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GRANGER CAUSALITIES BETWEEN INTEREST RATE, PRICE LEVEL, MONEY SUPPLY AND REAL GDP IN THE CZECH REPUBLIC

Tomáš Urbanovský[1]

[1]Department of Finance, Faculty of Economics and Administration, Masaryk University in Brno, Lipová 41a, 602 00 Brno, Czech Republic

Abstract

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The main aim of this paper is to investigate relationships between selected macroeconomic variables – interest rate, price level, money supply and real GDP – in the Czech Republic in order to find out definite implications of its interactions and give recommendations to macroeconomic policy authorities. Two implemented vector autoregression models with different lag length reached slightly different conclusions. VAR(1) suggests that three pairs of Granger causality exist, in particular between price level and interest rate, between real GDP and interest rate and between real GDP and price level. VAR(2) uncovered two more pairs of Granger causality between money supply and interest rate and between money supply and price level. Despite better prediction power of VAR(2) in case of money supply, low correlation coefficient comprising variable money supply raises doubts about the factual existence of causality between money supply and other variables. However, both models allow forecasting the direction of change in case of variables interest rate and real GDP with the same success rate nearly 82 %. Both VARs also agreed that interest rate could be changed by change of price level and that interest rate could be changed by change of real GDP. These conclusions represent potential recommendations to macroeconomic policy authorities. For the purpose of further research, exchange rate variable will be included in the model instead of interest rate, because effect of interest rate turned out to be limited in times of weakened state of Czech economy.

Keywords: Interest rate, price level, money supply, GDP, VAR, Granger causality

INTRODUCTION

Relationships among macroeconomic variables have been always in the spotlight of macroeconomists, because they could be used to address theoretical questions of interest. One group of researchers may be interested in investigation, whether Keynesian views of the economy are supported. On the contrary, other researchers could investigate, whether monetarist theory could be applied on economy under study. Someone could be interested in an issue, whether inflation is a monetary phenomenon (Grauwe and Polan, 2005) or whether it is connected to real economy and economic growth (Herwartz and Reimers, 2006).

Author decided to investigate potential relationships between interest rate, money supply, price level and real GDP in the Czech Republic in order to find out definite implications of its interactions and give recommendations to macroeconomic policy authorities. Because we have four variables, we can have six possible relationships, which are illustrated in Tab. I.

Mutual interconnection of these variables was investigated in an extensive number of studies, which differ in methodology, economies under study and even in results.

Omay and Kan (2010) found statistically significant negative relationship between inflation and output growth with use of non-linear panel regression. Drukker *et al.* (2005) reached the same conclusion

I: *Pairs of variables with potential relationships*

real GDP	price level
real GDP	money supply
real GDP	interest rate
price level	money supply
price level	interest rate
interest rate	money supply

with use of unbalanced panel method, time varying estimates employed in Eggoh and Khan (2014) and trend cycle decomposition model employed in Macchiarelli (2013) showed also negative and nonlinear inflation-growth relationship. Baglan and Yoldas (2014) used semiparametric panel data model to ascertain that inflation is associated with significantly lower growth only after it reaches about 12 percent. Kremer *et al.* (2013) used dynamic panel threshold model and found that inflation must exceed certain rate to be associated with lower economic growth – this rate depends on whether the country under study is industrialized or non-industrialized.

Relationship between real GDP and money supply was investigated in Ravn, Psaradakis and Sola (2005). With use of VAR models with time-varying parameter, they found that the causality between money and output varies in time. Detection of causality with use of VAR was content of Favara and Giordani (2009). This causality was also found in Caraiani (2015) by means of estimated DSGE model. International evidence as to the role of money was provided by Canova and Menz (2011). They showed that monetary aggregates made a significant contribution to explaining the dynamics of the output in USA, Eurozone countries, Japan and UK. Nelson (2002) reached the same conclusion in cases of US and UK economy.

Investigation of potential relationship between interest rate and other macroeconomic variables is a content of Garcia and Rigobon (2004), where VAR is proposed to estimate the correlation pattern of the macro variables of the Brazilian economy and use it to implement Monte-Carlo simulations. Another relevant study dealing with interest rate and its connection to macroeconomic variables is Diaz *et al.* (2016).

The fourth relationship, which attracts attention, is the one between money supply and price level. ECB research proved existence of long-run relationship between money growth and inflation in European countries, see for example Benati (2005) or Lenza (2006). Existence of this relationship was examined and proved in Thornton (2014), who concentrated on US economy. According to Nguyen (2015), money supply influence inflation also in selected Asian countries.

Investigation of connection between interest rate and inflation draws attention for example in case of Turkish economy. Gul and Ekinci (2006) examined this issue by means of Johansen co-integration technique and Granger causality test. They found a causal unidirectional relationship between nominal interest rates and inflation in Turkish economy. Gul and Acikalin (2008) used Johansen co-integration method and found that it is possible to determine the long-term relationship – but not on one-to-one basis – between nominal interest rates and inflation. Close relationship was also found in Kose *et al.* (2012) using the test of cointegrating rank and application of exogenity tests. Close relationship was also proved, again by use of cointegrating methods, in European countries and in the US economy in Booth and Ciner (2001).

Closeness of interest rate and money supply in the euro area is shown in Cendejas *et al.* (2014). Another relevant study on this matter is for example Schabert (2009).

MATERIALS AND METHODS

In our analysis we use above mentioned macroeconomic variables: interest rate, money supply, price level and real GDP. We use seasonally adjusted quarterly data on these variables for the Czech Republic from 1996Q1 to 2015Q3, which means that 79 observations for each variable were collected from this period. Tab. II contains a short description of variables and their abbreviations used in the analysis.

