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FACTOR-AUGMENTED VAR MODEL FOR IMPULSE RESPONSE ANALYSIS

Abstract. *Structural Vector Autoregressive Models are largely used in the economic literature in order to uncover the way the transmission of a shock in one macroeconomic variable is seen in the evolution of other macroeconomic variables. These models have the advantages that a small number of restrictions needs to be set in order to be able to estimate the transmission. Despite this, for small open economies the estimated results might be affected by the so called "puzzles" or the initial data set may omit important information which is a major disadvantage for studies on the effect of monetary policy innovations.*

The above mentioned issues are solved by Factor Augmented Vector Autoregression models, therefore the purpose of this paper is to estimate this type of model on a sample of 20 variables for the Romanian economy, by using quarterly data over the period: 2000:Q1 and 2014:Q2. The factors are estimated using Principal Component Analysis and Bayesian inference is used as methodology in order to compute the parameters of the model.

Keywords: *Factor Augmented VAR, Gibbs sampling, Principal Component Analysis, Romanian Economy.*

JEL Classification: E31, E52, C15, C58, C82

1. Introduction

The purpose of this paper is to examine the evolution of different macroeconomic variables to a shock in interest rate for Romanian economy. The empirical framework incorporates substantially more information than an usual three or four variable VAR model. More precisely a FAVAR model including variables such as: consumption, government expenditure, exports, imports, gross capital formation, gross domestic product, wages, production indexes by main activities, monetary aggregates, exchange rates is estimated.

The paper has the following structure: the first section, entitled *Literature review* makes a short presentation of the way factor augmented vector autoregressive models were introduces into the economic literature. The section that follows the above mentioned one is the *Econometric framework*. The aim of this section is to present the FAVAR methodology and a small illustrative example with three factors. It also describes the principal component analysis used to estimate the factors and mentions about the Bayesian inference used to estimate the parameters of the model. The following section, *Empirical evidence* presents a description of all the transformation applied on the data, the percentage variance or the informational content of each one of the factors and also the impulse response functions with the corresponding interpretations. The final section, *Conclusions*, comes with a short presentation of the important aspects described in this paper and also makes several proposals for further research.

2. Literature review

FAVAR models represent a way to improve the standard VAR analysis by incorporating the information included in a larger number of macroeconomic series. The appearance of FAVAR models can be argued by the fact that standard empirical models that were used to examine the behavior and response of different economies to shocks were too small and did not incorporate all the characteristics of a specific economy. For this reason, only a small subset of variables such as inflation, monetary policy interest rate, gross domestic product or unemployment rate were included in the model, leaving behind macroeconomic variables such as monetary aggregates or asset prices.

The FAVAR proposed by Bernanke et al. (2005) allows for observed variables to be entered in the VAR model besides the set of latent dynamic factors, the observed variable being represented by the federal fund rate. While Bernanke et al. (2005) estimate FAVAR using both a two-step semi-parametric principal component method and a one-step Bayesian likelihood method. Lasse Bork (2009), in his paper, estimates FAVAR using one step fully parametric iterative maximum likelihood method – Expectation Maximization (EM) algorithm. This algorithm allows for correlated dynamic factors which in the case of principal component analysis are not allowed, the factors being computed as orthogonal.

The principal component analysis is a two-step approach which is used to estimate the latent factors as a first step, and the parameters in the VAR model, as a second step. Impulse responses and decomposition of the variance of the prediction error could be also estimated afterwards. Therefore, it can be noticed the computational simplicity of this method. A drawback of FAVAR methodology is that the factors have no clear interpretation. Bernanke, Boivin and Eliasz (2004) applied this approach in their paper. On the other hand, the one-step Bayesian method, which is applied in Bernanke et al. (2005) as well as in Banbura et al. (2008) and the EM algorithm estimates all the parameters and the dynamic factors simultaneously, the last mentioned method allowing for classical inference. The fact that factors are allowed to be correlated is relevant if one desires to attach a macroeconomic interpretation to the factors according to the amount of information that these factors explain from each one of the observable series. The fully parametric one-step EM algorithm method has recently been applied to large panels by Jungbacker and Koopman (2008) or by Reis and Watson (2008) who estimate inflation using a VAR(4) in absolute price and relative price components.

The approach that is adopted in this paper is the two-step approach: the latent factors are estimated as a first step by using principal component analysis and the parameters in the VAR model are estimated as a second step by using Bayesian inference.

