EXCHANGE RATE PASS-THROUGH INTO ROMANIAN PRICE INDICES. A VAR APPROACH[1]

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Abstract

This paper investigates the exchange rate pass-through (ERPT) into import prices, producer prices and several different measures of consumer price indices for the Romanian economy. In order to determine the size and describe the dynamics in ERPT the paper employs an array of econometric methods belonging to the VAR family. The methods employed are RVARs (on different price indices and/or on a rolling window) and Sign-restriction VARs (also using different consumer inflation measures). The results point to an almost complete pass-through into import prices and incomplete pass-through into producer and consumer prices. In all cases except import prices the ERPT displays a decline in magnitude over the analysed time interval.

Keywords: exchange rate, pass-through, import prices, producer prices, consumer prices, vector autoregression, sign-restriction.

JEL Classification: C32, E31, E52, F31, O52.

1. Introduction

In the context of the current financial crisis, the convergence of the Romanian economy towards that of the euro zone and the euro adoption process should foster renewed effort of understanding the causes of inflation - as this is currently the most important obstacle to the fulfilment of the Maastricht criteria. In an inflation targeting country like Romania, understanding the inflation causes is critical, as a sine qua non condition for sound economic decisions is the existence of a well performing forecasting model. The misunderstanding or erroneous measurement of the

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[1] The authors are very grateful to the excellent comments they received from Moisă Altăr, Ciprian Necula and Răzvan Stanca. All remaining errors are entirely the authors' responsibility. The views expressed in this paper are those of the individual authors and do not necessarily reflect the position of the National Bank of Romania, RBS or the Academy of Economic Studies.
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inflation's causes could jeopardize the economic prospects and endanger the desired objectives. The exchange rate is bound to be an important determinant of the inflation rate in a small open economy like Romania. Thus, investigating the exchange rate pass-through (ERPT) is a necessary, even if not sufficient, condition for sound economic policies. The paper aims at investigating the subject using various econometric techniques. Its findings could be employed in enhancing the understanding of the inflation's determinants, in calibrating macroeconomic models – especially for modeling variable pass-through, in designing various policies aiming to make some sectors of the economy more flexible and competitive and also in designing sound, flexible and robust policies. Examples of macro models of the Romania economy which incorporate the pass-through from the exchange rate to various price indices are Dobrescu (2006), the macro model employed by the National Bank of Romania in the inflation targeting framework (Popa (2005)) or used by IMF (Christou, Klemm şi Tiffin (2007)).

ERPT is frequently defined as the responsiveness of domestic prices - including consumer prices, producer prices, import prices and sometimes the prices set by domestic exporters - to exchange rate movements. The key concepts in this literature are those of local currency pricing and producer currency pricing (LCP and PCP, respectively), representing the situation in which exporters set their prices in the currency of the importing country or in their own currency, respectively. This topic has been the focus of interest in the international economics literature for a long time, important contributions to the early literature being that of Dornbusch (1987), Krugman (1987) and Froot and Klemperer (1988). Empirical literature on pass-through has principally adopted three approaches, namely standard single-equation regression techniques, stationary VAR and cointegration. The literature examining the effects of exchange rates on prices concentrates on import prices at an aggregate, sectoral or industry level (Campa and Goldberg (2005), Campa, Goldberg and González-Mínguez (2005)), on consumer prices (Taylor (2000), Burstein, Neves and Rebelo (2001), Gagnon and Ihrig (2004), Burstein, Eichenbaum and Rebelo (2005), Campa and Goldberg (2006b)), on both import and consumer prices (Ihrig, Marazzi, and Rothenberg (2006), Campa and Goldberg (2006a)) or on export prices (Vigfusson, Sheets and Gagnon (2007), Bussière and Peltonen (2008)).

2. Recursive Vector Autoregression (RVAR)

Economic framework

The structural vector autoregression (VAR) methodology was developed for advanced countries by McCarthy (2000). The analysis is carried out within a Vector Autoregression (VAR) model, which is well suited to capture both the size as well as the speed of the pass-through. In the baseline model identification is achieved by resorting to the Cholesky decomposition. Impulse response functions are constructed in order to provide information on the size and the speed of the pass-through, while variance decompositions are computed to point out the relative importance of external shocks in explaining fluctuations in the price indices. This methodology permits the tracking of the pass-through from exchange fluctuations to each stage of the distribution chain in a simple integrated framework. Thus, it is examined the pass-through of exchange rate and import price fluctuations to domestic producer and consumer inflation.

McCarthy (2000) proposed equations for inflation rates of country *i* in period *t* at each of the three stages – import (IVU), producer (PPI), and consumer (CPI), considering the following assumptions:

- Supply shocks are identified from the dynamics of oil price inflation denominated in the local currency.
- Demand shocks are identified from the dynamics of the output gap in the country after taking into account the contemporaneous effect of the supply shock.
- External shocks are identified from the dynamics of exchange rate appreciation after taking into account the contemporaneous effects of the supply and demand shocks.

$$\pi_{it}^{oil} = E_{t-1}\left(\pi_{it}^{oil}\right) + \varepsilon_{it}^{s} \quad (1)$$

$$\tilde{y}_{it} = E_{t-1}\left(\tilde{y}_{it}\right) + a_{1t}\,\varepsilon_{it}^{s} + \varepsilon_{it}^{d} \quad (2)$$

$$\Delta e_{it} = E_{t-1}\left(\Delta e_{it}\right) + b_{1t}\,\varepsilon_{it}^{s} + b_{2t}\,\varepsilon_{it}^{d} + \varepsilon_{it}^{e} \quad (3)$$

$$\pi_{it}^{m} = E_{t-1}\left(\pi_{it}^{m}\right) + \alpha_{1t}\,\varepsilon_{it}^{s} + \alpha_{2t}\,\varepsilon_{it}^{d} + \alpha_{3t}\,\varepsilon_{it}^{e} + \varepsilon_{it}^{m} \quad (4)$$

$$\pi_{it}^{w} = E_{t-1}\left(\pi_{it}^{w}\right) + \beta_{1t}\,\varepsilon_{it}^{s} + \beta_{2t}\,\varepsilon_{it}^{d} + \beta_{3t}\,\varepsilon_{it}^{e} + \beta_{4t}\,\varepsilon_{it}^{m} + \varepsilon_{it}^{w} \quad (5)$$

$$\pi_{it}^{c} = E_{t-1}\left(\pi_{it}^{c}\right) + \gamma_{1t}\,\varepsilon_{it}^{s} + \gamma_{2t}\,\varepsilon_{it}^{d} + \gamma_{3t}\,\varepsilon_{it}^{e} + \gamma_{4t}\,\varepsilon_{it}^{m} + \gamma_{5t}\,\varepsilon_{it}^{w} + \varepsilon_{it}^{c} \quad (6)$$

where

$\pi_{it}^{m}, \pi_{it}^{w}, \pi_{it}^{c}$	-	import prices (IVU), producer price index (PPI) and consumer price index (CPI) respectively
$\varepsilon_{it}^{s}, \varepsilon_{it}^{d}, \varepsilon_{it}^{e}$	-	supply, demand, and exchange rate shocks respectively
$\varepsilon_{it}^{m}, \varepsilon_{it}^{w}, \varepsilon_{it}^{c}$	-	IVU, PPI and CPI shocks respectively
$E_{t-1}(.)$	-	the expectation of a variable based on the information set at the end of period *t-1*

The shocks are assumed to be serially uncorrelated as well as uncorrelated with one another within a period. The conditional expectations in equations (1)–(6) can be replaced by linear projections of the lags of the six variables in the system. Under these assumptions, the model was estimated as a VAR using a Cholesky decomposition. The impulse responses of IVU, PPI and CPI inflation to the orthogonalized shocks of exchange rate change then provide estimates of the effect of this variable on domestic inflation indicators.