Data on variable M and Y were acquired via time series database ARAD administrated by Czech National Bank, data on variable R and P

II: *Variables used in analysis.*

abbreviation of variable	variable characteristic
R	3 month Prague InterBank Offered Rate (PRIBOR)
M	money supply (M2) measured in billions of CZK
P	price level measured by the GDP deflator (a price index with 2010 = 100)
Y	real GDP measured in billions of 2010 CZK

were acquired via Bloomberg database. Data were processed in econometric software Gretl.

We are not going to use above mentioned variables in their absolute values – it is quite common to work with natural logarithms of variables in econometric analysis, so this approach is adopted in this paper as well (but we maintain abbreviation mentioned above).

Time series have some special properties, which can lead to invalid results of regression. Before the regression could be conducted including all the input variables, isolated analysis of each time series needs to be executed to check assumptions associated with appropriate lag length selection and stationarity (or non-stationarity). In other words, univariate time series analysis needs to be performed for each variable.

The first phenomenon typical for time series data is correlation across observations – a value can depend on previous value(s). The appropriate number of lags for each variable needs to be determined to assess which data are independent. In order to find the correct number of lags, the sequential testing procedure will be adopted – a chosen number of lags will be included in order to assess the intensity of the influence of previous values on the current value. We use quarterly data, so it is reasonable to suspect that the value of variable from the same period year ago can help explain value in current period (i.e. value in first quarter 2011 can explain value in first quarter 2012, etc.). For this reason, the highest number of lags is set at four and then lag lengths would be sequentially dropped if the relevant coefficients turn out to be statistically insignificant. The resulting regression will be known as autoregressive model of order p (AR(p) model) and because four variables are considered in the analysis, we will get four equations. Formally:

$$X_t = \alpha + \sum_{i=1}^{p} \phi_i X_{t-i} + (\varphi t) + \varepsilon_t$$

where X_t represents corresponding variable. Comment on potential inclusion of φt will be made immediately afterwards.

A second property investigated is whether the time series under study are stationary or not. Main characteristic of non-stationary time series is a presence of unit root. In the above mentioned equation, this fact would be demonstrated by a coefficients ϕ_1 equal to unity. In discussing (or testing) unit root behavior, it is convenient to subtract X_{t-1} from both sides of the equation. We obtain:

$$\Delta X_t = \alpha + \rho X_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta X_{t-i} + (\varphi t) + \varepsilon_t$$

where and $\rho = \phi_1 - 1$ and $\rho = 0$ implies that the AR(p) time series contains unit root and is non-stationary. On the other hand, if $\rho = 0$, term X_{t-1}drops out in the time series ΔX_t and stationarity of these series is induced. Test performed by means of this equation is called augmented Dickey-Fuller test, invented in Dickey and Fuller (1979) – from now on it will be abbreviated as ADF test. It is often difficult to distinguish between non-stationary time series, which contains stochastic trend, and trend stationary variable, which contains deterministic trend. For this reason, it was decided to include deterministic trend t into equations. Statistical significance of this component means trend stationary variable and special measures need to be undertaken to deal with this finding.

We need to define the precise form of equations for every variable, i.e. we need to find appropriate number of lags of dependent variable. Otherwise, it will not be possible to perform ADF tests correctly. Highest number of lags is set at the level of four (for the same reason as discussed above) and use of sequential testing procedure ensures that insignificant lags are dropped from regressions.

Previous studies showed that it is likely to find these variables to be non-stationary and that phenomenon of co-integration does not occur, so co-integration analysis is not possible to perform. It is also not possible to perform simple OLS regression with variables in these forms, because trend components present in time series will lead to incorrect results and conclusions. The most suitable approach to properly perform analysis is to use VAR based on differenced variables. Potential issue can arise if time trend component in equations turns out to be statistically significant. It means that removing trend component from equation by differencing is not suitable (this approach is suitable only in case of nonstationary variables which contain stochastic trend). This variable contains deterministic trend (this is confirmed by statistical significance of trend component in previously performed ADF test). Variable containing deterministic trend is called trend-stationary and the technique used to remove this trend is called simply de-trending, which is accomplished by regression of the variable on a deterministic polynomial time trend. Formally:

$$X_t = \alpha + \sum_{i=1}^{n} \varsigma_i t^i + e_t$$

Subtraction of these estimated values of X_t from the actual values yields a time series of residuals, which is stationary, and which can be used in further analysis in form of VAR, along with stationary differences of remaining variables.

VAR is a typical econometric tool to identify Granger causality in case of stationary time series. It is a system of regression equations, where the number of equations matches the number of variables under study. In each equation we have different dependent variable – it is always one of the variables under study. Each equation uses as its explanatory variables lags of all variables. Because it would be time and space consuming to find specific number of lags for each variable, it was decided to use the same lag length for every variable in every equation (note that this is a common practice in research papers). The resulting model will be known as a VAR(p) model with p indicating number of included lags.

The research process will have the following structure. Firstly, appropriate number of lags has to be determined. Second step is the estimation of VAR(p). Third step is an interpretation of results with respect to Granger causality followed by comparison of discovered causality with correlation relationship. And finally, the analysis will be concluded with verification of (in)validity of estimated regression models by way of forecasting

RESULTS

Adressing the issues of stationarity and non-stationarity of variables

First step was to determine the order of AR(p) process for each variable under study in order to find out potential correlation between consecutive values of each variable. Results of performed OLS regressions of variables under study on their lags are stated in Tab. III. Statistically insignificant lags were sequentially dropped from regressions in order to receive more accurate estimations of significant coefficients – these dropped lags are illustrated by blank spaces (please note that expression X in first column always represents lags of corresponding dependent variable). Based on results, we can see that the best way how to describe behavior of variable R is by means of AR(2) process, variable M by means of AR(4) process, variable P by means of AR(1) process and variable Y by means of AR(2) process. Please note that in case of variable P, time trend component turned out to be statistically significant – because of this finding this variable requires special treatment, which will be discussed immediately afterwards.