3. Econometric framework

3.1. The factor augmented VAR

The FAVAR model can be written in the following form, similar to the one described by Blake and Mumtaz(2012) in their technical workbook:

$$X_{i,t} = b_{ij} * F_{jt} + \gamma_i * IR_t + \vartheta_{i,t} \tag{1}$$
$$Z_t = c_t + \sum_{j=1}^{P} B_j * Z_{t-j} + e_t$$
$$Z_t = \{F_t,\ IR_t\}$$
$$VAR(\vartheta_{i,t}) = R \text{ and } VAR(e_t) = Q$$

where:

- $X_{i,t}$ is a $T \times M$ matrix containing the initial sample of time series;
- IR_t is the monetary policy interest rate or any proxy for monetary policy interest rate;
- F_{jt} are the unobserved factors extracted starting from the initial sample of macroeconomic variables;
- $X_{i,t}$ is related to the factors through the loading matrix under b_{ij};

- $X_{i,t}$ is related to the interest rate through the coefficients γ_i;
- $IR_t$is included in the state vector even though it is observed because it will be included in the transition equation.

The first equation is the observation or the state equation and the second one is the transition equation.
If the number of factors is considered to be equal to three and the number of lags in the VAR model is considered to be equal to two, F_t would be equal to $F_t = \{F_{1t}, F_{2t}, F_{3t}\}$ and this is how the observation equation would look like:

$$\begin{pmatrix} X_{1t} \\ X_{2t} \\ X_{3t} \\ \dots \\ X_{Mt} \\ IR_t \end{pmatrix} = \begin{pmatrix} b_{11} b_{12} b_{13} \gamma_1 & 0 & 0 & 0 & 0 \\ b_{21} b_{22} b_{23} \gamma_2 & 0 & 0 & 0 & 0 \\ b_{11} b_{12} b_{13} \gamma_3 & 0 & 0 & 0 & 0 \\ \dots \\ b_{M1} b_{M2} b_{M3} \gamma_M & 0 & 0 & 0 & 0 \\ 0 \quad 0 \quad 0 \quad 1 & 0 & 0 & 0 & 0 \end{pmatrix} * \begin{pmatrix} F_{1t} \\ F_{2t} \\ F_{3t} \\ IR_t \\ F_{1t-1} \\ F_{2t-1} \\ F_{3t-1} \\ IR_{t-1} \end{pmatrix} + \begin{pmatrix} \vartheta_{1t} \\ \vartheta_{2t} \\ \vartheta_{3t} \\ \dots \\ \vartheta_{Nt} \\ 0 \end{pmatrix} \quad (2)$$

Or the simple form:

$$\bar{X}_{it} = H * \beta_t + \vartheta_t \quad (3)$$

The variance-covariance matrix of the error of the state equation has the following representation:

$$VAR(\vartheta_t) = R = \begin{pmatrix} R_1 & 0 & 0 & \dots & 0 & 0 \\ 0 & R_2 & 0 & \dots & 0 & 0 \\ & & & \dots & & \\ 0 & 0 & 0 & \dots & R_M & 0 \\ 0 & 0 & 0 & \dots & 0 & 0 \end{pmatrix} \quad (4)$$

The transition equation of the model takes the following form:

$$\begin{pmatrix} F_{1t} \\ F_{2t} \\ F_{3t} \\ IR_t \\ F_{1t-1} \\ F_{2t-1} \\ F_{3t-1} \\ IR_{t-1} \end{pmatrix} = \begin{pmatrix} u_1 \\ u \\ u_3 \\ u_4 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} + \begin{pmatrix} A_{11} & A_{12} & A_{13} & A_{14} & A_{15} & A_{16} & A_{17} & A_{18} \\ A_{21} & A_{22} & A_{23} & A_{24} & A_{25} & A_{26} & A_{27} & A_{28} \\ A_{31} & A_{32} & A_{33} & A_{34} & A_{35} & A_{36} & A_{37} & A_{38} \\ A_{41} & A_{42} & A_{43} & A_{44} & A_{45} & A_{46} & A_{47} & A_{48} \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{pmatrix} * \begin{pmatrix} F_{1t-1} \\ F_{2t-1} \\ F_{3t-1} \\ IR_{t-1} \\ F_{1t-2} \\ F_{2t-2} \\ F_{3t-2} \\ IR_{t-2} \end{pmatrix} + \begin{pmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad (5)$$

