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International linkages and external shocks: A Global VAR perspective for Belarus. Evidence from different model specifications

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International linkages and external shocks: A Global VAR perspective for Belarus. Evidence from different model specifications

Executive Summary

Belarus as a small, open economy is closely integrated into the global economy via complex commodity, trade and financial channels. The empirical investigation of the impact of different external shocks, e.g. changes in the global price of crude oil, or a recession in Belarus' main trading partners on its main macroeconomic variables like GDP, inflation and the exchange rate is of concern to policymakers and researchers alike.

In this policy study, we use a very modern and sophisticated econometric approach to investigate these issues further. The Global Vector Autoregression (GVAR) as a multi-country model has been specifically developed to study such global macroeconomic issues, and has to our knowledge not previously been applied to the case of Belarus.

In our empirical GVAR work, we use two distinct modelling approaches. In the first step, we analyse the propagation of shocks in a small model of the Eurasian Economic Union (EAEU), which comprises the five member countries, including Belarus, as well as some selected external variables. The second step involves a much larger data-set of 35 countries, which allows a much deeper analysis of economic cross-border links.

What are our main results, and what policy conclusions can be drawn? We use generalized impulse response functions (GIRF) to analyse the transmission of external as well as domestic shocks on Belarus. In general, empirical reactions follow theoretical considerations. In both versions of the model, the strong effect of the exchange rate on prices ("pass-through") is clearly observed, as is the pattern of inflation following a shock to broad money aggregates. We also find only weak evidence of the interest channel of monetary transmission. External shocks like a drop in the price of oil, or a fall in Russian or global GDP have also the negative impact on Belarusian output that one would expect. What is perhaps surprising is that the link of Belarus' GDP appears to be stronger with oil rather than with Russia's GDP. For Russia, we can identify the typical reaction to a fall in the price of oil, which is a fall in its GDP.

How do the GVARs we estimated perform in comparison with a standard single country Structural Vector Autoregression (SVAR)? For this comparison, we estimated an SVAR model of the Belarusian economy and investigated similar external and domestic shocks. In general, the results obtained from all three different models (large-scale GVAR, small-scale GVAR, and SVAR) point in the same direction, which supports the robustness of the results. What specific model should be applied depends largely on the concrete context of the question.

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Contents

Figures

Tables

1. Introduction

In the global economy, individual economies are interrelated through many different channels in a complex way. But even after allowing for these effects, there may be residual interdependencies due to unobserved interactions and spillover effects not taken properly into account by using the common channels of interactions. Taking into consideration these channels of interactions is a major challenge to modelling national economies as well as for conducting policy simulations in a global context. The Global Vector Autoregression (GVAR) model is quite modern and a useful tool for such kind of modelling.

The Global Vector Autoregression (GVAR) model originates from Pesaran, Schuermann, Weiner, (2004). Since this seminal paper there is a voluminous literature devoted to the GVAR modelling has been appeared. A comprehensive survey of GVAR modeling is presented in Chudik, Pesaran (2016). Current empirical applications of the GVAR models involve the following issues: (1) global macroeconomic applications (global inflation, global imbalances and exchange rate misalignments, role of the United States as a dominant economy, business cycle synchronization and rising role of China in the world economy, impact of Eurozone-membership, commodity price models, housing, effects of fiscal and monetary policy, labour market, the role of credit and macroeconomic effects of weather shocks); (2) forecasting applications; (3) global finance applications; (3) sectoral and regional applications. A comprehensive review of existing applications of GVAR for policy analysis is disused in di Mauro, Pesaran, (2013). To the best of our knowledge, an empirical analysis of the Belarusian economy using the GVAR model is absent. Therefore, we have tried to fill this gap.

In this paper we have tried to employ the GVAR model for analysis of Belarusian economy. The main aim of the study is to put the Belarusian economy into a global context and analyze the effect of various external shocks on the major macroeconomic variables (real GDP, inflation, exchange rate) and transmission channels of the shocks using a the advantages of the GVAR model. We were exploring two possible options: (i) using a large data set (35 countries); (ii) using a small Eurasian Economic Union (EAEU) data set (5 countries) and external variables of the EU, the US and China and the oil price as well. To be more specific, we are conducting the following tasks:

- To analyze the impact of external shocks coming from Russia and the major world economies on the Belarusian economy;
- To analyze interrelations within EAEU countries (if any);
- To compare small and large data sets results;
- To compare the results of the GVAR modeling with the comparable single country Structural VAR (SVAR) models for the Belarusian economy, augmented with relevant external variables (using analysis of transmission mechanism of monetary policy as an example).

The rest of the paper has the following structure. In the next section we briefly discuss the methodology of the GVAR modeling in a non-technical manner, and then describe the data set used for the GVAR modeling, and discuss the issues of model identification and estimation. The third section is devoted to empirical analysis; namely we analyze the shocks of both external and domestic variables and their propagations across the Belarusian economy and its main trade partners. Here two models are considered: A large scale GVAR model (35 countries) and a small GVAR model for the Eurasian Economic Union (EAEU)[1]. In the fourth section, we have built a Structural Vector Autoregression (SVAR) model, augmented with external variables and compare the results obtained from different approaches. The fifth section briefly concludes.

[1] The results of this analysis were presented in Policy Briefing 08/2016: "International linkages and external shocks: A Global VAR perspective for Belarus. Evidence from a small EAEU model".

2. Building the global VAR model

2.1. Global VAR modeling: a brief overview

The GVAR model is a multi-country model intended to analysis inter-country relationships. This model supposes the interactions between analyzed countries through international trade and demonstrates an influence of various country (group of countries) specific shocks on other countries or their groups. The formal detailed explanation of the GVAR methodology is presented in Pesaran, Schuermann, Weiner (2004), di Mauro, Pesaran (2013), Smith, Galesi, (2014), Chudik, Pesaran, (2016) and many other papers on the subject. Here we very briefly discuss the basics of the GVAR modeling in a non-technical manner.

In general, the GVAR methodology involves two stages:

1) For each country chosen for the analysis, the standard VAR model consisting of a set of the relevant domestic variables (say, real GDP, consumer price index, various interest rates, exchange rate, etc.) is built. Hereafter, this VAR model is extended by a set of foreign (external) variables that are treated as weakly exogenous in the model. The foreign variables generally coincide with the domestic variables of the single country model, and these variables are constructed as weighted averages of the domestic variables of all trading partners of the individual country included in the GVAR model. The weighing scheme usually reflects foreign trade linkages (bilateral trade weights) among studied countries, although alternative weighs are also possible. In addition to the foreign variables, the VAR model can include so-called global variables that are considered as exogenous to the system in whole (for example, prices for natural resources). Finally, using the domestic, foreign and global variables, a Vector Autoregressive (VAR)/Vector Error Correction (VEC) model is separately estimated for each country involved in the analysis. It is assumed that external variables appearing in country-specific models are empirically weakly exogenous and country-specific models are structurally stable (testable hypothesis). It should be noted that the lag structure of the models and the number of foreign variables can vary country by country, and it is also a subject of empirical testing.