Formally, we can put above mentioned results in equations (please note that upper indexes serve only to distinguish coefficients across the equations – they do not represent exponents):

$$R_t = \alpha_1 + \sum_{i=1}^{2} \phi_i^R R_{t-i} + \varepsilon_t^R$$

$$M_t = \alpha_2 + \sum_{i=1}^{4} \phi_i^M M_{t-i} + \varepsilon_t^M$$

$$P_t = \alpha_3 + \phi_1^P P_{t-1} + \varphi t + \varepsilon_t^P$$

$$Y_t = \alpha_4 + \sum_{i=1}^{2} \phi_i^Y Y_{t-i} + \varepsilon_t^Y$$

After order determination of AR processes, we were free to construct equations for ADF tests. After subtraction of first lag of dependent variable in each equation, we got:

$$\Delta R_t = \alpha_1 + \rho^R R_{t-1} + \gamma_1^R \Delta R_{t-1} + \varepsilon_t^R$$

III: *OLS regressions of variables under study on their lags*

explanatory variable	dependent variable (X_t)			
	R	M	P	Y
constant	−0.0343125 (0.0343623)	0.101501* (0.0534063)	0.225052*** (0.0450693)	0.0320060 (0.0354335)
X_{t-1}	1.29843*** (0.129256)	0.566747*** (0.119805)	0.951345*** (0.0100493)	1.71506*** (0.0881876)
X_{t-2}	−0.300533** (0.130411)	0.260084* (0.136783)		−0.719597*** (0.0880098)
X_{t-3}		−0.227660* (0.135032)		
X_{t-4}		0.391751*** (0.118298)		
R^2	0.969662	0.997166	0.992799	0.998244
adjusted R^2	0.968698	0.996974	0.992689	0.998188
P-value (F)	1.52e-48	2.12e-74	2.29e-71	1.60e-87
DW stat.	2.002839	2.038469	1.982299	2.021365

Notes: Figures in parentheses are standard errors, *, ** and *** denote significance at the 10 %, 5 % and 1 % levels respectively.
Source: Gretl output based on data acquired via ARAD and Bloomberg Database

$$\Delta M_t = \alpha_2 + \rho^M M_{t-1} + \sum_{i=1}^{3} \gamma_i^M \Delta M_{t-i} + \varepsilon_t^M$$

$$\Delta P_t = \alpha_3 + \rho^P P_{t-1} + \varphi t + \varepsilon_t^P$$

$$\Delta Y_t = \alpha_4 + \rho^Y Y_{t-1} + \gamma_1^Y \Delta Y_{t-1} + \varepsilon_t^Y$$

ADF tests were performed on each variable under study with use of sequential testing procedure. Parameters of executed regressions are stated in Tab. IV (only characteristics crucial to decide of existence of unit roots are stated).

We can claim that coefficients are statistically insignificant in case of variables ΔY_t, ΔM_t and ΔR_t. In other words, we cannot decline hypotheses that they are equal to zero. Therefore, we can conclude that original time series R_t, M_t, and Y_t have unit roots and display non-stationary behavior.

This is not the case of variable P_t – corresponding row in Tab. IV shows exactly opposite result than ADF tests performed on remaining variables. The conclusion is that variable P_t does not express non-stationary behavior.

On the grounds of these results, we cannot perform cointegration analysis, because it is conditioned by non-stationarity of every included variable (besides other things). It is also not possible to perform simple OLS regression with variables in these forms, because trend components present in time series will lead to incorrect results and conclusions. First we need to remove the trend from variables. Two different approaches need to be adopted. Variables R, M, and Y contain stochastic trend, therefore differencing is suitable – we get difference stationary variables. Case of variable P is somehow more complicated. If we take a look in Appendix A, we can see that there is clearly some kind of trend. However, this trend is not stochastic, it is deterministic (this is confirmed by statistical significance of trend component in previously performed ADF test). Variable containing deterministic trend is called trend-stationary and the technique used to remove this trend is called simply de-trending, which is accomplished by regression of the variable on a deterministic polynomial time trend.

It was found (again with use of sequentional testing procedure) that time series P has polynomial trend of fifth degree. Parameters of executed regression are not stated here in order to save space. The regression has following form:

$$P_t = \alpha_3 + \sum_{i=1}^{5} \varsigma_i^P t^i + \varepsilon_t^P$$

Appendix B shows the actual values of P (red line) and estimated values of P with use of above mentioned polynomial time trend (blue line).

IV: *ADF tests performed on variables under study*

explanatory var. (X_{t-1})	dependent variable (ΔX_t)			
	ΔR_t	ΔM_t	ΔP_t	ΔY_t
R_{t-1}	−0.00210212 (0.0226434)			
M_{t-1}		−0.0068206 (0.00703043)		
P_{t-1}			−0.0511613** (0.0160432)	
Y_{t-1}				−0.00449835 (0.00542479)

Notes: Figures in parentheses are standard errors, ** denotes significance at the 5 % level.
Source: Gretl output based on data acquired via ARAD and Bloomberg Database

V: *ADF tests performed on differenced/de-trended variables under study*

explanatory variable	dependent variable			
	$\Delta^2 R_t$	$\Delta^2 M_t$	ΔP^*_t	$\Delta^2 Y_t$
ΔR_{t-1}	−0.543879** (0.166064)			
ΔM_{t-1}		−1.07156** (0.330019)		
P^*_{t-1}			−0.350741*** (0.101579)	
ΔY_{t-1}				−0.177718** (0.0853691)

Notes: Figures in parentheses are standard errors, ** and *** denote significance at the 5 % and 10 % levels respectively.
Source: Gretl output based on data acquired via ARAD and Bloomberg Database

VI: *Lag length determination.*

	lags 1	lags 2	lags 3	lags 4
AIC	**17.0884**	17.1633	17.2683	17.3854
BIC	**17.7688**	18.3880	19.0372	19.6987
HQC	**17.3560**	17.6450	17.9640	18.2952

Source: Gretl output based on data acquired via ARAD and Bloomberg Database

Subtraction of these estimated values of P from the actual values yields a time series of residuals, which is stationary, and which will be used in further analysis, along with stationary differences of remaining variables. For completeness, crucial results of performed ADF tests on these new variables are stated in Tab. V. From now on, we are going to label variables R, M and Y with symbol Δ (which stands for differences) and variable P with * (which stands for de-trended variable).