Or the simple representation:

$$\beta_t = \mu + F * \beta_{t-1} + e_t \quad (6)$$

The variance-covariance matrix of the error of the transition equation has the following form:

$$VAR(e_t) = Q = \begin{pmatrix} Q_{11} & Q_{12} & Q_{13} & Q_{14} & 0 & 0 & 0 & 0 \\ Q_{21} & Q_{22} & Q_{23} & Q_{24} & 0 & 0 & 0 & 0 \\ Q_{31} & Q_{32} & Q_{33} & Q_{34} & 0 & 0 & 0 & 0 \\ Q_{41} & Q_{42} & Q_{43} & Q_{44} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \quad (7)$$

3.2. Principal component analysis and Bayesian inference

This technique is used in order to decompose the total variability of the initial causal space with the purpose of keeping as much information as possible within a reduced number of components. The obtained data series are the principal components, they are linear combinations of the original characteristics which are maximizing the variability, but their number is significantly smaller than the number of original characteristics. Therefore only those combinations with maximum variance are included in the analysis.

A more technical explanation supposes that the initial representation in the system of coordinates is not the optimal one and by reducing the dimensionality and assuring in the same time that important information is not left behind, a new representation in a new system of coordinates could be more efficient by maximizing the variance.

The solution to this affirmation is the eigenvalue-eigenvector pairs of the variance-covariance matrix of the original observations,Σ_x, denoted by:
$\{(\lambda_1, e_1), (\lambda_2, e_2), \dots, (\lambda_p, e_p)\}$, where $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_p \geq 0$ and the eigenvectors are of unity length.

The eigenvalues are considered to reflect the amount of information included in the corresponding factor, for this reason they are sorted in descending order. Therefore, the percentage amount of information kept within a factor is given by the amount computed as corresponding eigenvalue divided by the sum of total eigenvalues: $\frac{\lambda_k}{\sum_{j=1}^{p} \lambda_j}$, where p is the number of initial observed components.

3.3. Gibbs sampling algorithm

In order to estimate the posterior distributions of the parameters of interest, Bayesian methods are used instead of classical maximum likelihood estimator due to the fact that Bayesian methods deal efficiently with the existence of unobservable components and high dimensionality of the parameters space, but also with the non-linearity of the model;

Once the factors are estimated, they are considered as observed in the Gibbs sampling algorithm, therefore the observation equation becomes a list of M linear regressions in the form of: $X_{i,t} = b_{ij} * F_{jt} + \gamma_i * IR_t + \vartheta_{i,t}$ and b_{ij}, γ_i, R can be estimated. Also, given the factors, the transition equation becomes a VAR model and $H, R, u, F\ and\ Q$ can be estimated.

4. Empirical evidence

4.1. Data analysis and factors

The estimation is ran on a sample of 21 time series out of with the first 20 are used as observable components in the extraction of the factors and the last one is the three-rate money market interest rate used as proxy for the money market interest rate dues to the availability of data for the period of time the analysis was ran. The first 20 variables are macroeconomic variables such as: Final Consumption Expenditure, Final Consumption Expenditure of General Government, Exports of Goods and Services, Imports of Goods and Services, Gross Capital Formation, Gross Domestic Product, Compensation of Employees, Mining and Quarrying, Manufacturing, Electricity, Gas, Steam and Air Conditioning Supply, Monetary Aggregate M1, Monetary Aggregate M2, EUR/RON and USD/RON exchange rate.

These are Romanian macroeconomic variables with quarterly observation starting from 2000Q1 and ending in 2014Q2. All the time series were downloaded from Eurostat as a source of data and expressed in national currency at current prices. Several transformations were applied: data used in logarithm except rates such as unemployment rate and money market interest rate in order to have consistency regarding the measuring scale. They were also transformed into real amounts instead of nominal amounts by dividing the amounts expressed at current prices with the harmonized index of consumer prices.

The time series included in this analysis were also checked for seasonality and adjusted if needed using Demetra+ as a financial software and TRAMO/SEATS method with RSA4 specification, which means that series as kept in level or in logarithm and the adjustment is done for working days, Easter and outliers by using an automatic model identification (Demetra+ automatically identifies and estimates the best Arima model). The peaks that can be noticed in *Figure 1* and *Figure 2* for consumption and GDP real time series show the necessity of seasonal adjustment. It can be also seen a difference between values when grouped by quarters.