2) Using the estimated individual countries models, a global VAR is constructed and estimated as a single model, which is used for analysis of a dynamic behavior of the system (how the various shock are propagated across different countries and regions, using the impulse response functions and variance decompositions) or forecasts and counter factual experiments. It is important that the GVAR model allows modeling a group of related countries together as region and correspondingly investigating shocks propagation between different countries, their groups, blocks, economic unions and regions as well.

The GVAR model methodology is practically implemented in a special software – GVAR Toolbox – that is a collection of MatLab procedures with an Excel-based interface, designed for the purpose of GVAR modelling and policy analysis (for details see Smith, Galesi, 2014). The main steps of the GVAR modeling are as follows: (1) Data set creation (defining the countries and regions used in the analysis, variables of interest involved into the model, collecting cross-country trade flow data, creation the weight matrix for the GVAR model); (2) Defining the preliminary settings and selecting the weights for construction of the foreign variables (selecting the weights for constructing the foreign variables, defining the preliminary settings of the model); (3) Specification of the individual VARX* models (defining domestic, foreign and global variables, lag order selection); (4) Determining the rank orders (testing for cointegration); (5) Imposing overidentifying restrictions on the cointegrating vectors (if necessary); (6) Testing for weak exogeneity test; (7) Defining the dominant unit, specification and estimation of the dominant unit model for global variables; (8) Solving the GVAR model; (9) Performing structural stability tests; (10) Conducting dynamic analysis of the GVAR model (defining forecast horizon, bootstrapping for confidence intervals, regional aggregation, shock selection, generalized impulse response functions (GIRF) and generalized forecast error variance decomposition (GFEVD) or orthogonalized IRFs and FEVD).

In the following analysis we use generalized impulse response functions (GIRF) to analyze the shocks propagation (see Koop, et al., 1996; Pesaran, Shin, 1998). The GIRF functions are an alternative to the orthogonalized impulse response function, and it is invariant to the variables and countries ordering in the model. The GIRF approach has the advantage that in the absence of strong prior belief of the ordering of the shocks or countries, it can provide useful information on the transmission of the individual shocks in the system.

2.2. Data set used

The paper aims at analyzing the influence of external shocks on the Belarusian economy and mechanisms of their transmission. Despite being an open economy, it is believed that most of global shocks affect Belarusian economy only indirectly through dynamics of Russian macroeconomic indicators. Therefore, we also model specific external shocks relevant to the Russian economy and the economies of the EAEU in general checking for their influence on Belarus. This kind of analysis requires a large dataset, containing time series of economic indicators of EAEU countries, their main trade partners and global variables.

The list of countries of interest was determined based on trade flows of EAEU countries. We selected 29 countries that stood for more than 0.5% of foreign trade of the EAEU region in the period of 2013–2015. Most of the countries represented EU and South-East Asia (see Table 1). Hence, total number of countries analyzed was 34. In order to simplify modelling procedures, and taking into account limited integration of the EAEU region with majority of economies, most of the countries were aggregated into the groups. Groups were defined based on geographical principal and level of economic development of countries. In particular, we defined Eurozone and Central and Eastern Europe regions that unite majority of the EU countries, CIS region, a group of developed market economies and a group of emerging market economies. These aggregations allow for regional shocks in the model, which should be relevant, taking into account effects of regional integration and global inter linkages of developed and emerging market economies. Separate models were estimated only for Belarus and Russia, as well as China, Great Britain, Japan and the USA stressing their role in global economy.

Table 1. List of countries included into the GVAR model and their grouping

Abbr.	Country name	Abbr.	Country name
BLR	**Belarus**	GER	Germany
RUS	**Russia**	GRE	Greece
CIS	**CIS**	ITA	Italy
ARM	Armenia	NLD	Netherlands
KAZ	Kazakhstan	SPN	Spain
KYR	Kyrgyzstan	**CHN**	**China**
UKR	Ukraine	**OEE**	**Other emerging market economies**
CEE	**Central and Eastern Europe**	BRA	Brazil
CZE	Czechia	IND	India
HUN	Hungary	KOR	Korea
LAT	Latvia	TUR	Turkey
LTH	Lithuania	VNM	Viet Nam
POL	Poland	**USA**	**USA**
ROM	Romania	**GBR**	**United Kingdom**
SVK	Slovakia	**JPN**	**Japan**
EUR	**Eurozone**	**ODE**	**Other developed market economies**
AUT	Austria	CAN	Canada
BEL	Belgium	SUI	Switzerland
FIN	Finland	SWE	Sweden
FRA	France		

Source: compiled by the authors.

The analysis of the external shocks in GVAR models usually grounds on monetary transmission mechanism analysis (Mauro, Pesaran, 2013), as monetary policy is the main stabilisation policy that reacts to external shocks and internal misbalances. Therefore, key variables analyzed in the majority of research papers employing the GVAR methodology are gross domestic product, inflation, exchange rate, short- and long-term interest rates. Besides, specifications can include housing prices, stock indexes, as well as fiscal and labour indicators (Chudik, Pesaran, 2014), describing inter linkages of global markets. As our research is focused on Belarus and the EAEU region, we limited the analysis of external shock transmission to monetary variables, as Belarus and other EAEU countries are either weakly integrated into global markets, or related data is not available. So, our model contains the following variables: real GDP, consumer price index, nominal exchange rate, nominal short-term interest rate, broad money (see Table 2). Choice of these variables to some extent was determined by previous research on monetary transmission mechanism in Belarus (Pelipas, Kirchner, 2015).

The construction of the time series of the short-term interest rates and broad money was complicated by different approaches applied by countries to data reporting. In case of money indicators, many countries use non-standardized report forms where broad money is represented by line "sum of money and quasi-money". It is analogue of M3 indicator in standardized forms. Moreover, in some cases there were switches from one methodology to another. Related structural breaks in time series were avoided by use of growth rates, assuming that change in methodology affected only volume of broad money and not dynamics. Growth rates were also used to reconstruct time series of broad money for countries constituted euro area.

Short-term interest rates are represented by households deposit interest rates with maturity up to 3 months and interbank interest rates of same maturity. In case of CIS and emerging market economies deposit interest rates were largely used due to better availability, while interbank interest rates were applied to developed market economies.

Table 2. List of variables included into the GVAR model

Abbr.	Name	Description
	Domestic variables	
gdp	real GDP	index, 2010 = 1
cpi	consumer price index	index, 2010 = 1
ner	nominal exchange rate to US dollar	index, 2010 = 1
nsr	short-term interest rate	1–3 months deposit rate or interbank rate, fraction
m	broad money	broad money (M3), money plus quasi-money, index, 2010 = 1
	Foreign variables	
$gdpx$	foreign real GDP	Calculated as weighted average of corresponding indicators of other countries. The weights are determined by geographical foreign trade structure in 2011–2015.
$cpix$	foreign consumer price index	
$nerx$	foreign nominal exchange rate to US dollar	
$nerx$	foreign short-term interest rate	
mx	foreign broad money	
	Global variable	
oil	oil price	WTI, index, 2010 = 1

Source: compiled by the authors.