In this case, we can claim that coefficients are statistically significant in case of all variables. In other words, we decline hypotheses that they are equal to zero. Therefore, we can conclude that time series ΔR_t, ΔM_t, ΔY_t and P^*_t do not have unit roots and display stationary behavior. Look into Appendix C can provide an initial proof about their stationarity. Now we perform a transformation of our variables. We already had our variables in natural logarithms at the beginning of analysis. Then we differenced these logarithms in case of variables R, M and Y and we de-trended the logarithm of variable P. Now we multiply all variables by 100, because it allows us to work with percentage changes.

Stationarity of selected variables allows us to perform VAR. First step is to find appropriate number of lags for each variable. Including small number of lags can lead to invalid results and missing relationship among variables. On the other hand, it is highly unlikely that differences have long memory (it is the main issue of level variables), therefore inclusion of high number of lags is also not reasonable. From these reasons, highest number of lags is set at the level of four (for the same reason as discussed in part of paper about methodology concerning specification of ADF tests). The decision of most appropriate number of lags is based on information criteria – Akaike criterion (AIC), Schwarz Bayesian criterion (BIC) and Hannah-Quinn criterion (HQC). The best value of each criterion is always the lowest one. The best option appears to be option with 1 lag according to each criterion. Therefore the most suitable option appears to be regression in form of VAR(1). However, because the risk mentioned above – missing potential relationship among variables – it was decided to use VAR(2) as well. Comparison of achieved results is made at the end of this section.

VAR(1)

Tab. VII presents results from OLS estimation of a VAR(1). Since there are four variables, there are four equations to estimate. Each equations regresses a dependent variable on one lags of all the variables in the VAR.

VII: *The VAR(1) using ΔR, ΔM, P* and ΔY as dependent variables.*

explanatory variable	dependent variable			
	ΔR	**ΔM**	**P***	**ΔY**
constant	–6.03716**	2.25604***	–0.15832	0.217663*
	(2.63746)	(0.367462)	(0.181422)	(0.125495)
ΔR_{t-1}	0.123942	–0.000442511	–0.0139025	0.000411744
	(0.135851)	(0.0189273)	(0.00059)	(0.00646401)
ΔM_{t-1}	–0.544096	–0.464787***	–0.0106133	–0.0507247
	(0.818035)	(0.113972)	(0.0562697)	(0.0389234)
P^*_{t-1}	2.98544**	0.1241	0.665307***	–0.0661076
	(1.46284)	(0.203809)	(0.100624)	(0.0696044)
ΔY_{t-1}	4.20611**	0.327101	0.26833*	0.752161***
	(2.01611)	(0.280892)	(0.138681)	(0.0959296)
R^2	0.224669	0.238236	0.491135	0.53392
adjusted R^2	0.173827	0.188284	0.457767	0.503357
P-value (F)	0.003345	0.002055	0.000000	0.000000
DW stat.	1.9861	1.976828	2.096444	1.920183

Notes: Figures in parentheses are standard errors, *, ** and *** denote significance at the 10 %, 5 % and 1 % levels respectively.
Source: Gretl output based on data acquired via ARAD and Bloomberg Database

First interesting finding is that lags of dependent variable are statistically significant in all cases with exception of variable ΔR, where it has no explanatory power. It means that current change in variable M can be explained by previous change of this variable, current change in variable Y can be explained by previous change of this variable, etc.

Values of determination coefficients (R^2) suggest that models with P* and ΔY as dependent variables are more accurate in explaining changes of these variables than the models with ΔR and ΔM as dependent variables. In particular, in case of ΔY we can say that given variables explain in 53.39 % the variability of variable ΔY, etc.

Joint test for statistical significance of explanatory variables (F-test) give very small p-values in all cases, so we can claim that explanatory variables together have high explanatory power (even on the significance level 1 % we decline null hypothesis that all coefficients are equal to zero).

The last row represents values of Durbin-Watson statistics. We can see that all values are very close to value 2, which indicates desirable property of regression – no autocorrelation of residuals.

The interpretation of coefficients will not be made here, because it is not relevant to our task – our task was to only discover Granger causality among variables, not to mention that interpretation of some coefficients can be quite problematic, i.e. interpretation of coefficient corresponding to variable P^*_{t-1} (because of specific construction of this variable by de-trending).

Secondly, the results for these four equations demonstrate some interesting patterns of Granger causality. In the equation with ΔR as the dependent variable, it is clear that past price level change and past GDP change have explanatory power for interest rate change – in other words, they Granger-cause interest rate change. The third and last case of Granger causality is that past GDP change Granger-causes price level change. However, any of these causalities does not flow the other way – in other words, change in GDP can explain change in interest rate, but change in interest rate cannot explain change in GDP, etc. We witness three one-way Granger causalities. Results are summarized in the Tab. VIII.