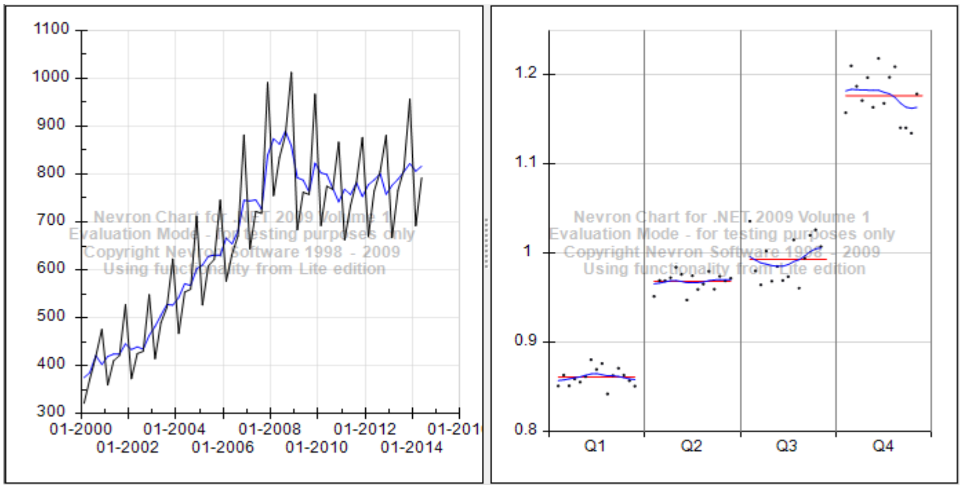


Figure 1. Consumption evolution (real values) and group by Quarter

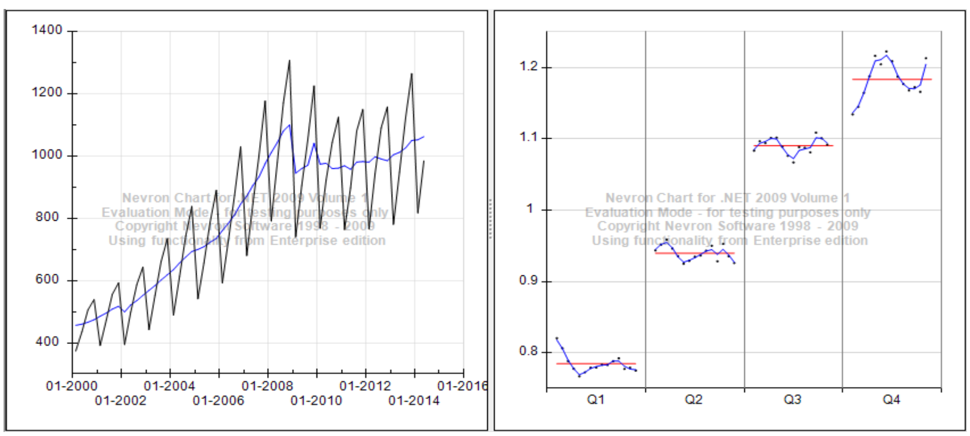


Figure 2. GDP evolution (real values) and group by Quarter

Unit root testes were also applied in order to ensure that the series are stationary. These teste are: Augmented Dickey Fuller (ADF) test and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test. Both tests have the same purpose: ADF test assesses the null hypothesis of a unit root in univariate time series. KPSS test assesses the null hypothesis that a univariate time series is trend stationary against the alternative that it is a nonstationary unit-root process. The probability computed by the test is compared with the significance level of five percent and if it is larger than the significance level, the null hypothesis is accepted. If according to the computed statistic, the series are not stationary, which means they are integrated of a certain order, they need to be differentiated.

The accepted hypothesis of the ADF and KPSS tests for some of the time series after applying the above mentioned transformations could be found in *Table I*.