McCarthy (2000) estimated the model for nine industrialised economies using quarterly data (1976Q1:1998Q4). Six variables are used: local currency oil price index, output gap, nominal effective exchange rate, import price index (or an index of import unit values), producer price index and consumer price index. The impulse response functions and variance decompositions suggest that exchange rate and import price shocks have "modest effects" on CPI for most of the countries analysed, especially for larger economies. Thus, McCarthy draw the conclusion that ERPT is very small, being largest on the import prices, followed by the effect on PPI and trailing is the effect on CPI. On the other hand, ERPT is larger in countries with a larger import share and more persistent exchange rate shocks. Following the framework introduced by McCarthy (2000), other authors analyze the ERPT: Hahn (2003) for the euro area (1970Q2 to 2002Q2), Gueorguiev (2003) for Romania (1997M07 to 2003M01), Faruqee (2004) for euro area (1990M01 to 2002M12) and Ca'Zorzi, Hahn and Sánchez (2007) for twelve emerging markets in Asia, Latin America, and Central and Eastern Europe (1975Q1 to 2004Q1).

Econometric methodology

The VAR models were introduced by Christopher Sims (1972, 1980, 1986) and have passed through a continuous development, from explaining and correcting some of the discrepancies with economic theory (e.g. price puzzles) to the improvement of initial technique by applying new methods of identification of structural shocks.

A vector autoregression was defined a generalization of the AR(p) model to the multivariate case. We have considered a vector of variables y_t. The analysis of any VAR model starts off by estimating a *reduced form* VAR model of order *p*, where A is an $(n \times n)$ matrix of autoregressive coefficients for $j = 1,2,\dots,p$, α denotes an $(n \times 1)$ vector of intercept terms allowing for the possibility of nonzero mean $E(y_t)$ and e_t is an $(n \times 1)$ dimension vector of white noise. Σ is an $(n \times n)$ symmetric positive definite matrix.

$$\begin{aligned} y_t &= \alpha + A_1 y_{t-1} + A_2 y_{t-2} + \dots + A_p y_{t-p} + e_t \\ E(e_t) &= 0 \\ E[e_t e_t^{'}] &= \Sigma \end{aligned} \tag{7}$$

Considering:

$$Y_t = \left[y_t^{'}, y_{t-1}^{'}, \dots, y_{t-p+1}^{'} \right] \tag{8}$$

we can write the VAR as an AR(1) process:

$$Y_t = \begin{bmatrix} \alpha \\ 0 \\ \vdots \\ 0 \end{bmatrix} + \begin{bmatrix} A_1 & A_2 & \cdots & A_{p-1} & A_p \\ I & 0 & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & I & 0 \end{bmatrix} Y_{t-1} + \begin{bmatrix} e_t \\ 0 \\ \vdots \\ 0 \end{bmatrix} \tag{9}$$

or as:

$$Y_t = \Gamma_0 + \Gamma_1 Y_{t-1} + e_t \quad (10)$$

It is considered that the structural relations between variables can be written under the following form:

$$BY_t = \Phi_o + \Phi_1 Y_{t-1} + \varepsilon_t \quad (11)$$

Premultiplication by B^{-1} allows us to obtain the VAR model in a *standard* form, similar to that in eq. (10):

$$Y_t = B^{-1}\Phi_0 + B^{-1}\Phi_1 Y_{t-1} + B^{-1}\varepsilon_t \quad (12)$$

Identifying the terms from eq. (10) it results:

$$\begin{aligned} &\Gamma_0 = B^{-1}\Phi_0 \\ &\Gamma_1 = B^{-1}\Phi_1 Y_{t-1} \\ &e_t = B^{-1}\varepsilon_t \\ &E\left(e_t e_t^{'}\right) = E(B^{-1}\varepsilon_t \varepsilon_t'(B^{-1})') = B^{-1}E(\varepsilon_t \varepsilon_t')(B^{-1})' = B^{-1}\Omega(B^{-1})' = \Sigma \end{aligned} \quad (13)$$

The problem is to take the observed values of e_t and to restrict the system so as to recover ε_t as $\varepsilon_t = Be_t$. Since Σ is symmetric, it contains only $n(n-1)/2$ distinct elements. Given that the diagonal elements of B are all unity, B contains n^2 -n unknown values. In addition, there are the n unknown values for $\mathrm{var}(\varepsilon_{it})$ for a total of n^2 unknown values in the structural model. Thus, in order to identify the n^2 unknowns from the known $n(n-1)/2$ independent elements of Σ, that is to identify the structural model from an estimated VAR, it is necessary to impose $n(n-1)/2$ restrictions on the structural model. Assuming that all structural shocks are mutually independent and normalized to be of variance 1, we can write that $\Omega = I_n$. In this context:

$$\Sigma = B^{-1}(B^{-1})' = CC' \quad (14)$$

A method of identification of the structural shocks of this model in the can be accomplished by applying a Cholesky decomposition. The Cholesky decomposition includes the decomposition of the variance covariance matrix Σ of the reduced form residuals in a lower triangular matrix C and an upper triangular matrix $\tilde{C}$. Thus the $n(n-1)/2$ economic restrictions, necessary to identify the structural model, are imposed as zero restrictions on the matrix C, that links the reduced form and the structural residuals. Economically, these restrictions imply that some of the structural shocks do not have a simultaneous impact on some of the variables. In this case, we can identify the magnitude of the effect of an structural shock in the *j*th variable on future values of each of the variables in the system. According to eq. (13), the VAR innovation e_t is a linear combination of the structural disturbances ε_t.

Empirical analysis

Data description

We estimated for Romania a seven-variable VAR model similar to that of McCarthy (2000). The analysis is based on monthly data covering the period between 2000M01 and 2008M12.

The variables used are:

- WPI - US dollar based all Commodities Index - The source of data is IMF's International Financial Statistics (henceforth IFS). This is converted into a local currency index. The variable was seasonally adjusted using EViews 6.0 Census X12. Then it was normalized (considering 2000=100) and transformed into logarithm. (*l_wpi_u_sa_idx*);
- Output gap: The series was determined by applying Hodrick-Prescott Filter to monthly real GDP series. The monthly data were calculated by interpolating the quarterly seasonally adjusted[4] real GDP data (expressed in national currency) in logarithm through Chow-Lin method[5] using as indicator variable the industrial production. The Hodrick-Prescott Filter was applied on the series with additional twelve observations forecasted from a simple ARIMA model in order to avoid the end point problem. (*l_y_sa_yindcl_hpgap*);
- Nominal effective exchange rate: The RON nominal effective exchange rate was determined as a basket of two exchange rates, one against the EUR (70%) and the other against the USD (30%). The weights are that of EUR and USD-denominated transactions of Romania's international trading. The series was normalized (considering 2000=100) and transformed into logarithm. (*l_s_ef_sa_idx*);
- Import prices: The series used were unit value index (expressed in national currency), the source of the data being Eurostat. The series was normalized (considering 2000=100) and transformed into logarithm. (*l_ivu_imp_t_sa_idx*);
- Producer Price Index: The industry PPI index was used. The series was normalized (considering 2000=100) and transformed into logarithm. (l_ppi_n_sa_idx);
- Consumer Price Index: The CPI index published by Romanian National Institute of Statistics was used. The series was normalized (considering 2000=100) and transformed into logarithm (*l_cpi_u_sa_idx*). Besides the CPI index, several other measures of inflation were employed: CORE1 price index (total CPI excluding administered prices[6]), CORE2 price index (total CPI excluding vegetables, fruit, eggs, fuels and administered prices) and Adjusted

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[4] The seasonally adjustment was made using Tramo/Seats method in Demetra 5.1

[5] The program employed for interpolation is using Matlab R2008a, the source being Spain National Institute of Statistics (Quilis (2004)).

[6] The administered prices are: medicines, electric energy, gas, heat energy, rent established by local government, water, sewerage, sanitation, urban transport, railway, transport by inland waterway, post services, fix telephone services, radio-TV subscription, services for the issuance of identity cards, driving licences and passports.