VIII: *Granger causality.*

only one direction
P* → ΔR
ΔY → ΔR
ΔY → P*

Source: Gretl output based on data acquired via ARAD and Bloomberg Database

In order to test validity of above constructed VAR(1) model, it was decided to try to forecast future values of all variables under study with exception of variable P* for the reason of its complicated interpretation. Analysis, as well as results, was based on data from the period 1996Q1 to 2012Q4 so far. The forecast focuses on estimating values of ΔY, ΔM and ΔR in period 2013Q1 to 2015Q3 – therefore we get 11 estimated values.

According to figures in Tab. IX, our model is unable to reliably forecast magnitude of changes of variables. On the other side, model is quite reliable in forecasting direction of change in case of variables ΔY and ΔR – it can predict, whether the values will be positive or negative. Model successfully predicts 9 cases from total number of 11, which means success rate nearly 82 %. Predictions of variable ΔM are successful only in 54 % of cases, which means that the model is unable to predict the sign of change better than it is possible to determine it by sheer chance.

IX: *Forecast of variables ΔR, ΔM and ΔY by means of VAR(1) in period 2013Q1 to 2015Q3*

period	ΔR		ΔM		ΔY	
	actual	prediction	actual	prediction	actual	prediction
2013Q1	−6.18750	−14.00090	−0.53280	0.62680	−0.91050	−0.19283
2013Q2	−2.15060	−10.68190	1.11110	2.19450	0.53720	−0.43519
2013Q3	−2.19790	−4.30060	0.91840	1.93070	0.41360	0.55674
2013Q4	−16.90760	−4.79840	3.15980	1.97670	1.39950	0.47524
2014Q1	−2.66680	−5.37030	−0.21010	1.19430	−0.21860	1.13414
2014Q2	−5.55700	−10.64020	−0.02930	2.13920	0.51600	0.13956
2014Q3	0.00000	−8.14400	−0.66060	2.29110	0.61170	0.68477
2014Q4	−2.89880	−7.05290	4.08870	2.01480	0.40250	0.71579
2015Q1	−9.23730	−8.95770	−0.20660	0.40420	2.45800	0.35675
2015Q2	0.00000	2.44950	1.11510	3.12610	1.02710	2.09132
2015Q3	−6.66910	−0.47510	2.44220	2.15060	0.53790	0.89272
correct sign predictions (%)	81.8		54.5		81.8	

Source: Gretl output based on data acquired via ARAD and Bloomberg Database

X: *The VAR(2) using ΔR, ΔM, P* and ΔY as dependent variables*

explanatory variable	dependent variable			
	ΔR	ΔM	P*	ΔY
constant	−10.7598***	2.44679***	0.000495263	0.0139334
	(3.61680)	(0.514548)	(0.00251956)	(0.175224)
ΔR_{t-1}	0.0301896	−0.00755213	−0.0156399	−0.00017228
	(0.138550)	(0.0197110)	(9.65179e−05)	(0.00671240)
ΔR_{t-2}	0.0319713	0.0360295*	−0.00904297	−0.0153783**
	(0.136996)	(0.0194898)	(9.54347e−05)	(0.00663707)
ΔM_{t-1}	0.375226	−0.476561***	−0.0868381	−0.0304807
	(0.926547)	(0.131816)	(0.0645457)	(0.0448888)
ΔM_{t-2}	1.67136*	−0.0390086	−0.11797*	0.0476009
	(0.922972)	(0.131308)	(0.0642967)	(0.0447155)
P^*_{t-1}	0.629374	0.00161516	0.633326***	−0.148561
	(0.185952)	(0.000264546)	(0.129539)	(0.0900887)
P^*_{t-2}	3.91262*	0.112146	0.0640253	0.143233
	(0.198652)	(0.00282615)	(0.138386)	(0.0962417)
ΔY_{t-1}	7.31024**	0.14174	0.0907761	0.834886***
	(2.80343)	(0.398834)	(0.0195295)	(0.135819)
ΔY_{t-2}	−3.07177	0.208962	0.273075	−0.0290261
	(2.88497)	(0.410433)	(0.0200975)	(0.139769)
R^2	0.329322	0.302229	0.547638	0.582757
adjusted R^2	0.233511	0.202548	0.483015	0.523151
P-value (F)	0.002766	0.006673	0.000000182	0.0000000225
DW stat.	1.890464	1.907525	2.146225	2.052746

Notes: Figures in parentheses are standard errors, *, ** and *** denote significance at the 10 %, 5 % and 1 % levels respectively.
Source: Gretl output based on data acquired via ARAD and Bloomberg Database.

VAR(2)

Tab. X presents results from OLS estimation of a VAR(2). Each equations regresses a dependent variable on two lags of all the variables in the VAR.

On the first look, we did not received outputs too different from outputs of VAR(1). Results concerning statistical significance of lags of dependent variables are the same as in case of VAR(1) – only lags of variable ΔR cannot contribute to explaining current value of ΔR.

The same can be told about accuracy of regressions by means of determination coefficients (R^2). Similarly to VAR(1), models with P* and ΔY as dependent variables are more accurate in explaining changes of these variables than the models with ΔR and ΔM as dependent variables (even though the values are a bit lower).F-tests give very small p-values in all cases, so we can point out high explanatory power of explanatory variables together. Values of Durbin-Watson statistics are close to value 2, so we witness no autocorrelation of residuals.

So far we reached the same conclusions as in the case of VAR(1). But VAR(2) allowed us to uncover two more pairs of potential Granger causality than VAR(1). In particular, relationship between money supply and interest rate, and relationship between money supply and price level came out. Another difference to VAR(1) is that two way Granger causality emerged in case of VAR(2). Results are summarized in Tab. XI.