Table I: ADF and KPSS Unit Root Test for Several Indexes

Title	Data	H0/H1 hypothesis for ADF Test	H0/H1 hypothesis for KPSS Test
Final Consumption Expenditure	Million Units National Currency	[1, 1, 1, 1]	[0, 0, 0, 0]
Final Consumption Expenditure of General Government	Million Units National Currency	[1, 1, 1, 1]	[0, 0, 0, 0]
Exports of Goods and Services	Million Units National Currency	[1, 1, 1, 1]	[0, 0, 0, 0]
Imports of Goods and Services	Million Units National Currency	[1, 1, 1, 1]	[0, 0, 0, 0]
Gross Capital Formation	Million Units National Currency	[1, 1, 1, 1]	[0, 0, 0, 0]
Gross Domestic Product	Million Units National Currency	[1, 1, 1, 1]	[0, 0, 0, 0]
Compensation of Employees	Million Units National Currency	[1, 1, 1, 1]	[0, 0, 0, 0]
Mining and Quarrying	Volume index of production	[1, 1, 1, 1]	[0, 0, 0, 0]
Manufacturing	Volume index of production	[1, 1, 1, 1]	[0, 0, 0, 0]

Electricity, Gas, Steam and Air Conditioning Supply	Volume index of production	[1, 1, 1, 1]	[0, 0, 0, 0]
M1	Million Units National Currency	[1, 1, 1, 1]	[0, 0, 0, 0]
Exchange Rate EUR/RON	Units National Currency	[1, 1, 1, 1]	[0, 0, 0, 0]

Note: *Number of lags used to generate ADF/KPSS statistics varies from one to four. Source of data: Eurostat, own calculations with Matlab*

An index is being used in order to indicate which one of the variables is a "fast moving" and which one is a "slow moving" one. A variable is considered to be a "fast moving" one if the impact of a change in monetary policy interest rate has a contemporaneous impact on its evolution. In this situation, as a dependent variable, it is expressed as a function of the factors and the monetary policy interest rate. Otherwise, it is depended only by the unobserved factors. The series that are considered to be "fast moving" are the EUR/RON and the USD/RON exchange rates.

Similar to Blake and Mumtaz (2012), a number of three factors is extracted. Korobilis (2009) also mentioned in his paper that three and four factors perform really well in many empirical applications. Moreover, the amount of information contained by each one of the 20 factors is represented below, in *Table II*. Therefore it can be seen that the first three factors are keeping 51.7199% of the total amount of information expressed by all the observed components.

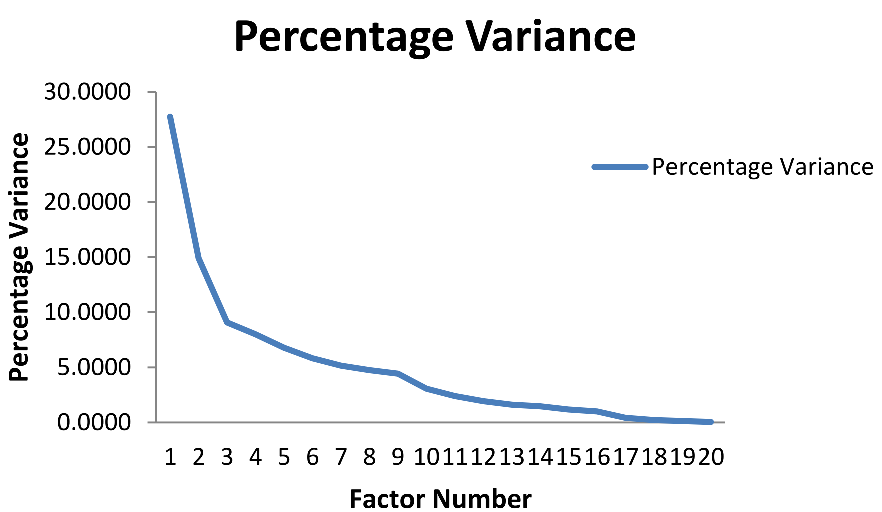
Table II: Percentage and Cumulative Percentage Variance for the first 20 factors
Source of data: Eurostat, own calculations with Matlab

Factor Number	**Percentage Variance**	**Cumulative Percentage Variance**
1	27.7396	27.7396
2	14.9093	42.6489
3	9.0710	51.7199
4	8.0092	59.7291
5	6.7844	66.5136
6	5.8073	72.3208

7	5.1496	77.4704
8	4.7419	82.2123
9	4.4290	86.6413
10	3.0538	89.6951
11	2.4013	92.0964
12	1.9144	94.0108
13	1.5959	95.6067
14	1.4563	97.0631
15	1.1831	98.2461
16	0.9903	99.2364
17	0.4176	99.6540
18	0.2055	99.8595
19	0.1161	99.9756
20	0.0244	100.0000