The data sources for macroeconomic and monetary variables were International Financial Statistics database of the IMF, OECD Statistical Database, Eurostat, European Central Bank, national statistical committees, central banks, and relevant literature sources.[2] Collected data covers period from 1997Q1 to 2016Q2 (78 observations). The GVAR program does not allow for missing values, which limited possible time horizon. Therefore, in case country data for an indicator was missing for some observations it was extrapolated within TRAMO/SEATS seasonal adjustment procedures.[3] Additionally, seasonal adjustment of row time series was performed automatically using TRAMO-SEATS procedure when combined test for presence of identifiable seasonality depicted seasonal pattern.[4] Tests revealed that seasonal adjustment was needed for most of time series used with exception of the short-term interest rates and exchange rates. Interest rates were also the only variable that was not taken in natural logarithms.

On the one hand, country specific real GDP, CPI, exchange rate, short-term interest rates and broad money indictors of a country were used as domestic variables in the GVAR model. On the other hand, they also served for construction of foreign variables, which are weighted average of related indicators of all foreign

[2] For instance, real GDP time series for early periods were estimated based on data form Ukrainian-European Policy and Legal Advice Centre (2002). Ukrainian Economic Trends. Monthly update: January. Vie Nam quarterly real GDP data was taken from Vu Tuan Khai (2012). Estimates of Quarterly Real GDP for Vietnam, Seikei University, Economic Department Journal, 43 (2).

[3] This method was employed for estimation of Japan monetary indicators in 2016Q2, Viet Nam inflation in 2016Q2; Armenia quarterly GDP in 1997 and Kazakhstan quarterly GDP based on annual grow rates in 1997–1999.

[4] Software JDemetra+ 2.1 is used for extrapolation, seasonality testing and seasonal adjustment.

countries. The weights were calculated based on trade volume between the countries.[5] The GVAR Toolbox 2.0 provides choice between time-varying and constant weights. We applied constant weights based on average volume of trade flows between analyzed countries in 2011–2015. The weights obtained after aggregation of countries into the groups are presented in Table 3.

They illustrate dominant role of Russia in determining dynamics of foreign variables for Belarus. Eurozone economy and CEE region play although important, but a lesser role in shaping Belarusian foreign variables. In case of other CIS countries Russia and Eurozone countries have similar weights in constructed foreign variables. Another important partner for the region is China. Russian foreign variables at a large extent represent dynamics of Eurozone variables with the some influence of CEE countries, China and other emerging market economies.

The only global variable included into the analysis was oil price. The EEU countries are exporters of natural resources and oil price is a good approximation for changes in their terms of trade originated from global market dynamics.

Table 3. Weights applied for construction of foreign variables

	BLR	CEE	CHN	CIS	EUR	GBR	JPN	ODE	OEE	RUS	USA
BLR	–	0.008	0.001	0.030	0.002	0.000	0.000	0.000	0.001	0.051	0.000
CEE	0.104	–	0.022	0.093	0.186	0.050	0.010	0.026	0.029	0.108	0.012
CHN	0.038	0.066	–	0.138	0.142	0.092	0.356	0.076	0.303	0.136	0.240
CIS	0.097	0.026	0.018	–	0.017	0.003	0.003	0.004	0.011	0.084	0.002
EUR	0.164	0.623	0.194	0.287	–	0.497	0.128	0.294	0.231	0.366	0.191
GBR	0.026	0.051	0.034	0.015	0.138	–	0.022	0.065	0.036	0.027	0.045
JPN	0.003	0.012	0.150	0.014	0.039	0.023	–	0.026	0.103	0.048	0.085
ODE	0.008	0.040	0.051	0.044	0.132	0.110	0.041	–	0.054	0.033	0.286
OEE	0.031	0.053	0.243	0.078	0.116	0.066	0.172	0.053	–	0.103	0.124
RUS	0.523	0.092	0.040	0.271	0.077	0.020	0.035	0.013	0.045	–	0.015
USA	0.007	0.029	0.246	0.028	0.152	0.139	0.234	0.443	0.187	0.044	–

Source: own estimates in GVAR Toolbox 2.0 based on Trade MAP data.

2.3. GVAR identification and estimation

Basic specification of each country model included five domestic variables (gdp, cpi, ner, nsr, m) treated as endogenous, and a set of exogenous variables constituted by oil prices and foreign variables with exception of exchange rate (oil, $gdpx$, $cpix$, $nsrx$, mx). The different specification was applied only to the USA, as US dollar was used as a benchmark for exchange rates of other currencies. Consequently, US dollar exchange rate in the USA model was introduced as a foreign variable, determined by exogenous factors – currency movements in other countries. Oil prices were treated as exogenous for all countries. Other authors, e.g. Dees, et al. (2007), viewed oil prices as endogenous with respect to the USA. However, the appropriate tests suggest weak exogeneity of oil prices for the USA in the period covered by our dataset.

The GVAR methodology is based on cointegration analysis. Therefore, it is vital that time series are integrated at most of order 1. In many cases authors use real money indicators, real exchange rates, and inflation rate in order to transform $I(2)$ variables into $I(1)$. Unit root tests performed by GVAR Toolbox 2.0 show that almost all domestic variables in our model are $I(1)$. Both Augmented Dickey Fuller (ADF) and Weighted-Symmetric Dickey Fuller (WS) unit root tests show non-stationarity of first differences only in case of cpi in Belarus and broad money (m) in Great Britain. Consumer price index in Belarus has been tested for unit roots numerous times previously (for instance, in Pelipas, Kirchner, 2015). The results suggest that it is $I(1)$ process with multiple structural breaks. Hence, inclusion of Belarus CPI in the model does not affect the quality of the results.[6] Detailed analysis of broad money dynamics in Great Britain is beyond the scope of

[5] Trade flows were retrieved from Trade MAP database.

[6] The problem of structural breaks is not addressed in the GVAR Toolbox due to its complexity. It is believed that the problem is mitigated by usage of foreign variables that may stand for majority of structural breaks in domestic variables.

this study, so we excluded it from the model in order to avoid possible problems related to introduction of non-stationary variable in the short-run dynamics.

Majority of the foreign variables were also non-stationary in levels and stationary in first differences. Exclusions were foreign consumer price index ($cpix$) for eurozone countries, and foreign broad money (mx) for China, Russia and the USA. These variables were excluded from the analysis, which is supported by marginal influence of foreign inflation and money demand on domestic variables in general (see Table 6 below).