XI: *Granger causality.*

both direction	only one direction
ΔY ↔ ΔR	P* → ΔR
ΔM ↔ ΔR	ΔM → P*

Source: Gretl output based on data acquired via ARAD and Bloomberg Database

Validity of VAR(2) model was tested again by forecasting. Our modified model is still unable to reliably forecast magnitude of changes of variables. The success rate in sign prediction in case of variables ΔY and ΔR remains the same as in VAR(1) – 82 %. Successfully predicted sign changes of variable ΔM increase by 1 from 6 to 7 of total number 11 observations, so we can point to slight improvement of prediction power compared to VAR(1).

XII: *Forecast of variables ΔR, ΔM and ΔY by means of VAR(2) in period 2013Q1 to 2015Q3*

period	ΔR		ΔM		ΔY	
	actual	prediction	actual	prediction	actual	prediction
2013Q1	−6.18750	−9.38540	−0.53280	0.05740	−0.91050	0.16920
2013Q2	−2.15060	−11.41170	1.11110	0.68970	0.53720	0.27500
2013Q3	−2.19790	−5.14230	0.91840	1.60470	0.41360	0.49610
2013Q4	−16.90760	−6.80630	3.15980	2.08900	1.39950	0.40520
2014Q1	−2.66680	0.39950	−0.21010	1.24780	−0.21860	1.23730
2014Q2	−5.55700	−14.64720	−0.02930	2.04140	0.51600	0.31320
2014Q3	0.00000	−12.23530	0.66060	2.31010	0.61170	0.49690
2014Q4	−2.89880	−13.25610	4.08870	1.99030	0.40250	0.56140
2015Q1	−9.23730	−11.80580	−0.20660	0.55690	2.45800	0.18560
2015Q2	0.00000	9.52460	1.11510	2.70690	1.02710	2.24490
2015Q3	−6.66910	−11.70850	2.44220	2.22010	0.53790	0.76700
correct sign predictions (%)	81.8		63.6		81.8	

Source: Gretl output based on data acquired via ARAD and Bloomberg Database

XIII: *Correlation matrix.*

ΔY	ΔM	ΔR	P*	
1.0000	0.0298	**0.3520**	**0.3155**	ΔY
	1.0000	0.1441	0.0788	ΔM
		1.0000	**0.3269**	ΔR
			1.0000	P*

Source: Gretl output based on data acquired via ARAD and Bloomberg Database

The end of this section is dedicated to relationship between discovered Granger causality and correlation. Findings from VAR(1) and VAR(2) are incorporated in below stated correlation matrix. Bold values represent one-way Granger causality discovered by VAR(1). Boxed values represent Granger causality discovered by VAR(2). Both models agreed on existence of Granger causality between variables ΔR and ΔY and between P* and ΔR. Causality between P* and ΔY was proved only in VAR(1), causality between ΔR and ΔM and between P* and ΔM only in VAR(2). Despite better prediction power of VAR(2) in case of variable ΔM, the correlation coefficient comprising ΔM is rather low.

DISCUSSION

Several facts have been discovered in presented paper. First of all, both VARs revealed Granger causality between interest rate and price level, which coincides with findings of Gul and Ekinci (2006), Gul and Acikalin (2008), Kose *et al.* (2012) and Ciner (2001), even though we were forced to implement VAR approach instead of co-integration analysis.

Both VARs also pointed out the causality between interest rate and output (real GDP), which is the same result as in Garcia and Rigobon (2004), Diaz *et al.* (2016).

However, the effect of interest rate on remaining variables under study is limited. Main reason for this insufficient explaining power of interest rate is most likely recent financial crisis, even though Czech Republic was not hit so hard as European countries using euro. Short-term interest rate is an operative criterion of one of the classical transmission mechanism – credit channel. Interest rates are currently very low in the Czech Republic, therefore they should encourage economic activity. However, in times of recent economic and financial instability, commercial banks refuse to finance household's consumption and corporate investments via (cheap) loans, because they are afraid of possible problems with client's creditworthiness and repayments. And because household's consumption and corporate investments are the key components of aggregate demand, it is clear that change of interest rate cannot stand behind inflation and GDP growth development. In other words, causal relationships between interest rate and inflation and between interest rate and GDP growth are disrupted in time of financial crisis. Role of credit channel as a transmission mechanism is significantly suppressed.

Possible alternative how to deal with this setback is to modify presented model and replace credit channel with exchange rate channel, which uses exchange rate as an operative criterion. According to macroeconomic theory, depreciation (appreciation) of currency leads to increase (decrease) of exports and decrease (increase) of imports. Imports and exports are another components of aggregate demand, therefore they affect GDP growth and inflation rate. Exchange rate can also affect inflation via inflation differential. If the domestic currency depreciates (appreciates), domestic production and goods become cheaper (more expensive) to foreigners and they consequently replace foreign (domestic) goods with domestic (foreign) goods, which will lead to increase (decrease) in domestic prices and domestic inflation.

Inclusion of exchange rate into model could be desirable, especially because Czech National Bank is actively intervening on foreign exchange market since November 2013 in order to depreciate Czech currency, therefore exchange rate channel could be regarded as the most recent transmission mechanism of the Czech National Bank. All of these conclusions will be taken into consideration in author's next research.

If we get back to interpretation of presented analysis results, other relationships are inconclusive, because with use of two VARs with different lag length we got different outputs. VAR(1) suggests connection between price level and output, similarly as in Omay and Kan (2010), Drukker *et al.* (2005), Eggoh and Khan (2014), Macchiarelli (2013), Baglan and Yoldas (2014), Kremer *et al.* (2013). This relationship was not proved in case of VAR(2).

VAR(2) suggests connection between two pairs of variables – between money supply and interest rate and between money supply and price level. The former one confirms findings of Cendejas (2014) and Schabert (2009), the latter one confirms findings of Benati (2005), Lenza (2006), Thornton (2014) and Nguyen (2015). This relationship was not proved in case of VAR(1).