CORE2 (or CORE3) price index (total CPI excluding vegetables, fruit, eggs, fuels, administered prices, alcoholic beverages and tobacco);

- Short-term Interest Rate: computed as an arithmetic average of overnight tenor ROBID and ROBOR interest rates, the series was labelled ibon.

The variables were ordered in the model as listed above. Employing a recursive identification scheme effectively means that the identified shocks contemporaneously affect their corresponding variables and those variables that are ordered at a later stage, but have no impact on those that are ordered before. Therefore, it is reasonable to order the most exogenous variable, in our case the commodity prices, first, as their associated shock influences all other variables in the system contemporaneously, but they are not themselves influenced contemporaneously by any of the other shocks. The next variables in the model are the output gap and the nominal effective exchange rate. Thus, a contemporaneous impact of the demand shocks on the exchange rate is assumed while also imposing a certain time lag on the impact of exchange rate shocks on output. Next price variables follow, being contemporaneously influenced by all of the above mentioned shocks. Following the pricing chain, import prices precede producer and consumer prices. The last variable is interest rate, permitting for the money market, and in particular monetary policy, to react simultaneously to all variables in the model.

In order to assess the time series properties of the data unit root tests were completed. The results of the Augmented Dickey Fuller (ADF) and the Phillips Perron (PP) tests are summarized in Table 5 (Appendix 1). The tests indicate that commodities prices (*l_wpi_u_sa_idx*), nominal effective exchange rate (*l_s_ef_sa_idx*), import prices (*l_ivu_imp_t_sa_idx*), producer (*l_ppi_n_d_idx*) and consumer prices (*l_cpi_u_sa_idx, l_core1_u_idx*, *l_core2_u_sa_idx* and *l_core3_u_sa_idx*) are integrated of order one, I(1), while (by construction) the output gap (*l_y_sa_yindcl_hpgap*) is a stationary series. On the other hand, tests suggest that the short-term interest rate (*ibon*) is stationary, I(0).

Given these data properties, a VAR in the first differences of the non-stationary variables was estimated. To determine the lag order of the VAR model several order selection criteria were examined. While the Akaike Information Criterion (AIC), the Hannan-Quinn (HQ) and the Schwarz Criterion (SC) indicated one lag, the likelihood ratio (LR) test suggested two lags. We decided to rely on the LR test results and estimate the VAR with a constant and two lags.

Estimation results

In this section the impulse responses (IRFs) of the different price indices to exchange rate shocks are reported and analyzed along the distribution chain. Figures 1 and 2 display the impulse responses (non-accumulated and accumulated) of the IVU, the PPI, and the CPI to an exchange rate shock over a time horizon of sixty months. In this model, the exchange rate shock is estimated given past values of all the variables plus the current values of commodities prices and the output gap.

Figure 1 - IRFs of exchange rate, IVU, PPI and CPI to 1% rise in exchange rate

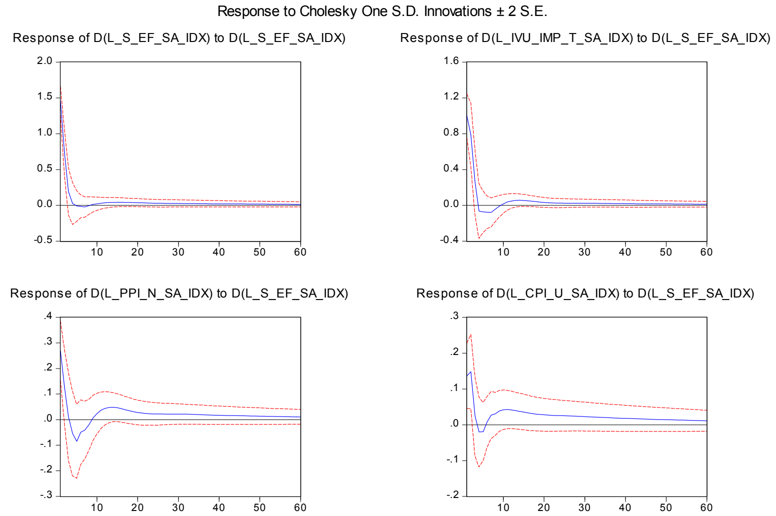
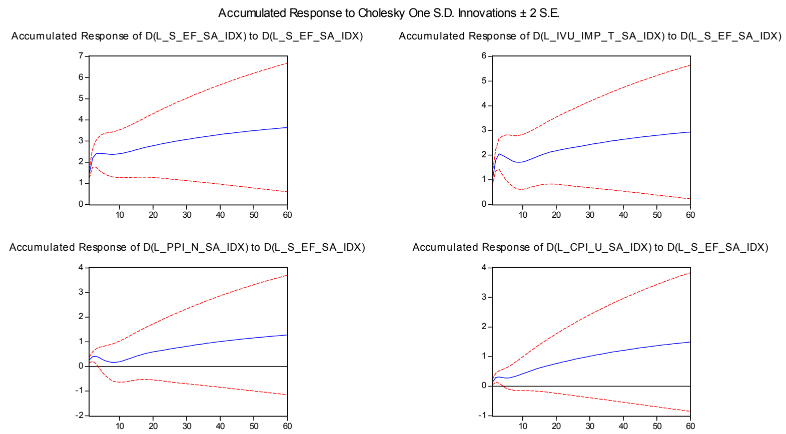


Figure 2 - Accumulated IRFs of exchange rate, IVU, PPI and CPI to 1% rise in exchange rate



As the figures show, the initial impact of an exchange rate appreciation on import prices, producer prices and consumer prices is positive as expected and remains so by the end of the 60 months.

The size of the pass-through was determined as the ratio of the accumulated response of the price index to a 1% shock of exchange rate and the accumulated response of the exchange rate to a 1% shock in the exchange rate. The results are presented in the following table:

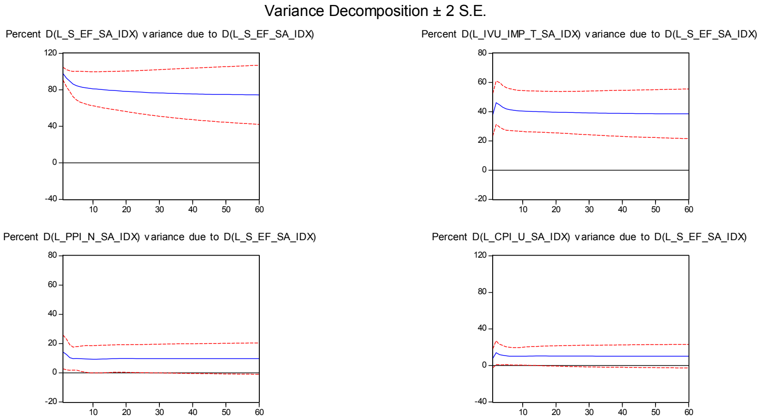
Table 1 - Exchange rate pass-through into price indices

Price Index	Time frame				
	3M	6M	12M	24 M	60M
ERPT into Import Prices	0.86	0.77	0.74	0.78	0.81
ERPT into Producer Prices	0.17	0.09	0.11	0.23	0.35
ERPT into Consumer Prices	0.13	0.12	0.20	0.30	0.41

Thus, it resulted that the ERPT to import prices after three months (the short-term pass-through) is 86%, declines to 74% after one year and increases to 81% after five years. On the other hand, the pass-through into producer prices after three months is very low (17%), declines to 11% after one years and increases to 35% after five years. The ERPT into consumer prices after three months is 13% and rise to 20% after one year and 41% after five years. Thus, as it was expected the ERPT into import prices is very high, but not complete. On the other hand, although the ERPT to import prices is significant higher than to producer and consumer prices, ERPT declines along the pricing chain only on short-term as after six months it becomes higher for the consumer than to producer prices.

Additional insights into the impact of external shocks on the different price indices to those obtained from the impulse responses functions may be received from variance decompositions. Although impulse response functions provide information on the size and speed of the pass-through, they give no information on the importance of the respective shocks for the variance of the price indices. The variance decompositions specify the percentage contribution of the different shocks to the variance of the k-step ahead forecast errors of the variables.

