in

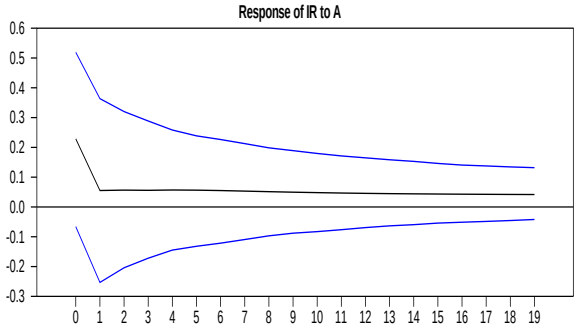
the theoretical PEG regime, none of the response functions are statistically significant at any point after the shock occurs. In other words, there is no evidence that changes in productivity in Croatia significantly impact output gap, interest rate, CPI inflation and terms of trade, as shown in Arčabić (forthcoming).

Figure 2: Impulse response functions of selected variables to a domestic productivity shock, empirical model

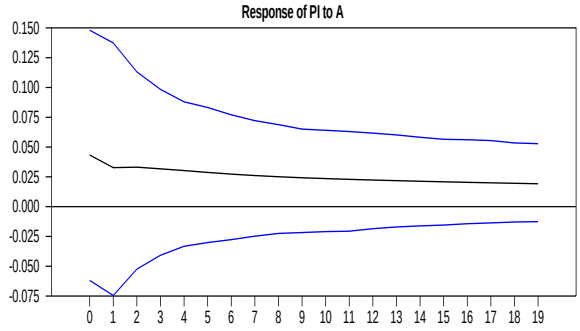
(a) output gap



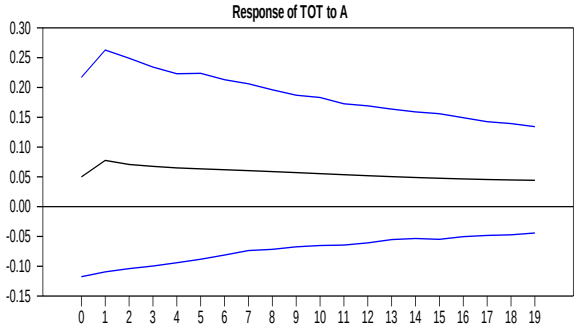
(b) nominal interest rate



(c) CPI inflation



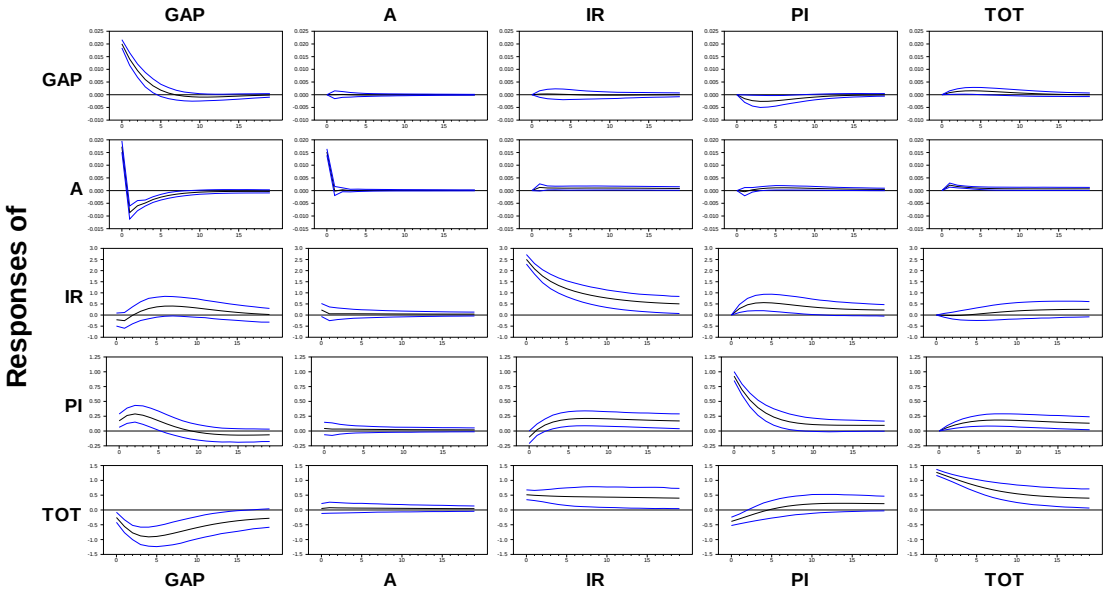
(d) terms of trade



Source: authors' calculations

Impulse responses of all other variables to five various shocks are reported in Figure 3. Output gap reacts significantly positive to the increase in terms of trade, i.e. real depreciation boosts economic activity through the trade channel and higher net exports. The same channel explains why a positive shock in inflation decreases output gap, reflecting a loss in competitiveness and appreciation of the real exchange rate. The responses of other variables to a shock in output gap are expected. Namely, inflation picks up after an increase in economic activity, while the terms of trade worsen due to a rise in the price level. It is interesting to note the reaction of productivity to a shock in output gap. Higher GDP initially leads to higher productivity, possibly reflecting higher number of working hours put in by the employees in periods of economic growth. However, the productivity response then turns negative before settling to zero eight quarters after the shock. Finally, the interest rate does not record a statistically significant response to an output gap shock, once again indicating that the monetary policy in Croatia does not follow any type of a Taylor rule, but rather focuses on anchoring the exchange rate to keep the inflation expectations at bay (see Vizek, 2008).

Figure 3: Impulse response functions, empirical model



Source: authors' calculations

Variance decompositions of analysed variables are reported in Table 3. The results confirm the finding that the productivity shocks do not play a significant role in determining the variation of selected macroeconomic variables, as their share in variance decomposition does not exceed 0.3 percent in each case. Impulse response functions showed a statistically significant response of output gap to CPI inflation and terms of trade shocks, but their share in output gap variance is fairly small, determining only 4.6 and 2 percent of its variance, respectively. The share of output gap in the variance of domestic productivity growth is sizeable, exceeding 63 percent, further confirming the results obtained from the impulse response analysis.