Finally, we did not find the evidence of existence of direct relationship between money supply and output – therefore, we got in contradiction with claims of Ravn, Psaradakis and Sola (2005), Favara and Giordani (2009), Caraiani (2015), Canova and Menz (2011) and Nelson (2002).

Even though VAR(2) has slightly better prediction power in case of variable money supply, low values of correlation coefficients, values of information criteria and the fact that stationary variables do not have long memory suggest that more suitable is use of VAR(1).

The proposed methodology helps to discover and describe hidden patterns, allowing for the study, characterization and description of the historic relationships between macroeconomic variables. These patterns can also be used in the forecasting of variables of concern. The output of the methodology can provide actionable information for market agents, such as monetary authorities, financial institutions, and individual investors, as well as for the academic community, to increase further the knowledge and understanding of financial markets, thus enriching and complementing existing financial theories.

Finally, both VARs give us two identical outputs and on basis of these outputs we are able to point out implications and recommendations for macroeconomic policy. Firstly, because change in price level leads to change in interest rate, Czech National Bank should affect the economy by means of change of the interest rate with use of change in price level as a medium. Second recommendation is to fiscal policy authorities – interest rate could be affected by change in real GDP (and government has two basic tools to do so – tax policy and government spending).

In the end of this section, author would like to briefly focus on classical monetary tools of Czech National Bank, in particular whether they can still be used in order to affect real economy of the Czech Republic or not. The main monetary tool of the Czech National Bank is two-week repo rate. This rate has been set on technical zero (0,05 %) in November 2012 and has not changed since. This measure has been adopted in order to boost consumption and investments, but it did not encourage commercial banks to provide more money in form of loans. Therefore, repo rate cannot be considered as operational monetary tool and credit channel is not suitable transmission mechanism of monetary policy in times of weakened state of Czech economy. This conclusion was already reached in previous part of this section.

Open market operations are another monetary tool. Czech National Bank can buy/sell securities from/to commercial banks in order to influence monetary base and monetary aggregates. However, effect of money supply on other variables also turned out to be limited in the model. Reason for this output is similar to the case of non-functionality of repo rate – national bank can buy securities from commercial banks, but these banks are unwilling to provide this money to households and companies. Desirable effects cannot be reached not even with usage of open market operations, which induces unsuitability of monetary transmission mechanism.

Third monetary tool are minimum reserves, but efficiency of this tool is poor in the Czech environment of a substantial liquidity surplus.

Foreign exchange interventions are the last monetary tool. They can be used to ease/tighten monetary policy, usually in situation of reduction in monetary policy interest rates to technical zero, where further easing can be achieved by weakening the koruna exchange rate. This is exactly what is going on since November 2013. One can say that Czech National Bank has approached exchange rate tool and exchange rate transmission mechanism, because it has no other possibilities left.

CONCLUSION

Relationships between four macroeconomic variables – interest rate, money supply, price level and real GDP – in the Czech Republic were investigated in the presented paper. After brief theoretical insight into this issue and review of existing literature, data and the methodology used in subsequent analysis were introduced. Several facts have been found in the empirical part of the paper. Implemented VAR(1) showed that Granger causality was found in three pairs of variables, in particular: past price level change Granger-causes interest rate change, past GDP change Granger-causes interest rate change and past GDP change also Granger-causes price level change. These findings are backed up by correlation coefficients between these variables. Reversed relationships do not hold, therefore existence of two-way Granger causality was not proven in any of the three cases. VAR(2) uncovered two more pairs of Granger causality – between money supply and price level and between money supply and interest rate. The latter one flows in both directions, which implies two-way Granger causality, even though the effects of money supply and interest rate are limited. Other relationships implying Granger causality were not discovered.

For the purpose of further research, inclusion of exchange rate variable in the model instead of interest rate seems desirable, because credit channel is not suitable transmission mechanism of monetary policy in times of weakened state of Czech economy.

Both VARs turned out to be unable to successfully predict magnitude of changes of variables under study, but it allowed us to predict direction of change in case of variables change in interest rate and change in real GDP with success rate nearly 82 %. Despite better prediction power of VAR(2) in case of money supply, low correlation coefficient comprising variable money supply raises doubts about the factual existence of causality between money supply and other variables.

However, both VARs agreed that interest rate could be changed by change of price level and that interest rate could be changed by change of real GDP. These conclusions represent potential recommendations to macroeconomic policy authorities.