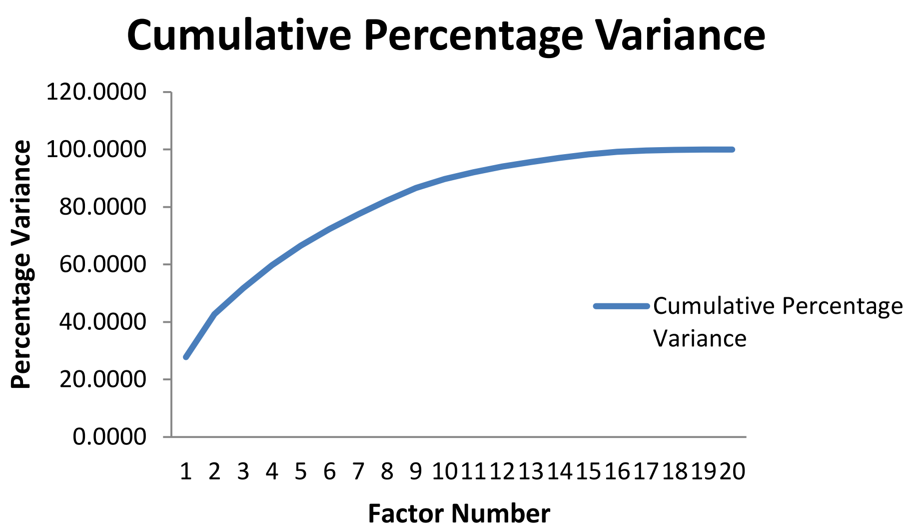
For a better visual representation, *Figure 3* and *Figure 4* show the percentage variance and the cumulative percentage variance for each one of the factors in descending order.

Figure 3. Percentage Variance of the factors, sorted in descending order



Source of data: Eurostat, own calculations with Matlab

Figure 4. Cumulative Percentage Variance of the factors, sorted in descending order



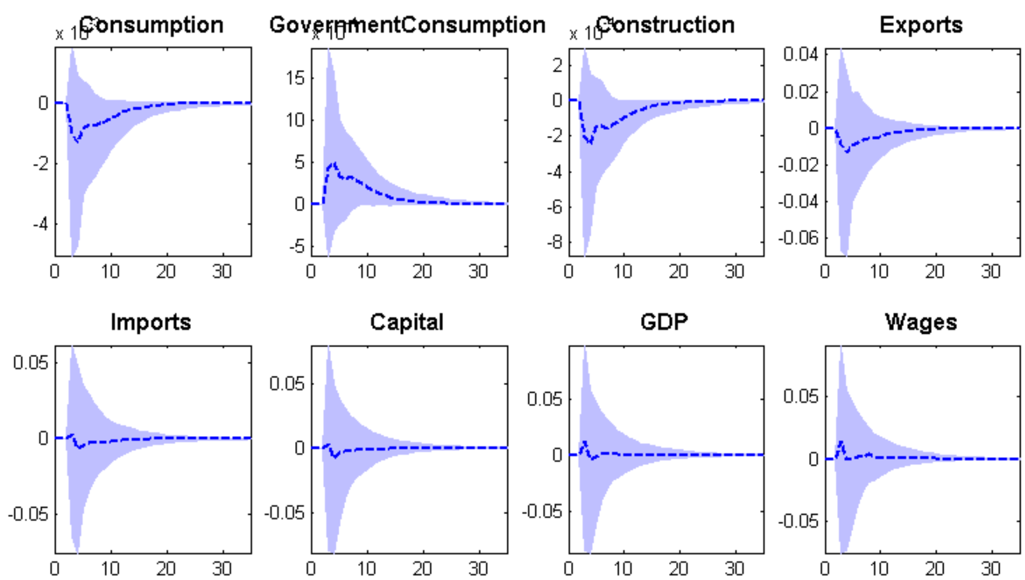
Source of data: Eurostat, own calculations with Matlab

4.2. Impulse response functions

In *Figure 5*, the evolution of final consumption expenditure, final consumption expenditure of general government, exports of goods and services, imports of goods and services, gross capital formation, gross domestic product and compensation of employees after an increase in the interest rate is plotted. It can be seen that the impact is contemporary, it is seen with lags and not immediately, this evolution matching the assumption regarding these variables as being "slow moving" ones. Also, the responses are adjusting back to the initial value, the impact dissipates in time, which means that interest rate cannot be used in order to stimulate the economy on the long run. Therefore, consumption decreases in favor of savings at a higher interest rate, the level of exports decreases also following the appreciation of the national currency due to an increased demand for it once the level of the interest rate is increased. The level of government consumption becomes also higher, which shows the fact that when the monetary policy is a restrictive one, the fiscal policy is an expansionary one. This doesn't necessary means that when the monetary policy was an expansionary one the fiscal policy was a restrictive one because, fiscal policy was instead a pro-cyclical one.