Table 3. Variance decomposition, empirical model

		Contribution of shocks to variance, after 16 quarters				
		GAP	*A*	*IR*	*PI*	*TOT*
Variable	*GAP*	93.3	0.0	0.1	4.6	2.0
	A	63.1	31.5	1.9	1.3	2.2
	IR	4.1	0.3	85.2	9.3	1.2
	PI	10.9	0.3	14.7	62.4	11.6
	TOT	32.5	0.3	15.0	3.6	48.6

Source: authors' calculations

For the purpose of robustness checks, an alternative extended model with foreign income included was estimated, but the results (available upon request) do not change with respect to the impact of productivity growth on all other variables.

Taking all into consideration, the results suggest that the small open economy model as designed and calibrated by Galí and Monacelli (2005) fits well with Croatian data in case of foreign income shocks, but does not resemble the empirical data at all in case of productivity shocks. A probable reason for this is a dominance of demand shocks in Croatian economy, as shown in Arčabić (forthcoming).

The results obtained in this paper and in the one that examines the impact of foreign income shocks on domestic variables strongly suggest that output fluctuations in Croatia are demand driven. This would mean that fluctuations do not represent equilibrium states of the economy which are driven by optimal

decisions made by economic agents, but are rather disequilibrium states which could (and should?) be moderated by counter-cyclical economic policy.

Conclusion

In the paper Croatian economy is modelled as a small open economy DSGE model as suggested in Galí and Monacelli (2005). Therefore, we estimate a five variable VAR model with purpose of modelling the impact of productivity shocks on the domestic output gap, nominal interest rate, CPI inflation and terms of trade. The results obtained from the empirical VAR model show that although the direction and sign of impulse responses of all of the variables to a productivity shock are somewhat similar to those in the theoretical PEG regime, none of the response functions are statistically significant at any point after the shock occurs. It can be concluded that the impulse responses from the empirical VAR model do not resemble those from the theoretical one for all the variables in any proposed monetary regimes.

VAR model also enables modelling of simultaneous interrelationships between variables. The results obtained from the impulse response analysis and variance decomposition of analysed variables also suggest that the productivity shocks do not play a significant role in determining the variation of selected macroeconomic variables. One important conclusion derived from this paper is that the demand shocks have the key role in Croatian output fluctuations. This result is consistent with the one obtained in the paper that examines the impact of foreign income shocks.

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