Figure 3 - Variance Decomposition



We begin by investigating the importance of ERPT for import price fluctuations (Table 2). Exchange rate shocks are particularly significant in explaining import price variance, their share ranging from over 38% to 46%. The percentage declines as the forecast horizon increases. For producer prices, the percentage of variance explained by exchange rates is quite low, ranging from 9% to 14%. The results for consumer price index are similar to the ones for producer price index, exchange rate shocks accounting for 8-14% of the variations in CPI.

Table 2 - Percentage of price index forecast variance attributed to exchange rate

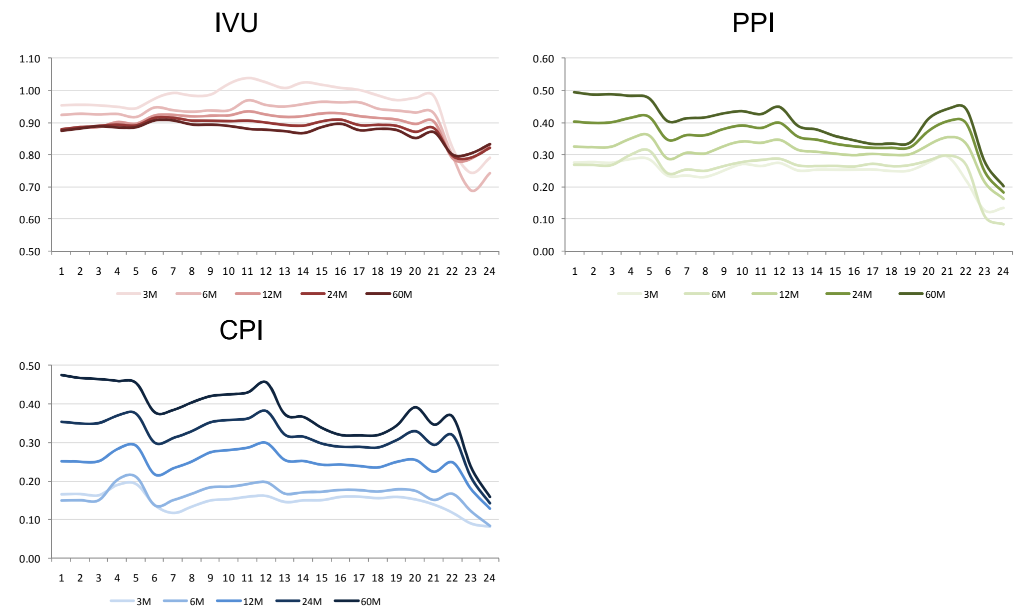
Price Index	Time frame				
	3M	6M	12M	24 M	60M
Import Prices	44.7	41.4	40.2	39.4	38.6
Producer Prices	10.4	9.6	9.3	9.7	9.7
Consumer Prices	11.8	10.2	10.3	10.2	10.1

RVAR rolling window estimation

We performed a rolling window estimation using the same specification as in previous estimated VAR, shortening the sample with two years. Thus, it yielded twenty-four VARs on successive time periods, spanning the entire sample used in the previous estimation (2000M1-2008M12).

The time dynamics in the successive rolling window estimations of ERPT into import, producer and consumer price indices are presented at different exchange rate shock propagation time periods. It resulted that the ERPT into producer and consumer price indices has declined in time while for import prices the case is less clear cut.

Figure 4 - Rolling window estimation of ERPT into price indices



Estimation results for different consumer price measures

We estimated other three VARs by replacing the *l_cpi_u_sa_idx* variable with other measures of inflation: CORE1 price index (*l_core1_u_idx*), CORE2 price index (*l_core2_u_sa_idx*) and Adjusted CORE2 (or CORE3) price index (*l_core3_u_sa_idx*). The pass-troughs into these price indices are presented in the following figure and table.

Figure 5 - Exchange rate pass-through into consumer price indices

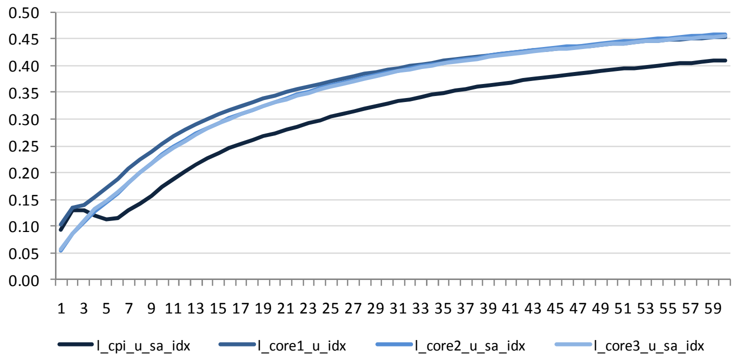


Table 3 - Exchange rate pass-through into consumer price indices

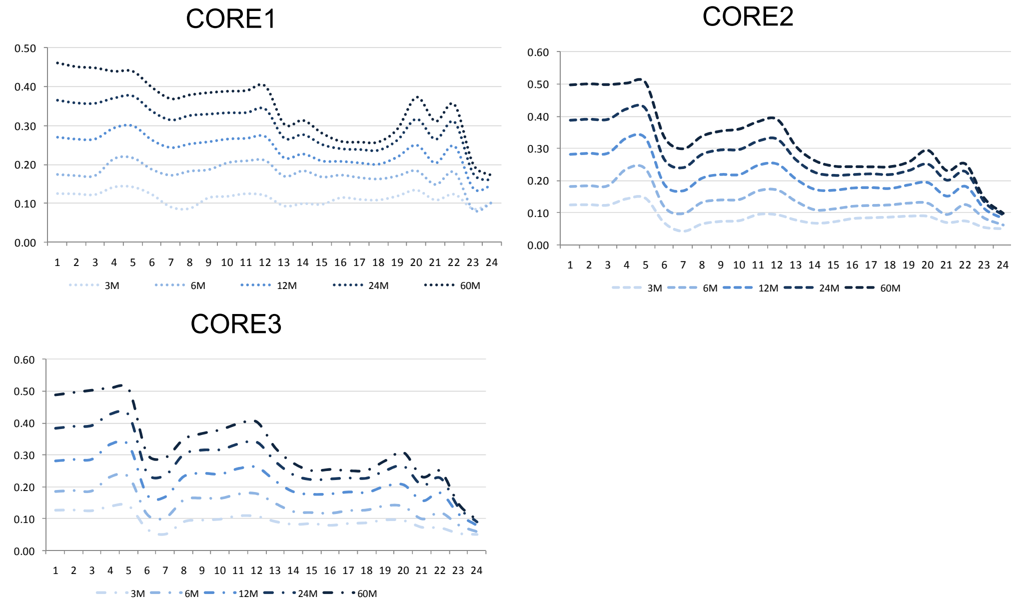
Price Index	Time frame				
	3M	6M	12M	24 M	60M
l_cpi_u_sa_idx	0.13	0.12	0.20	0.30	0.41
l_core1_u_idx	0.14	0.19	0.28	0.37	0.45
l_core2_u_sa_idx	0.11	0.16	0.26	0.36	0.46
l_core3_u_sa_idx	0.11	0.16	0.26	0.36	0.45

The results suggest that the ERPT is higher in the case of core measures than in the case of for total CPI. This could be explained by the consumer price index components that are not present in the core measures, some of which being legally linked to a fixed exchange rate from a particular moment of the previous year[7].

As in the previous section we performed rolling window estimates for these VARs. The results suggest that the ERPT into consumer prices' core measures corroborate the previous finding of a declining time path.

[7] For example the excises in the fuel prices (which represents roughly 50%) is linked to the exchange rate announced by the central bank on October 1st of the previous year.