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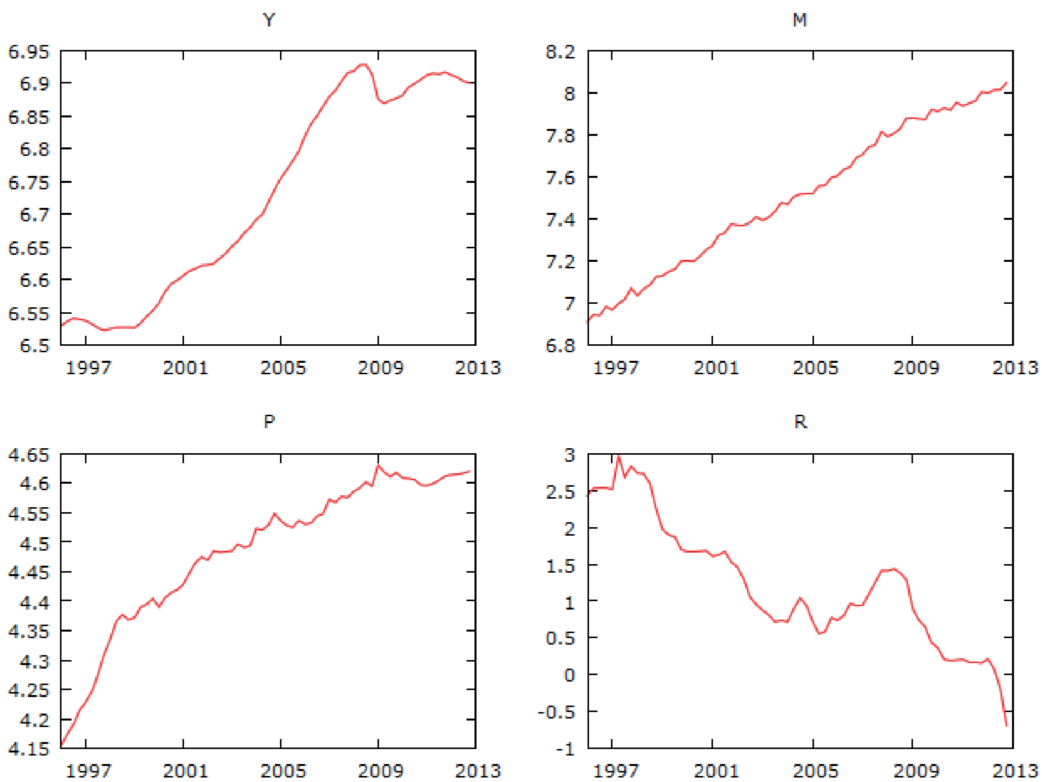
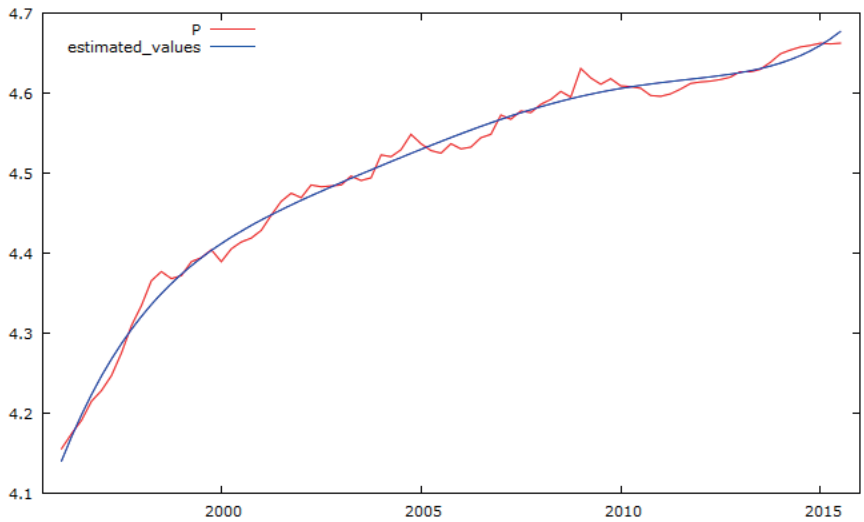
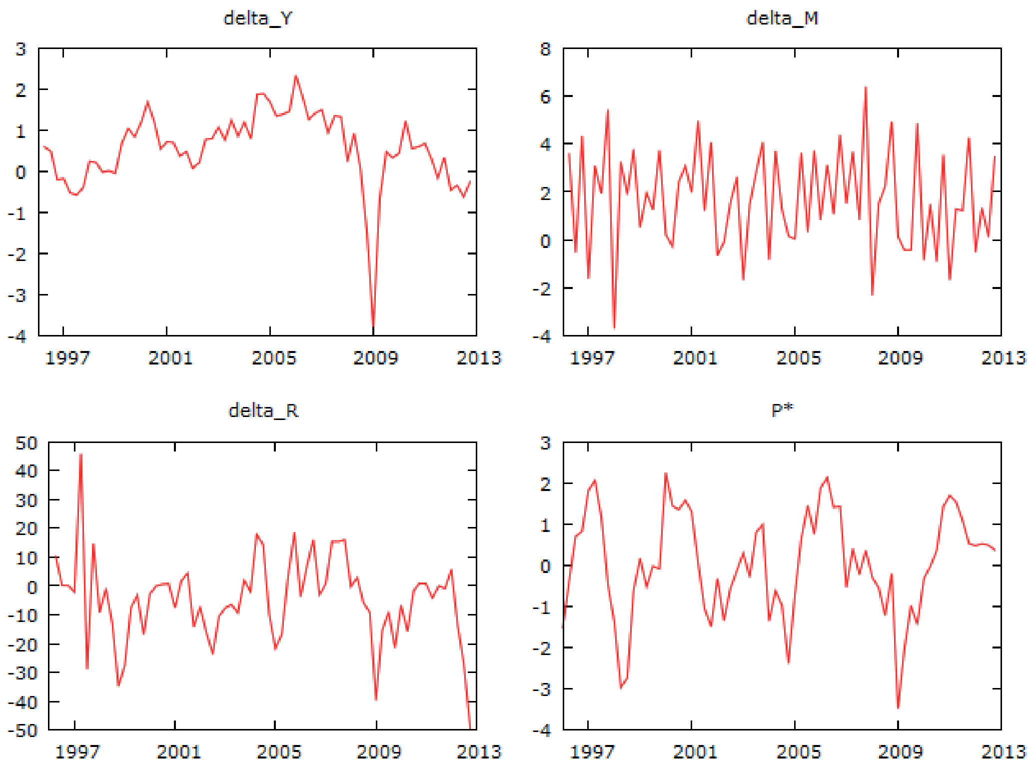


Appendix A: *Time series of natural logarithms of variables under study*
Source: Gretl output based on data acquired via ARAD and Bloomberg Database



Appendix B: *Deterministic trend behavior of variable P*
Source: Gretl output based on data acquired via Bloomberg Database



Appendix C: *Time series of differenced/de-trended variables under study*
Source: Gretl output based on data acquired via ARAD and Bloomberg Database

Contact information

Tomáš Urbanovský: urbanovsky@mail.muni.cz