Cointegration analysis starts with lag order selection and testing on cointegration rank. Lag structure was selected automatically based on Schwartz Bayesian Criterion with maximum number of lags set to 4 and 2 for domestic and foreign variables respectively. Criterion supposed inclusion of only 1 lag of domestic and foreign variables in country equations specifications. Only model for Belarus included 2 lags of domestic variables. Small number of lags was in fact desirable due to large number of variables and rather short sample used.

Trace tests on cointegration rank, based on specification with unrestricted intercept and restricted deterministic trend in the cointegrating space, demonstrated a rather large number of cointegration vectors. However, properties of the estimated vectors are often poor: the eigenvalues of the model exceed 1 and the shape of persistence profiles (see for details Pesaran, Shin, 1996) reveals slow equilibrium correction in case of shocks on cointegration relations or its absence at all, implying undesirable explosive process. In order to improve specification, we gradually reduced cointegration ranks of the country models until the persistence profiles confirmed convergence of cointegration relations to the equilibrium. This approach was used, for instance, in De Waal, van Eyden (2016). We had to refuse from long-term relations for some countries (see Table 4), as no plausible cointegration relations were estimated by the GVAR Toolbox.[7] In case of Belarus, we chose 3 cointegration relations, as all of them guaranteed at least gradual convergence, while further reduction of relations lead to explosive processes.

Table 4. Country models specification

	Country or group of countries	Lag structure		Cointegration rank
		Domestic variables	Foreign variables	
BLR	Belarus	2	1	3
CEE	Central and Eastern Europe countries	1	1	1
CHN	China	1	1	0
CIS	CIS countries	1	1	1
EUR	Euro-zone countries	1	1	0
GBR	United Kingdom	1	1	1
JPN	Japan	1	1	1
ODE	Other developed market economies	1	1	1
OEE	Other emerging market economies	1	1	1
RUS	Russia	1	1	1
USA	USA	1	1	0

Source: own estimations.

GVAR methodology also demands that all foreign variables are weakly exogenous within the long-run relations. Tests on weak exogeneity of the foreign variables included in the cointegration relations and global variable of oil price reject at 5% significance level hypothesis of week exogeneity only for foreign consumer price index ($cpix$) of Belarus. Hence, this variable was excluded from the final specification (Table 5), which did not affect obtained parameters of cointegration vectors.

[7] Detailed cointegration analysis is possible outside the GVAR package, but it is hindered by large number of variables, and its performance does not correspond to the purposes of our analysis.

Table 5. Final specification of country models

	Domestic variables					Foreign variables					Global variable
	gdp	cpi	ner	nsr	m	$gdpx$	$cpix$	$nerx$	$nsrx$	mx	oil
BLR	1	1	1	1	1	1	0	0	1	1	1
CEE	1	1	1	1	1	1	1	0	1	1	1
CHN	1	1	1	1	1	1	1	0	1	0	1
CIS	1	1	1	1	1	1	1	0	1	1	1
EUR	1	1	1	1	1	1	0	0	1	1	1
GBR	1	1	1	1	0	1	1	0	1	1	1
JPN	1	1	1	1	1	1	1	0	1	1	1
ODE	1	1	1	1	1	1	1	0	1	1	1
OEE	1	1	1	1	1	1	1	0	1	1	1
RUS	1	1	1	1	1	1	1	0	1	0	1
USA	1	1	0	1	1	1	1	1	1	0	1

Note: 1 and 0 means that variable is included in the model or excluded from it.
Source: own estimations.

Estimation of country models enables calculation of contemporaneous effects of foreign variables on their domestic counterparts.[8] According to Dees, et al. (2007) they can be interpreted as impact elasticities between domestic and foreign variables. Positive and statistically significant signs at GDP variable imply that domestic production immediately reacts to changes in foreign GDP. For instance, increase of foreign GDP by 1% leads to Belarusian GDP increase of 0.3%. In Russia and other CIS countries these elasticities are much higher (Table 6), implying their greater dependency on global markets. In fact, they overreact to the changes in foreign GDP, as related elasticities exceed 1. Statistically significant contemporaneous effects for GDP are observed in all countries and regions, which stress significant scale of inter linkages in the world economy and synchronization of business cycles (see Ricci-Risquete, Ramajo-Hernández, 2015). Synchronization is also typical for interest rates in developed economies. Countries with less advanced financial markets are less influenced by changes in global interest rates. Elasticities of Belarusian and Russian short-term interest rates to changes in foreign interest rates are not statistically significant. Other CIS countries show greater synchronization with foreign interest rates and even price dynamics, which is not widely observed.

[8] They are represented by coefficient estimates of the contemporaneous foreign variables in differences in country-specific models.

Table 6. Contemporaneous effects of foreign variables on domestic counterparts

Country/region	Coefficient/t-statistics	gdp	cpi	nsr	m
BLR	coefficient	**0.324**	–	2.214	−0.118
	Newey West t-statistics	4.309	–	1.799	−0.801
CEE	coefficient	**0.635**	**0.324**	0.434	0.145
	Newey West t-statistics	4.733	4.208	1.365	1.082
CHN	coefficient	**0.759**	−0.331	0.224	–
	Newey West t-statistics	2.100	−1.896	1.043	–
CIS	coefficient	**1.816**	**0.300**	**0.821**	**0.427**
	Newey West t-statistics	3.027	2.668	3.041	2.279
EUR	coefficient	**0.874**	–	**0.331**	0.365
	Newey West t-statistics	5.106	–	2.808	1.227
GBR	coefficient	**0.650**	**0.743**	**0.843**	–
	Newey West t-statistics	3.010	6.066	3.581	–
JPN	coefficient	**1.046**	0.201	**0.081**	**−0.279**
	Newey West t-statistics	3.442	1.064	2.544	−2.466
ODE	coefficient	**0.749**	0.694	**0.603**	**0.320**
	Newey West t-statistics	9.566	7.064	5.898	2.190
OEE	coefficient	**0.364**	**0.602**	0.796	0.301
	Newey West t-statistics	3.053	2.462	1.477	1.490
RUS	coefficient	**1.658**	3.141	0.156	–
	Newey West t-statistics	6.213	1.523	0.583	–
USA	coefficient	**0.425**	**0.599**	**0.841**	–
	Newey West t-statistics	2.908	4.379	3.260	–

Note: Bold font denotes statistically significant coefficients.
Source: own estimations.