From the same figure it can be noticed that the real level of gross capital formation, gross domestic product and compensation of employees, of imports were not impacted by a change in interest rate, the responses of these variables evolving around zero.

Figure 5. Impulse response functions after a shock in interest rate, over a period of 36 quarters (a)

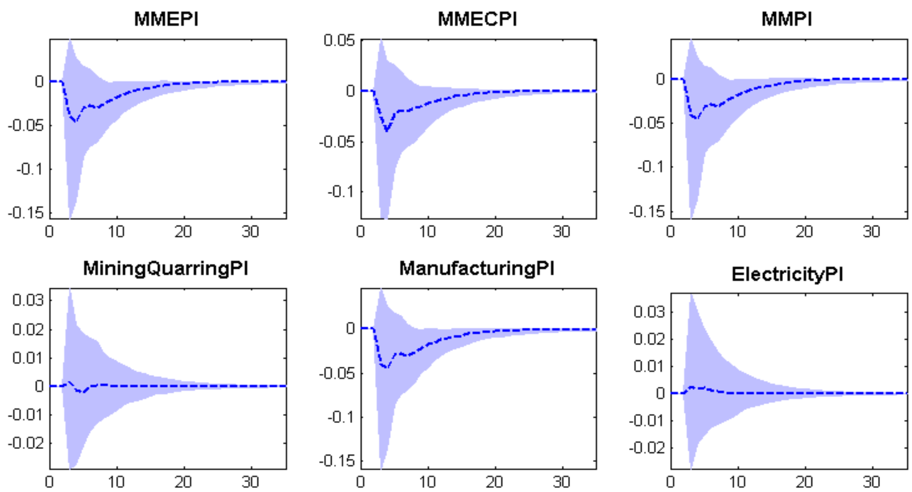


Source of data: Eurostat, own calculations with Matlab

In *Figure 6*, the evolution of the evolution of production indexes in (i) Mining and quarrying; manufacturing; electricity, gas, steam and air conditioning supply (ii) Mining and quarrying; manufacturing; electricity, gas, steam and air conditioning supply; construction (iii) Mining and quarrying; manufacturing (iv) Mining and quarrying (v) Manufacturing and (vi) Electricity, gas, steam and air conditioning supply after an increase in the interest rate is plotted. It can be seen that most of these production indexes are decreasing which is an expected behavior since the costs for the companies to continue with their activity are higher, therefore investments become less attractive. For the rest of them, mainly Mining and quarrying and Electricity, there is no impact once the interest rate is increased.

In *Figure 7*, the evolution of the evolution of the harmonized index of consumer prices, unemployment rate, monetary aggregate M1, monetary aggregate M2, EUR/RON and USD/RON exchange rates after an increase in the interest rate is plotted.

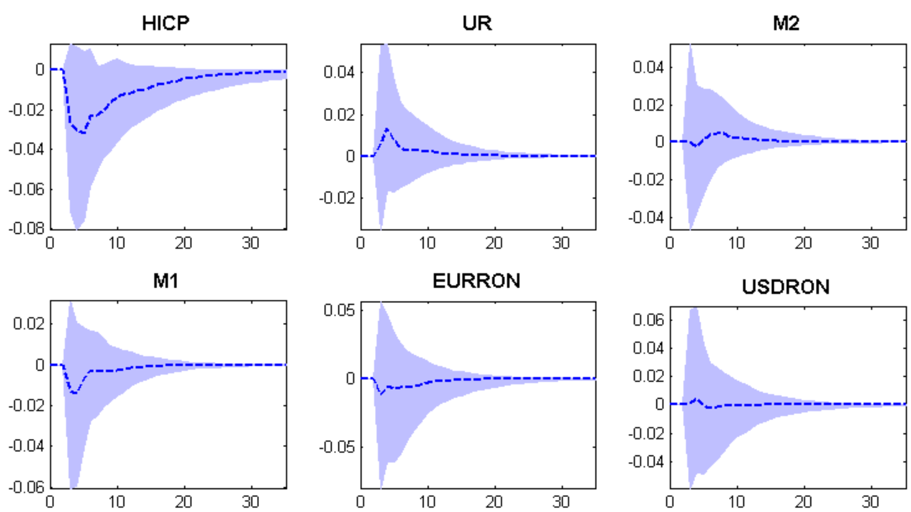
Figure 6. Impulse response functions after a shock in interest rate, over a period of 36 months (b)