Figure 6 - Rolling window estimation of ERPT into consumer price indices



3. Sign restriction VAR

Economic and econometric methodology

The literature regarding the VARs with restrictions on the impulse response functions developed much lately, applications of this method being found in all areas where the Structural VAR can be applied. Harald Uhlig (2006) presents the applications of this methodology in different areas of research. For the determination of the impact of a shock on a certain variable, the main problem that arises is that of identification, different methods of identification conducting to different results. In the case of VAR models the criteria on which the performance is judged are the amplitude, the shape and especially the sign of the impulse response function. Recent developments study the shock identification by imposing explicit restrictions and recovering the duration and amplitude, also analyzing the relevance of responses for the economic phenomenon studied. The literature presents different methods for the creation and for the implementation of the restrictions. Uhlig (1999) proposes sign restrictions on the impulse response functions. This method could be seen as minimalistic as it identifies only one shock with minimum of restrictions imposed.

In contrast to other types of identification methods that attempt to identify n fundamental innovations (as it was presented earlier in the paper), Uhlig[8] (2005) proceeded differently, being interested only in one fundamental innovation, the other $n \times 1$ fundamental innovations not being identified. Thus, by finding only one

[8] The theoretical framework described here is taken from Uhlig (2005).

fundamental innovation, only a single column $c \in \mathbb{R}^n$ of the matrix C (eq. (14)) has to be identified. The author proves that multiplying the Cholesky factor $\tilde{C}$ with a rotation matrix (a matrix which rotates a column and a row of the initial matrix) is equivalent with multiplying an impulse vector with a vector for which its components are drawn from a normal standard distribution. The vector $c \in \mathbb{R}^n$ is defined as an *impulse vector* if there is some matrix C, so that $\Sigma = CC'$ and so that *c* is a column of C. Considering $\tilde{C}\tilde{C}' = \Sigma$ be the Cholesky decomposition Σ, *c* will be an *impulse vector* if there exists a n-dimension vector α of unit length so that:

$$c = \tilde{C}\alpha \tag{15}$$

To determine the impulse response, it is considered $r_i(k) \in \mathbb{R}^n$ be a vector response at horizon *k* to the *i*th shock in a Cholesky decomposition of Σ. The impulse response $r_c(k)$ for c is then given by:

$$r_c(k) = \sum_{i=1}^{n} \alpha_i r_i(k) \tag{16}$$

Further, a vector $b' \neq 0$ is find with r $(\Sigma - cc')b = 0$ is normalised so that $b'c = 1$. Then, the real number $\varepsilon_t^{(c)} = b'e_t$ is the scale of the shock at date t in the direction of the impulse vector c and $\varepsilon_t^{(c)}$is the part of e_t which is attributable to that impulse vector. Basically, *b* is the appropriate row of C^{-1}.

The fraction of the variance of this forecast error for variable *j* explained by shock at horizon k is given by:

$$\Phi_{c,j,k} = \frac{(r_{cj}(k))^2}{\sum_{i=1}^{m}(r_{i,j}(k))^2} \tag{17}$$

Considering the coefficient matrices of a VAR (as in eq. (7)): $A = [A_1', \ldots, A_p']$, an error variance–covariance matrix Σ and some horizon K, a set $\mathcal{A}(A, \Sigma, K)$ of all impulse vectors is considered.

As a first step, Uhlig (2005) simply use the OLS estimate of the VAR, $A = \hat{A}$ and $\Sigma = \hat{\Sigma}$, fix K or try out a few choices for K and creates the entire range of impulse responses. The set $\mathcal{A}(\hat{A}, \hat{\Sigma}, K)$ results in an interval for the impulse responses. Numerically, this is performed by generating many impulse vectors, by calculating their implied impulse response functions, and checking whether or not the sign restrictions are satisfied. The impulse vectors are generated randomly: draw $\tilde{c}$ from a standard normal in $\mathbb{R}^n$, flip signs of entries which violate sign restrictions, multiply with $\tilde{C}^{-1}$to calculate the corresponding $\tilde{\alpha}$ and divide by its length to obtain a candidate draw for *c*. It is verified if $c \in \mathcal{A}(\hat{A}, \hat{\Sigma}, K)$ by verifying the sign restrictions on the impulse responses for all relevant horizons $k = 0, \ldots, K$. After the candidate draws for *c* were generated, the maximum and the minimum of the impulse responses for those *c* were plotted.

Based on a Bayesian approach, chosen by Uhlig (2005) as it is considered "computationally simple and since it allows for a conceptually clean way of drawing error bands for statistics of interest such as impulse responses", the author proposes two related, but different approaches: the "pure-sign-restriction approach" and the "penalty-function approach". In the first one, all impulse vectors satisfying the impulse response sign restrictions are considered equally likely, while in the second approach an additional criterion to select the best of all impulse vectors is used. For the "pure-sign-restriction approach" it is considered a lower triangular Cholesky factor of Σ: $\tilde{C}(\Sigma)$, a space of positive definite $n \times n$ matrices: $\mathcal{P}_n$ and $\mathcal{S}_n$ as the unit sphere in $\mathbb{R}^n$, with $\mathcal{S}_n = \{\alpha \in \mathbb{R}^n : \|\alpha\| = 1\}$. Numerically, the pure-sign restriction approach is implemented in the subsequent manner. The posterior is given by the usual Normal–Wishart posterior for (A, Σ), given the assumed Normal–Wishart prior for (A, Σ). To draw from this posterior, it is performed a joint draw from both the posterior for the unrestricted Normal–Wishart posterior for the VAR parameters (A, Σ) and from an uniform distribution over the unit sphere $\alpha\mathcal{S}_n$. A draw a from the n-dimensional unit sphere was obtained by drawing $\tilde{\alpha}$ from the n-dimensional standard normal distribution and after that normalizing its length to unity: $\alpha = \tilde{\alpha} / \|\tilde{\alpha}\|$. Then the impulse vector c is constructed and from eq. (16) are calculated the impulse responses $r_{k,j}$ at horizon $k = 0, \dots, K$ for the variables j and it was verified if the sign restrictions are satisfied. If they were satisfied, the draw was kept; otherwise, the next draw was initiated. Error bands were calculated using all the draws which have been kept.

An (2006) apply the VAR with sign restriction procedure in estimating ERPT at different stages of distribution for eight major industrial countries: United States, Japan, Canada, Italy, Finland, Sweden and Spain. The results indicate that the ERPT is incomplete in many horizons, though complete pass-through is observed occasionally.

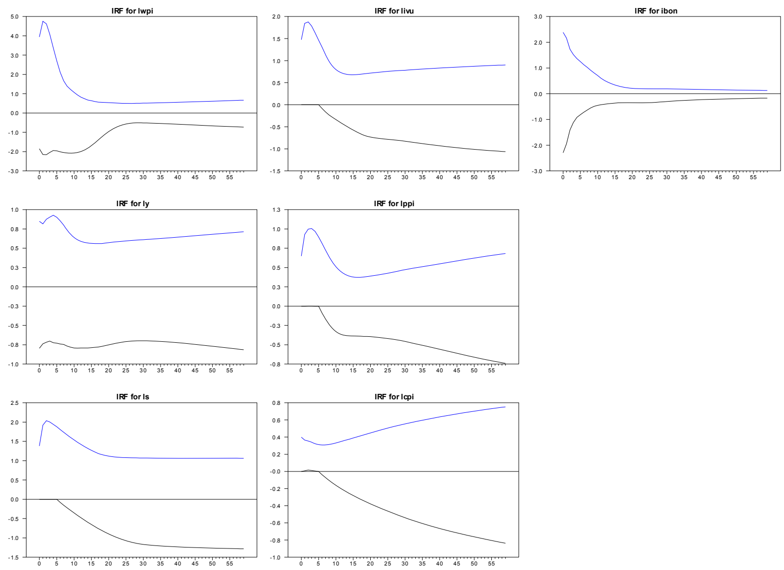
Empirical analysis

The methodology applied is based on a SVAR with sign restrictions on impulse responses of the variables, similar to that of Uhlig (2005). The programs used are the ones of the author, customised to the set of variables used and in accordance with the restrictions considered relevant. Routines for the variance decomposition of the variables and for the simulation of confidence intervals - corresponding to one standard deviation - were also implemented. All the programs are performed in WinRats 7.2.