3. Shocking the Belarusian economy: GVAR model results

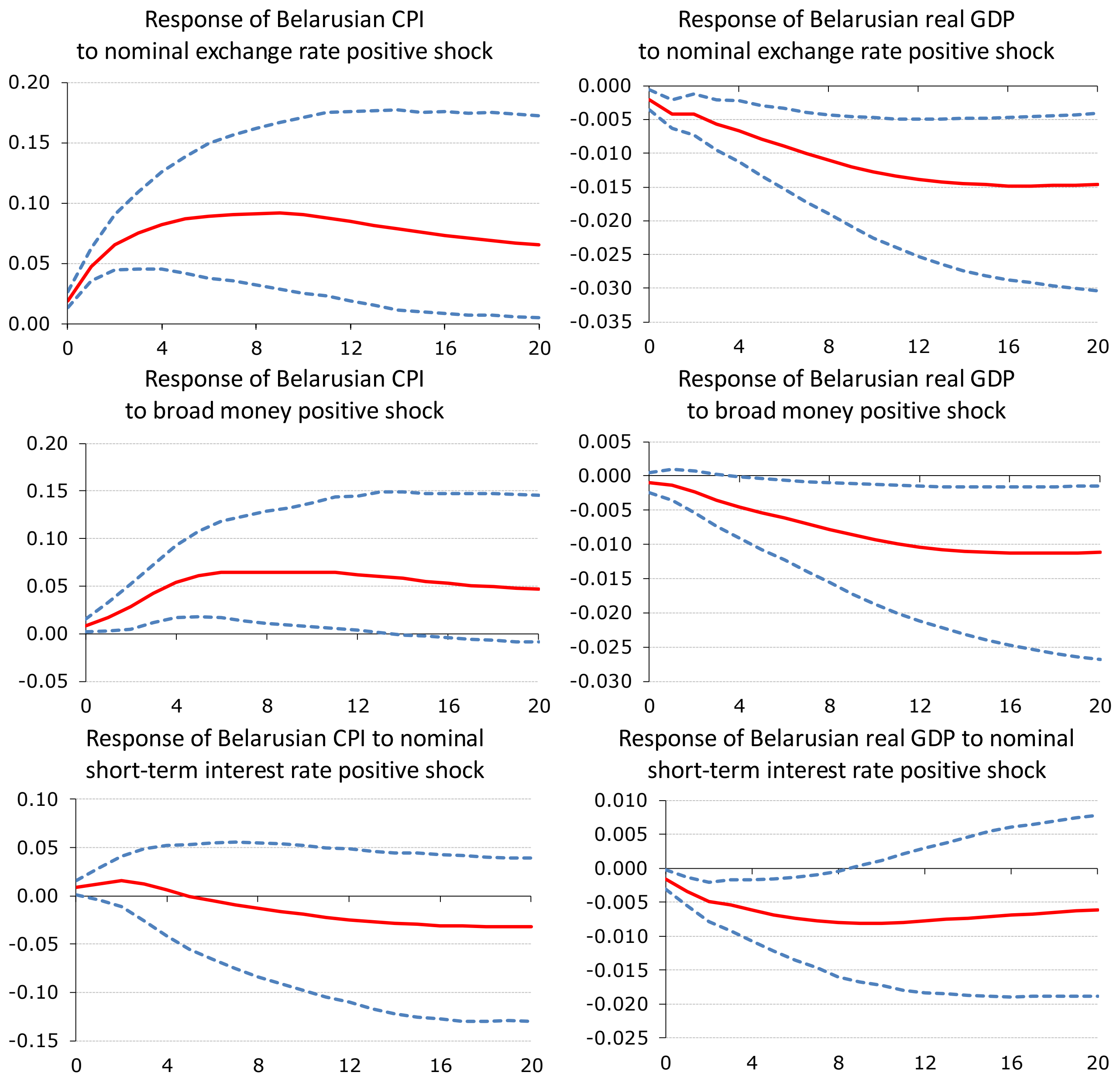
3.1. Evidence from a large scale GVAR model

Estimated GVAR model is designed to analyze exposure of Belarus to external shocks interrelated with global and regional economic trends by means of impulse response functions. We will employ generalized impulse response functions that do not demand identification of structural shocks, which is an overwhelming task in the GVAR context.

Belarusian internal shocks. Except external shocks analysis, GVAR model can be applied to analyze domestic shocks accounting for global environment. Results of the GVAR model in respect to Belarusian domestic shocks largely coincide with theoretical expectations. First, they show interrelation between exchange rate and inflation. Negative shock of Belarusian ruble depreciation is accompanied by statistically significant price increase (see Figure 1). Devaluation of national currency by its 1 standard deviation is associated with contemporaneous inflation of 2%, accelerating up to 8% within a year period. Negative shock of exchange rate is also interrelated with GDP reduction. Statistically significant effect of national currency devaluation (by 1 standard deviation) on output dynamics holds in time, although its scale is less pronounced then in case of inflation.

Second, broad money (M3) increase is also interrelated with inflation and economic contraction. Positive money supply shock may have a positive short-term effect over economic growth, but inevitably creates inflation pressure. However, high inflation expectations and dollarization make stimulation effect of money increase irrelevant for Belarus. Positive money shock is associated only with reduction of GDP in the long-term period. It also leads to statistically significant price increase that loses its effect only in 3 years.

Figure 1. Impact of domestic shocks on Belarusian macroeconomic variables



Note: Red solid line represents bootstrap median estimates of the generalized impulse response function (GIRF) of appropriate variable due to positive one standard deviation shock of Belarusian ruble nominal exchange rate, broad money (M3) or short-term interest rate. GIRF is calculated by a standard bootstrap procedure with 2000 replications. Blue dashed lines depict 90% bootstrap confidence intervals.
Source: own estimates.

Third, interest rates have little influence on inflation. Increase of the short-term interest rates has no statistical effect on CPI, which reflects weak effectiveness of interest rate channel of monetary transmission in Belarus. Still positive interest rate shock is accompanied by GDP reduction. Statistically significant effect holds for 2 years, illustrating interest rates influence on investments. Profiles of impulse responses suggest satisfactory quality of the GVAR model in describing macroeconomic linkages in Belarus. It provides ground to move to analysis of mechanisms of external shocks propagation in Belarus.