Source of data: Eurostat, own calculations with Matlab

It can be seen that the level of the harmonized index of consumer prices, which is used as a proxy for inflation rate is decreasing after an increase in the level of interest rate but not on the long run. This behavior shows the fact that this monetary policy instrument cannot be used in order to stimulate the economy for long time periods of time. Unemployment rate, on the other hand, increases after a shock in interest rate and it also stabilizes afterwards. This evolution is explained by the fact that investors have to face higher costs in order to continue with their activity. Monetary aggregate M1 is decreasing and this evolution is expected if one considers the fact that the purpose when raising the interest rate is to withdraw liquidity from the market. The impact on M2 monetary aggregate on the other hand is not very significant which means that it is more difficult for a central bank to control M2 rather than M1. Once the interest rate is increased, an appreciation of the EUR/RON exchange rate can be noticed due to that fact that the demand for the national currency increases which makes it to become more competitive. The impact on USD/RON though is not significant.

Figure 7. Impulse response functions after a shock in interest rate, over a period of 36 months (c)



Source of data: Eurostat, own calculations with Matlab

5. Conclusions

The purpose of this paper is to examine the evolution of different macroeconomic variables to a shock in interest rate for Romanian economy. The empirical framework incorporates substantially more information than the usual three or four variable VAR model. More precisely a FAVAR model including variables such as: consumption, government expenditure, exports, imports, gross capital formation, gross domestic product, wages, production indexes by main activities, monetary aggregates, exchange rates is estimated.

The estimation is ran on a sample of 21 time series out of with the first 20 are used as observable components in the extraction of the factors and the last one is the three-rate money market interest rate used as proxy for the money market interest rate due to the availability of data for the period of time the analysis was ran.

Principal component analysis is then used and the factors are extracted. The amount of information contained by each one of the 20 factors is represented afterwards and it can be seen that the first three factors are keeping 51.7199% of the total amount of information expressed by all the observed components.

The impulse response functions after a shock in interest rate show that the responses are adjusting back to the initial value, the impact dissipates in time, which means that interest rate cannot be used in order to stimulate the economy on the long run. Therefore, consumption decreases in favor of savings at a higher interest rate, the level of exports decreases also following the appreciation of the national currency due to an increased demand for it once the level of the interest rate is increased. Government consumption on the other hand is not impacted by monetary policy. Also, most of the production indexes are decreasing which is an expected behavior since the costs for the companies to continue with their activity are higher, therefore investments become less attractive.

It can be also noticed that the level of the harmonized index of consumer prices, which is used as a proxy for inflation rate is decreasing after an increase in the level of interest rate but not on the long run. This behavior shows the fact that this monetary policy instrument cannot be used in order to stimulate the economy for long time periods of time. Unemployment rate, on the other hand, increases after a shock in interest rate and it also stabilizes afterwards. This evolution is explained by the fact that investors have to face higher costs in order to continue with their activity. Monetary aggregate M1 is decreasing and this evolution is expected if one considers the fact that the purpose when raising the interest rate is to withdraw liquidity from the market. The impact on M2 monetary aggregate on the other hand is not very significant which means that it is more difficult for a central bank to control M2 rather than M1. Once the interest rate is increased, an appreciation of the EUR/RON exchange rate can be noticed due to that fact that the demand for the national currency increases which makes it to become more competitive.

As a proposal for further research, a comparative analysis between impulse response functions could be estimated when using different number of factors. The purpose of the analysis would be to observe the impact on the evolution of these responses when including more or less factors. More precisely the purpose of such estimations would be to see if the evolution of a certain variable after a change in interest rate is better outlined when including more informational content.

Also the coefficients that were estimated could be considered as not being constant, but as changing over time. This would allow for making comparisons on how the transmission changed over time

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