The analysis is made for the Romanian economy and it is based on monthly data covering the period between 2000M01 and 2008M12. The variables are the ones used in the previous section: WPI - an all commodities index (*l_wpi_u_sa*_idx), real GDP (*l_y_sa_yind_u_cl_idx*), nominal effective exchange rate (*l_s_ef_sa_idx*), import prices (*l_ivu_imp_t_sa_idx*), producer price index (*l_ppi_n_sa_idx*), consumer price index (*l_cpi_u_sa_idx*) and short-term interest rate (*ibon*). A VAR with two lags in levels was used. The sign restrictions imposed on impulse responses assure that the exchange rate will not decline in response to its own positive shock and that the import, producer and consumer prices will not decrease in the context of exchange rate depreciation. We did not impose additional restrictions on the GDP response as in the case of the Romanian economy the effect of the exchange rate on net exports may be compensated (or possibly overcompensated at times) by wealth and balance sheet effects. Also the monetary policy's response to an exchange rate shock in the context of an inflation targeting regime is not clear cut, the direct effect of the exchange rate in import prices could be overturned by an inverse response induced by an opposite reaction of the output gap. For robustness confirmation the horizon K for the sign restrictions will vary to 2 (3-month), 5 (6-month), 8 (9-month), 11 (one year) and 23 (two years).

First of all we applied the sign restriction approach that imply the simply use the OLS estimate of the VAR. Thus, we generated 1,000,000 candidate draws for *c* in order to plot the maximum and the minimum of the impulse responses for those *c* that satisfy the restrictions. Thus Figure 7 shows the range of impulse response functions, which satisfies the sign restrictions for $k = 0, ..., K$ months after the shock, where K=5.

Figure 7 - The maximum and the minimum of the IRF (10^6 extractions) when imposing the sign restrictions for K=5 at the OLSE point estimate for the VAR

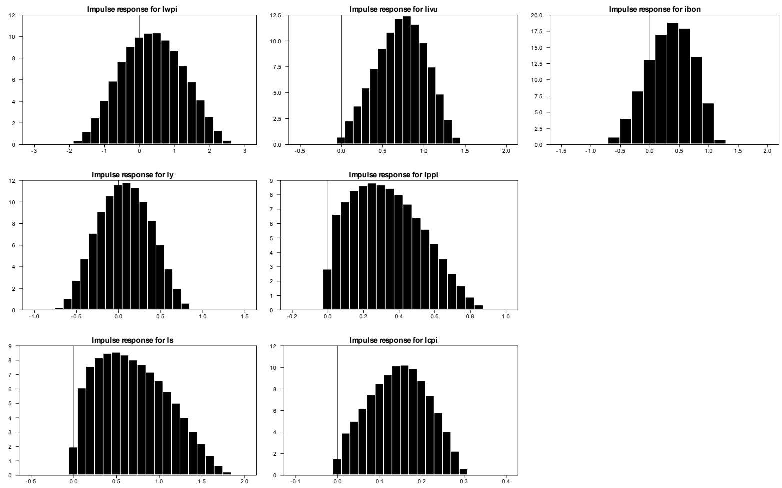


min & max for IRF K=5

In Figure 8 the histograms of the initial responses of all variables (at horizon 0) are constructed by extracting the orthogonalized impulse vectors uniformly from the unit sphere, as described for the pure-sign-restriction approach. It can be seen that for the initial response of the exchange rate and price indices the sign restrictions seem to leave intact most of the distributions.

For the pure sign restriction approach the number of draws from the posterior of the VAR (n_1) was chosen to be equal to the number of draws α from the unit sphere (n_2) and it was set to 750. Impulse responses to an exchange rate shock were constructed, considering K equal to 5. Thus, the responses of the exchange rate and of the import, producer and consumer price indices have been restricted to be positive for the next six months (k = 0, ..., 5) after the shock.

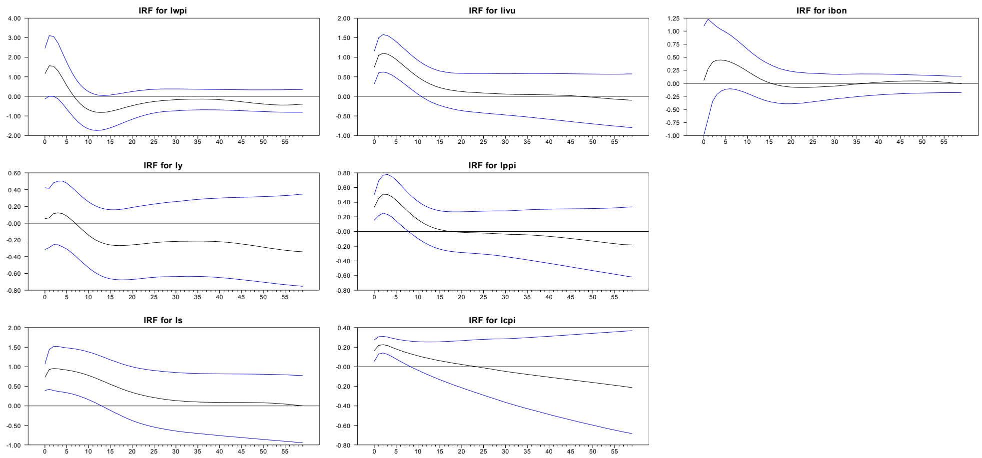
Figure 8 - Histogram for initial impulse responses (at horizon 0) when imposing the sign restrictions for K=5 at the OLSE point estimate for the VAR



Histogram for initial IRF

The Figure 9 presents the median as well as the 16% and the 84% quantiles for the sample of impulse responses: if the distribution was normal, these quantiles would correspond to a one standard deviation band. Thus, the nominal effective exchange rate increase right away and considerably in response to their own shocks and they remain significant for one year. The import price indices react strongly and positively instantly after the shock. It remains statistically significant for ten months. On the other hand, the producer and consumer price indices responded in the same way as import price indices, but at a smaller scale.

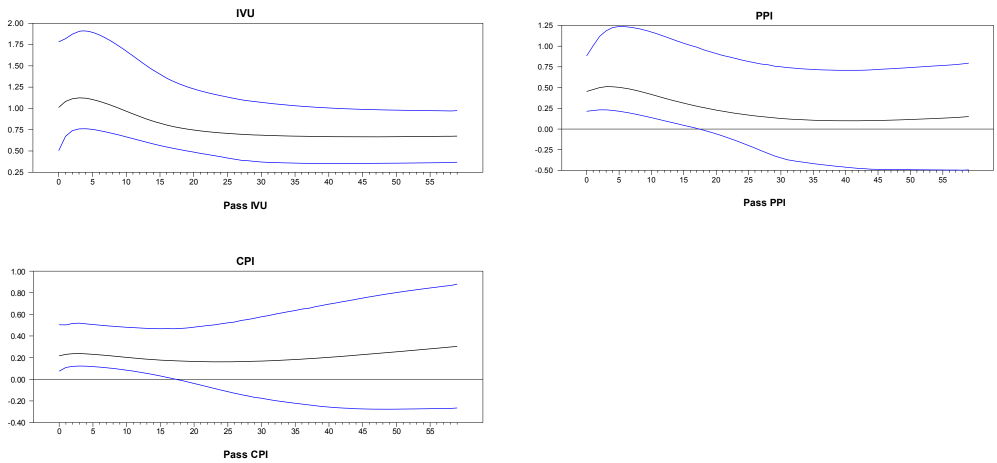
Figure 9 - Impulse responses to an exchange rate shock, using the pure sign restriction approach (K=5)



IRF for VAR with pure sign restrictions

The size of the pass-through was determined as the ratio of the accumulated response of the price index to an exchange rate shock and the accumulated impulse response of the exchange rate to its own shock. Figure 10 and Table 4 present the ERPT to import, producer and consumer price indices.