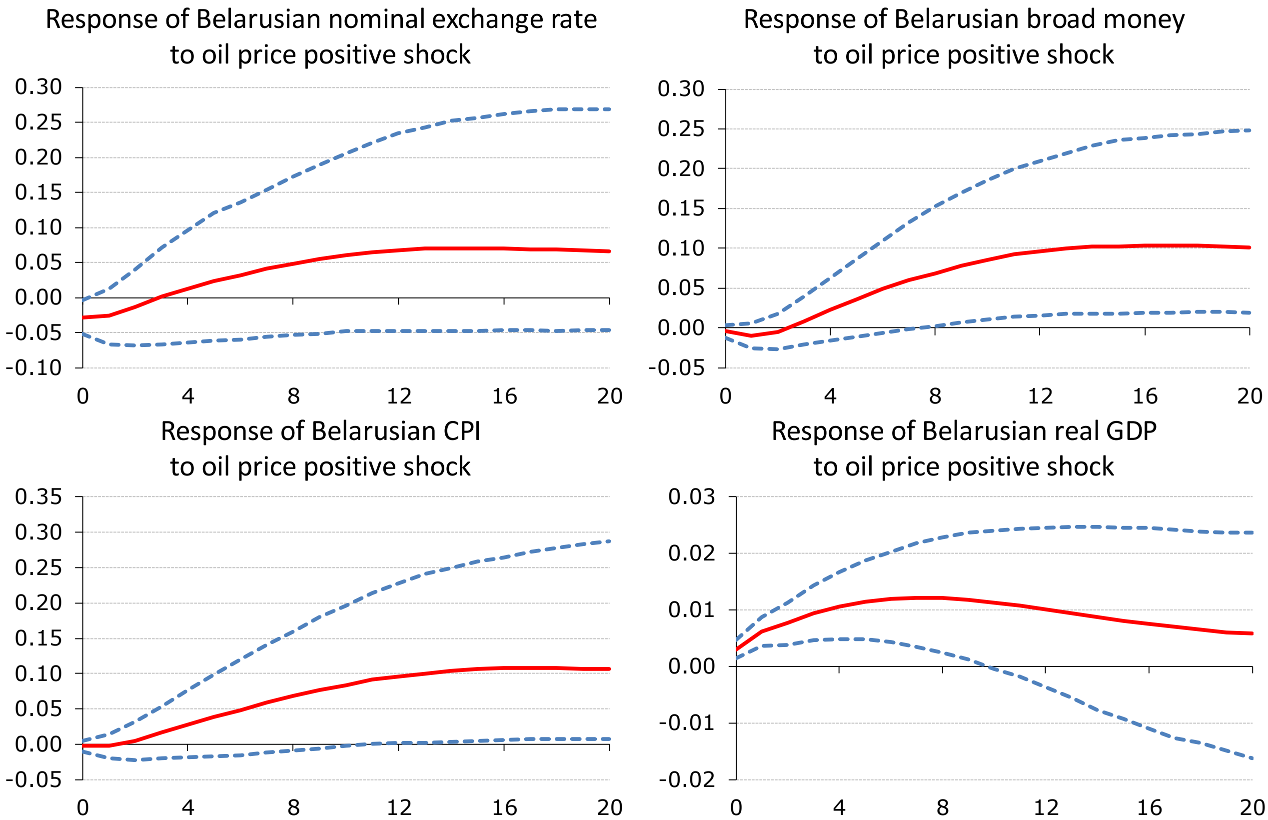
<u>External shocks: Oil price</u>. Oil price dynamics is often considered to be crucial for GDP growth in Belarus. In fact oil price and GDP they have been following similar paths in the recent years.[9] Belarus produces margin-

[9] See illustrations in Movchan (2016). On the verge of the new economic cycle – how to set up for the failure, and how not to, presented at the KEF conference “Reforms for Inclusive Growth”, Minsk, November 3-4, 2016, http://kef.research.by/webroot/delivery/files/kef-2016-slides/rusD1P1S4_KEF2016_Movchan_.pdf.

al amount of oil, but it benefits from low prices on energy goods imported from Russia. Besides, potash is important export good for Belarus and its prices correlate with prices on other raw and energy goods. Furthermore, Russia and other CIS countries that are key Belarus trade partners on great extent rely on raw and energy goods production. It implies that oil prices determine the stance of the key markets of Belarusian products. Hence, oil price dynamics influences Belarusian macroeconomic variables through numerous channels. Impulse response functions of the shock to oil prices in the GVAR model largely support this view.

Positive oil price shock (by 1 standard deviation, which equals to 15% price increase) is accompanied by real GDP increase (1% by the end of the year; see Figure 2). This effect remains statistically significant up to three years. The similar scale of GDP increase due to rise in oil price is observed in Russia and other CIS countries (see Annex, Figure A1). However, in case of Russia this effect is more persistent than in Belarus and other CIS countries.

Figure 2. Impact of oil prices shock on Belarusian macroeconomic variables



Note: Red solid line represents bootstrap median estimates of the generalized impulse response function (GIRF) of appropriate variable due to positive one standard deviation oil price shock. GIRF is calculated by a standard bootstrap procedure with 2000 replications. Blue dashed lines depict 90% bootstrap confidence intervals.
Source: own estimates.

On contrary, economic growth of developed countries is not interrelated with oil prices, as reaction of GDP of the USA, Japan, European countries on shock to oil prices is statistically close to zero. However, oil price dynamics influences price level of developed economies through increased production costs. In CIS countries, this effect is not observed as increase of world prices on energy goods does not necessary results in increase of domestic prices on these goods. Only Belarus faces inflation in the aftermath of positive oil price shock with 3 years delay. This inflation is a result of broad money increase that gradually accumulates within 4 years after the shock. It can be interpreted in a way that positive external environment allows for softer monetary policy that creates inflation pressure in a long-run when effect of oil price increase over GDP begins to melt down.

In Russia and other CIS countries oil price increase leads also to national currency appreciation due to improved terms of trade. This effect does not hold for a long time, as additional export revenues provide ground to domestic consumption and import increase, which neutralizes effect over exchange rate. Moreover, other national currencies also appreciate in relation to US dollar as a result of oil price shock. It is related to the fact that oil prices are nominated in US dollars. Hence, oil price dynamics is inversely related to US dollar exchange rate. In this regard, an absence of statistically significant reaction of Belarusian ruble to oil price shock looks controversial. It may be rooted in a long period of fixed exchange rate regime when ruble was actually pegged to dollar. Another explanation may by misspecification of the model related to the correlation of external shocks, in particular oil price and Russian GDP[10] or exchange rate. This assumption will be checked by construction of alternative to GVAR models, capturing external factor influence on monetary transmission mechanism in Belarus (see section 4).

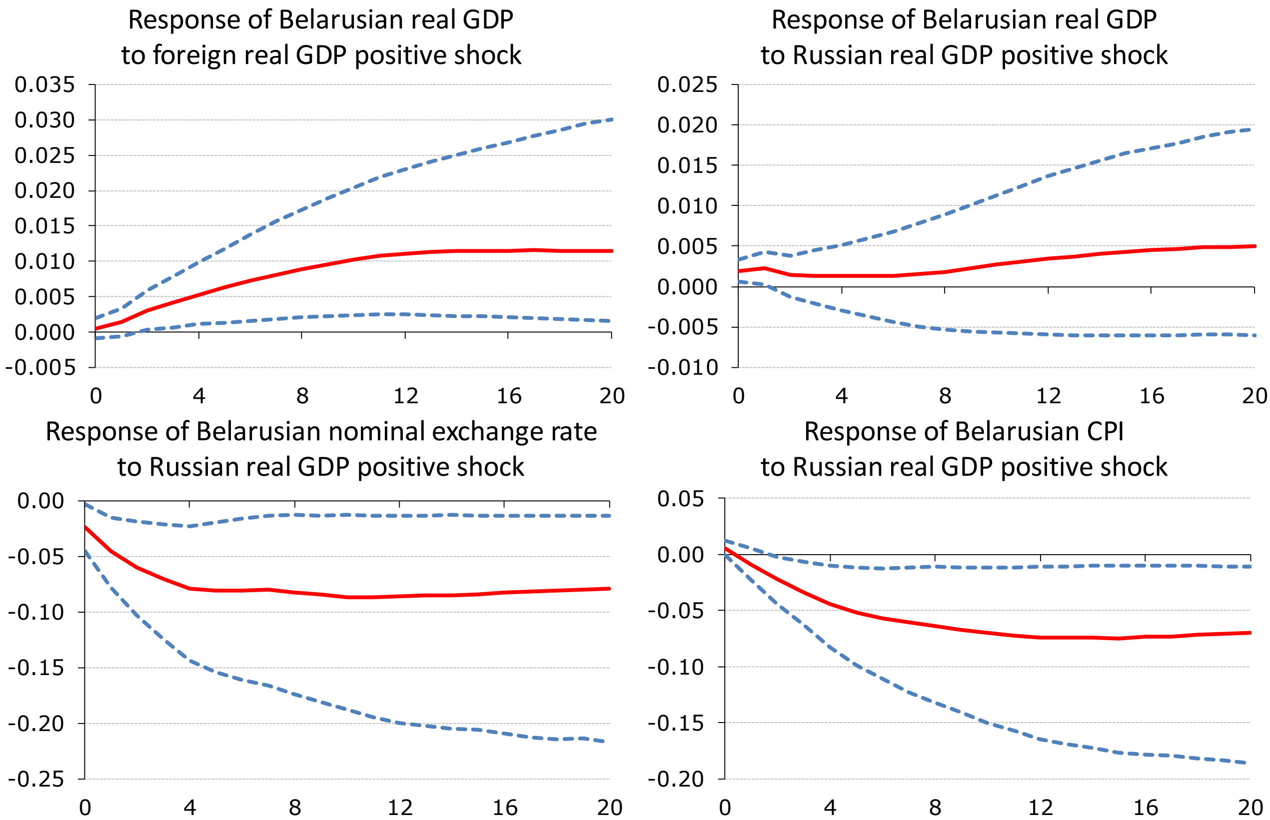
External shocks: World and Russia. Analysis of contemporaneous effects of foreign GDP on domestic GDP revealed low elasticity between these variables in Belarus if compared to other countries. Impulse response functions prove that the scale at which Belarusian GDP reacts to shock in GDP of its trade partners is rather limited in the short-run, although statistically significant in the long-run (Figure 3). It takes 3 years until effect of foreign GDP shock on Belarus GDP reaches the level typical for the CIS region (see Annex, Figure A3). This slow and constrained model reaction may be rooted in a long period when economic growth of Belarus was determined by domestic demand. However, the stance of the Russian market has always played an important role for Belarus' economic growth. The share of Russia in the weight matrix for Belarus' foreign variables exceeds 50%, stressing that trade with Russia accounts for half of Belarusian foreign trade. Contrary to this intuition, the model shows that a shock of Russian GDP influences economic growth rates in Belarus only marginally within a half-year period. For other CIS countries this effect is more distinct, but it also diminishes within a year (see Annex, Figure A2). Again, it is probably related to close linkages of Russian GDP and oil prices. Hence, Russian GDP shock in our specification is actually embodied in oil price shock. In order to analyze it explicitly we will estimate SVAR model in section 4.

According to the model, positive Russian GDP shock has effect over exchange rate and inflation in Belarus. Growth of Belarus exports related to increased Russian market leads to Belarusian ruble appreciation. Consequently, monetary transmission channel of exchange rate guarantees price level reduction. Recently, opposite situation has been more relevant. Negative shock of Russian GDP contraction boils down to depreciation of Belarusian ruble and consumer prices increase in Belarus.

Beside economic growth, changes in exchange rate of Russian ruble also influence macroeconomic situation in Belarus. According to the GVAR model results, shock of Russian ruble depreciation by 7.7% leads to 5% depreciation of Belarusian ruble in the short-run (Figure 4). Consequently, exchange rate transmission channel generates inflation pressure, which is illustrated by statistically significant price increase in the first year after shock to exchange rate of Russian ruble. For other national currencies in the CIS region effect of Russian ruble depreciation is slightly less pronounced, although statistical significant and persistent (see Annex, Figure A2).

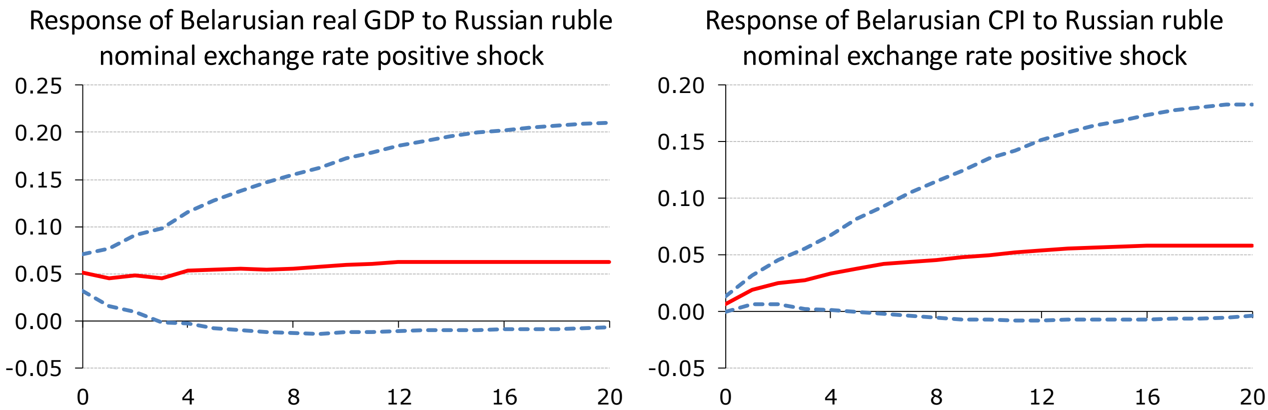
[10] See graphical illustration of oil price and Russian GDP correlation in Klepach (2016). Russian economy: Prospects for recovery, prospects for sustained growth, presented at the KEF conference "Reforms for Inclusive Growth", Minsk, November 3-4, 2016 http://kef.research.by/webroot/delivery/files/kef-2016-slides/rusD1P1S3_KEF2016_Klepach.pdf.

Figure 3. Impact of foreign and Russian GDP shocks on Belarusian macroeconomic variables



Note: Red solid line represents bootstrap median estimates of the generalized impulse response function (GIRF) of appropriate variable due to positive one standard deviation shock of foreign or Russian real GDP. GIRF is calculated by a standard bootstrap procedure with 2000 replications. Blue dashed lines depict 90% bootstrap confidence intervals.
Source: own estimates.

Figure 4. Impact of Russian ruble exchange rate shock on Belarusian macroeconomic variables



Note: Red solid line represents bootstrap median estimates of the generalized impulse response function (GIRF) of appropriate variable due to positive one standard deviation shock of Russian ruble nominal exchange rate. GIRF is calculated by a standard bootstrap procedure with 2000 replications. Blue dashed lines depict 90% bootstrap confidence intervals.
Source: own estimates.