Figure 10 - ERPT into IVU, PPI, CPI using the pure sign restriction approach (K=5)



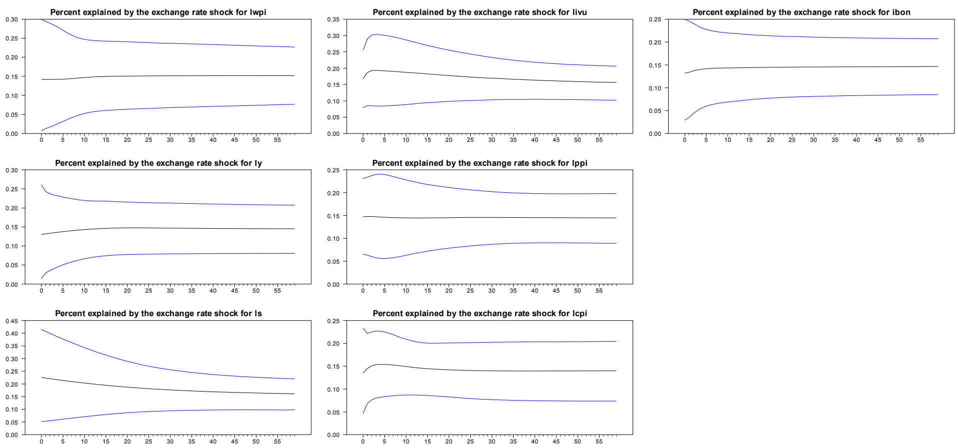
Thus, the ERPT to import prices is higher than 1 in the short run, but after one-year horizon it starts to decline towards 67% after five years. Even though the median of the ERPT distribution seems higher than one, the confidence intervals are relatively broad and encompass the full pass-through pointed by the previous econometric method applied (RVAR). The pass-through ratios are largest for import price index, followed by the producer price index and then by the consumer price index over a two-years horizon. Thus, up to two years period, the pass-through declines along the distribution chain; after that the pass-through to CPI exceeds that to PPI.

Table 4 - ERPT into price indices, using the pure sign restriction approach (K=5)

Price Index	Time frame				
	3M	6M	12M	24 M	60M
ERPT into Import Prices	1.11	1.10	0.94	0.72	0.67
ERPT into Producer Prices	0.50	0.50	0.40	0.19	0.15
ERPT into Consumer Prices	0.24	0.23	0.20	0.16	0.30

It is important to find out how much of the variation is explained by the shocks. Using the pure sign restriction approach with a six months restriction (K=5), the Figure 13 presents the variance decomposition. Thus, the plots show the fraction of the variance of the variables explained by the exchange rate shock. The three lines are the 16% quantile, the median and the 84% quantile. According to the median estimates, exchange rate shocks account for 15 - 20% of the variance in the import price index at all horizons and for 15% of the long-horizon variance in the producer and consumer prices. Thus, the variance decomposition indicates that the exchange rate shock explains a significant proportion of the forecast error variance of the price indices.

Figure 11 - Variance decomposition using the pure sign restriction approach (K=5)



VD for VAR with pure sign restrictions

Robustness check

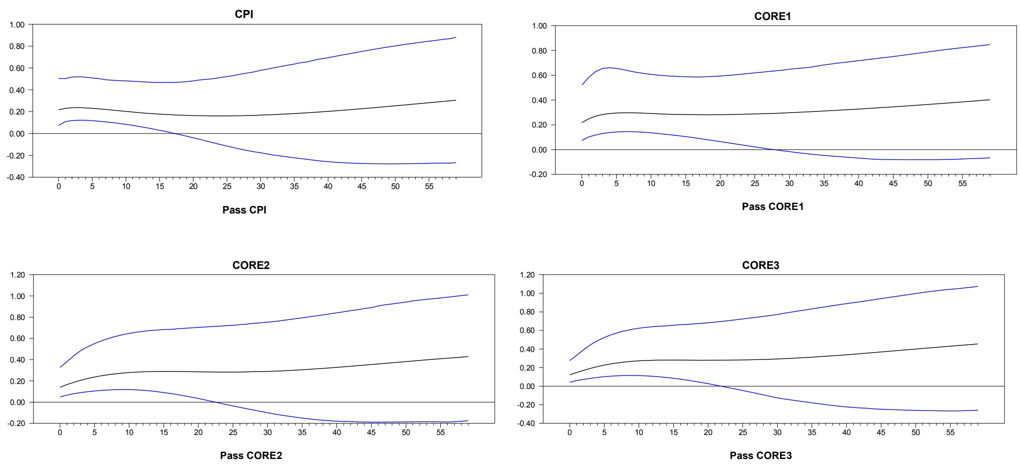
In order to establish how sensitive are the results to the variation in horizon K for the sign restrictions, we present the results for 3-months (K =2), 12-months (K =11) and

24-months (K =23) horizon restriction. Figure 13 (Appendix 2) presents the impulse response functions to an exchange rate shock for different K specifications. The results are fairly similar to that of the baseline setup, especially for K =2. But as horizon K increases, it seems that the bands move up. Figure 14 (Appendix 2) presents the ERPT into the price indices for different K. Up to six-months the exchange rate pass-trough for the four K specifications are almost equal in the case of import and producer price indices. After six-months the four estimations of the ERPT begin to distance a little from each other; the size of the pass-through increasing in proportion to K horizon. On the other hand, in the case of consumer price index, the four specifications of ERPT slightly differentiate since the beginning. Figure 15 presents the forecast error variance decompositions of the variables for different K specifications, suggesting that these results are similar to those from the baseline setup - only for the consumer price index the percentage of variance increases a little in line with K horizon. In general, the results seem to be quite robust to different horizons.

Estimation results for different consumer price measures

An examination of the ERPT into several consumer price index core measures was performed. It resulted that the ERPT is higher in the core measures than in total consumer price index. This evidence further substantiates the case previously exposed by the RVAR analysis.

Figure 12 - ERPT consumer price indices, using the pure sign restriction approach (K = 5)



3. Conclusions

The paper investigates, with various VAR models, the pass-through of an exchange rate shock into prices in the Romanian economy. The main findings of the paper are as follows:

Firstly, the *average pass-through throughout the entire sample* seems to be almost complete for import prices, around 35% for producer prices and around 30% for consumer prices as indicated by RVARs and the Sign-restriction VARs.

Secondly, the *pass-through in consumer prices is affected by the inflation measure used* (CPI, CORE1, CORE2, CORE3), the core measures being more responsive to an exchange rate shock, as the regulated prices are legally linked to a fixed exchange rate from a particular moment of the previous year.

Thirdly, the *rolling windows estimation* points on one hand, to a markedly decrease in the size of the pass-through for producer and consumer prices (irrespectively of the price measure used - CPI, CORE1, CORE2, CORE3) and on the other hand, to an almost constancy in import prices pass-through.

The paper tries to contribute to the growing field of empirical investigation of the ERPT by supporting existing conclusions and pointing to new ones. Further developments in the research could steam from employing single equation estimates for subsector of the importers, producers and consumers. Also, the conclusions drawn could be compared with the research results from other emerging economies.

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5. Appendixes

Appendix 1 - Unit root tests results

Table 5 - Augmented Dickey Fuller (ADF) and Phillips Perron (PP) tests results

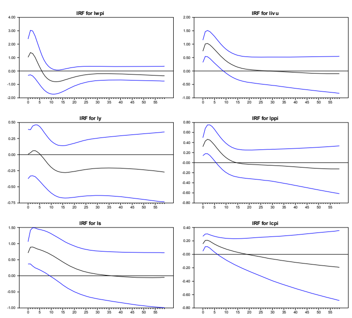
Test	ADF			PP		
Null Hypothesis	I(1)	I(2)	I(3)	I(1)	I(2)	I(3)
Variable	Prob.	Prob.	Prob.	Prob.	Prob.	Prob.
l_wpi_u_sa_idx	0.9657	0.0000 c,t	0.0000	0.9808	0.0000 c,t	0.0000
l_y_sa_yindcl_hpgap	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000
l_s_ef_sa_idx	0.9913	0.0000	0.0000	0.9940	0.0000	0.0000
l_ivu_imp_t_sa_idx	0.9986	0.0000	0.0000	0.9993	0.0000	0.0000
l_ppi_n_sa_idx	0.9998	0.0000 c,t	0.0000	1.0000	0.0000 c,t	0.0000
l_cpi_u_sa_idx	0.8715	0.0000 c,t	0.0000	0.9191	0.0000 c,t	0.0001
l_core1_u_idx	0.9988	0.0000 c,t	0.0000	0.9999	0.0000 c	0.0000
l_core2_u_sa_idx	0.9991	0.0000 c,t	0.0000	0.9998	0.0000 c,t	0.0000
l_core3_u_sa_idx	0.9986	0.0000 c,t	0.0000	0.9997	0.0000 c,t	0.0000
ibon	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

* MacKinnon (1996) one sided p-values.

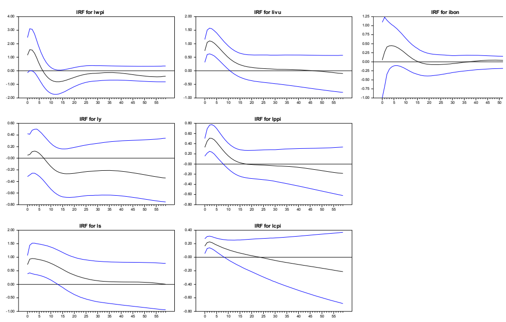
* c: constant, t: trend

Appendix 2 - Pure sign restriction approach - Outputs for different K

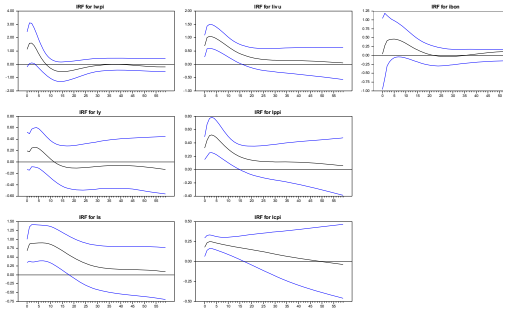
Figure 13 - IRFs to an exchange rate shock, using the pure sign restriction approach for K = 2, 5, 11, 23



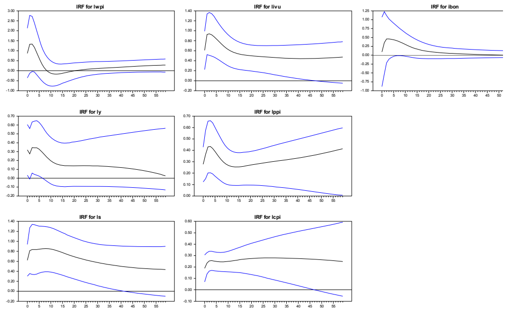
IRF for VAR with pure sign restrictions



IRF for VAR with pure sign restrictions



IRF for VAR with pure sign restrictions



IRF for VAR with pure sign restrictions, K=23

Figure 14 - ERPT into price indices - the pure sign restriction approach for K = 2, 5, 11, 23

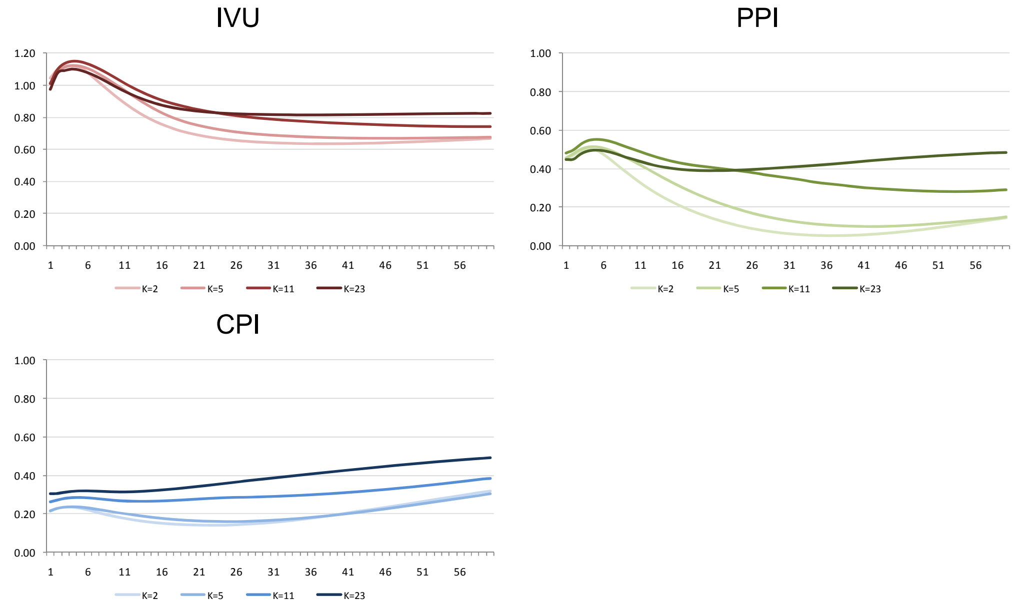
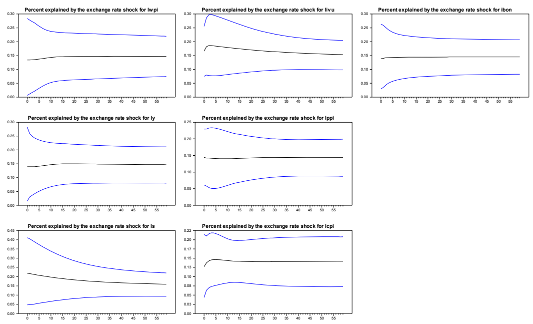
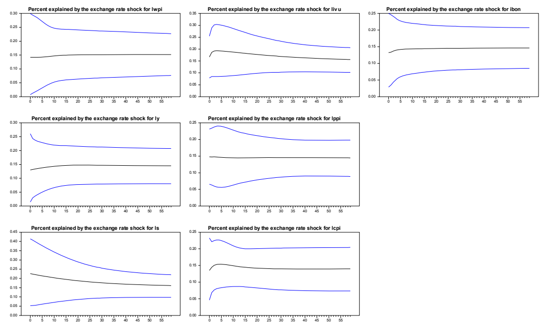


Figure 15 - Variance Decomposition using the pure sign restriction approach for K = 2, 5, 11, 23



VD for VAR with pure sign restrictions



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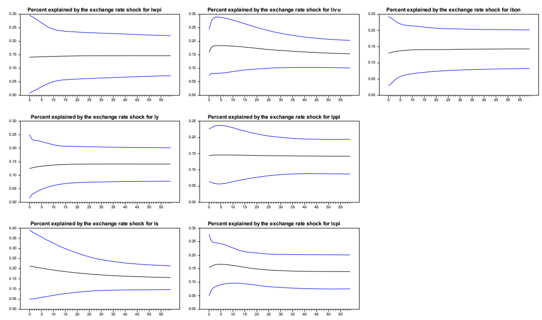

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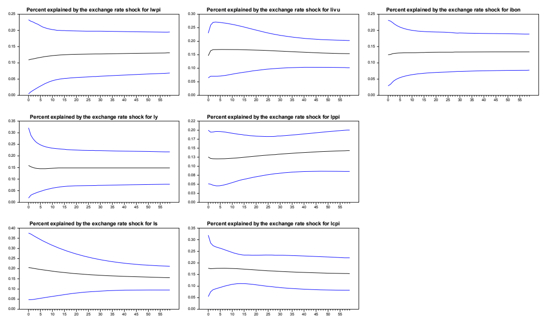

VD for VAR with pure sign restrictions, K=23