Other external shocks, including the US, Eurozone, China GDP growth, as well as the US interest rates increase do not influence macroeconomic variables of Belarus, and CIS region in general. These results suggest that analysis of external shocks on Belarus economy may be limited to oil prices and development of the CIS (EAEU) region. In regard of GVAR analysis, it implies that the model can be reduced to the regional level without significant loss of information (see the next sub-section).

3.2. Evidence from a small EAEU GVAR model

In order to check whether regional model can be sufficient to analyze influence of external shocks on Belarus economy we constructed GVAR model for 5 countries of EAEU (Armenia, Belarus, Kazakhstan, Kyrgyzstan and Russia). We used the same variables and data in order to maintain consistency in analysis, although regional approach substantially simplifies data collection and provides opportunity for more detailed analysis of domestic economic interrelation. So, we use real GDP, consumer price index, nominal exchange rate, short-term rate and broad money as domestic variables. Weakly exogenous variables were limited to foreign GDP, consumer price index, and nominal exchange rate. They were calculated as weighted average for EEU countries based on intra-regional trade flows. Foreign broad money and short-term interest rates were excluded from the model as monetary aggregates and interest rates of EEU countries hardly influence economic development of regional partners as they often have only moderate effect over domestic economy. Besides, we supposed that Russian indicators were not influenced by inflation and exchange rate dynamics of other EEU countries. Reduced number of foreign variables provided space for inclusion of several global variables into the model. In addition to oil prices, we included into the model the GDP of China, GDP of the USA/Eurozone and interest rates of the USA, assuming an impact of these variables on the global economy.

All variables are integrated of order 1, according to the ADF and WS unit-root tests. Hence, no adjustment to the model was required for VEC analysis. Its specification included unrestricted intercept coefficients in levels and restricted deterministic trend coefficients in the cointegrating space. The number of lags for endogenous and exogenous variables was set to 1, following the Schwartz Bayesian criterion (SBC). Initial cointegration rank was estimated at the level of 4 for most of the countries (except Kazakhstan, where rank according to trace statistics was equal to 3). However, adequate persistence profiles of cointegration vectors were achieved only after reduction of cointegration rank to 2 in all countries. This specification required adjustment of Belarusian model, as tests rejected hypothesis of weak exogeneity of foreign consumer price index for Belarus. Hence, only foreign GDP and the exchange rate among regional variables had a direct influence on Belarusian domestic macroeconomic variables in the final specification of the model (Table 7).

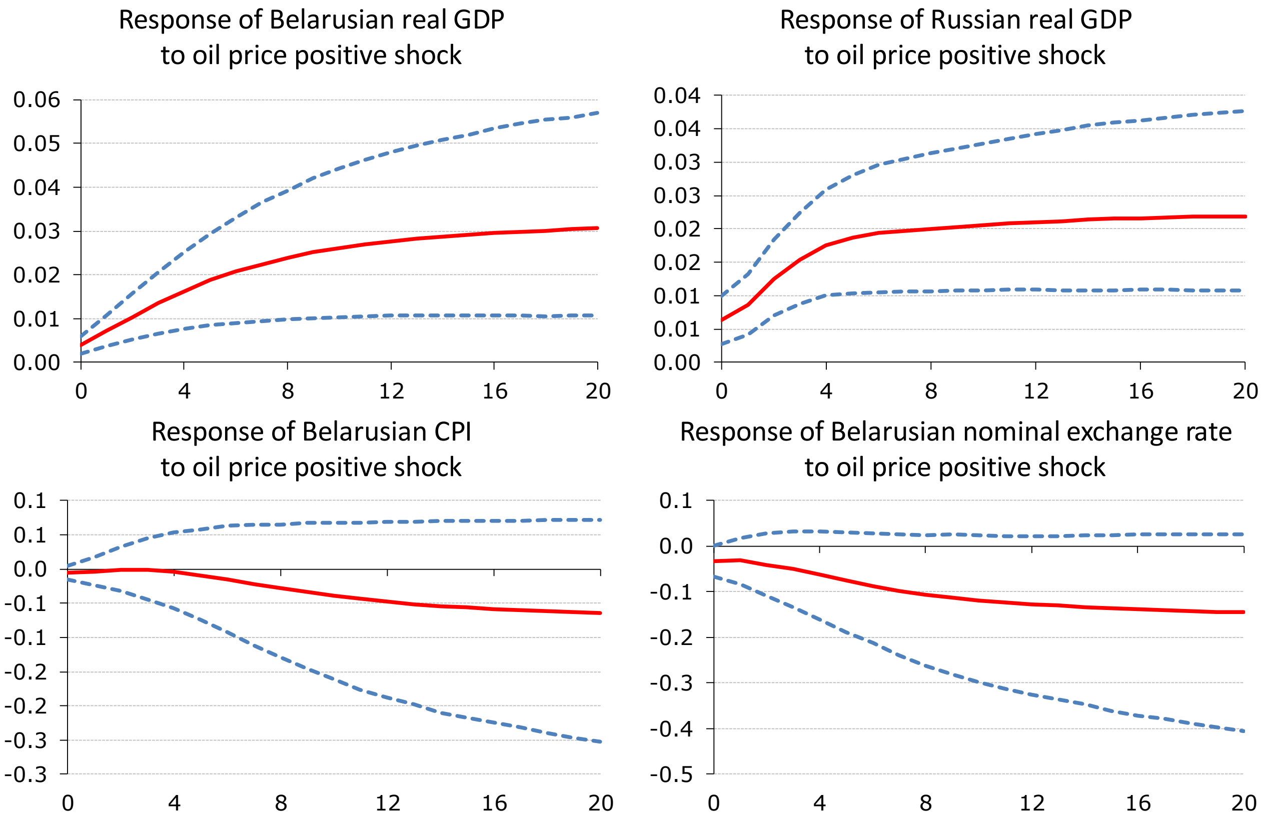
Table 7. Final specification of country models in the GVAR for EAEU region

EAEU	Foreign variables			Global variables				Lag order		Rank order
	$gdpx$	$cpix$	$nerx$	oil	gdp^{us}	gdp^{chn}	nsr^{us}	domestic variables	foreign variables	
arm	1	1	1	1	1	1	1	1	1	2
blr	1	0	1	1	1	1	1	1	1	2
kaz	1	1	1	1	1	1	1	1	1	2
kgz	1	1	1	1	1	1	1	1	1	2
rus	1	0	0	1	1	1	1	1	1	2

Note: Domestic variables are gdp, cpi, ner, nsr, m for all countries. Global variables were included into the model as dominant unit (see Chudik, Pesaran, 2014) and its VAR specification assumed no cointegration between variables, absence of feedback reaction from domestic variables, and included only 1 lag of global variables.
Source: own estimates.

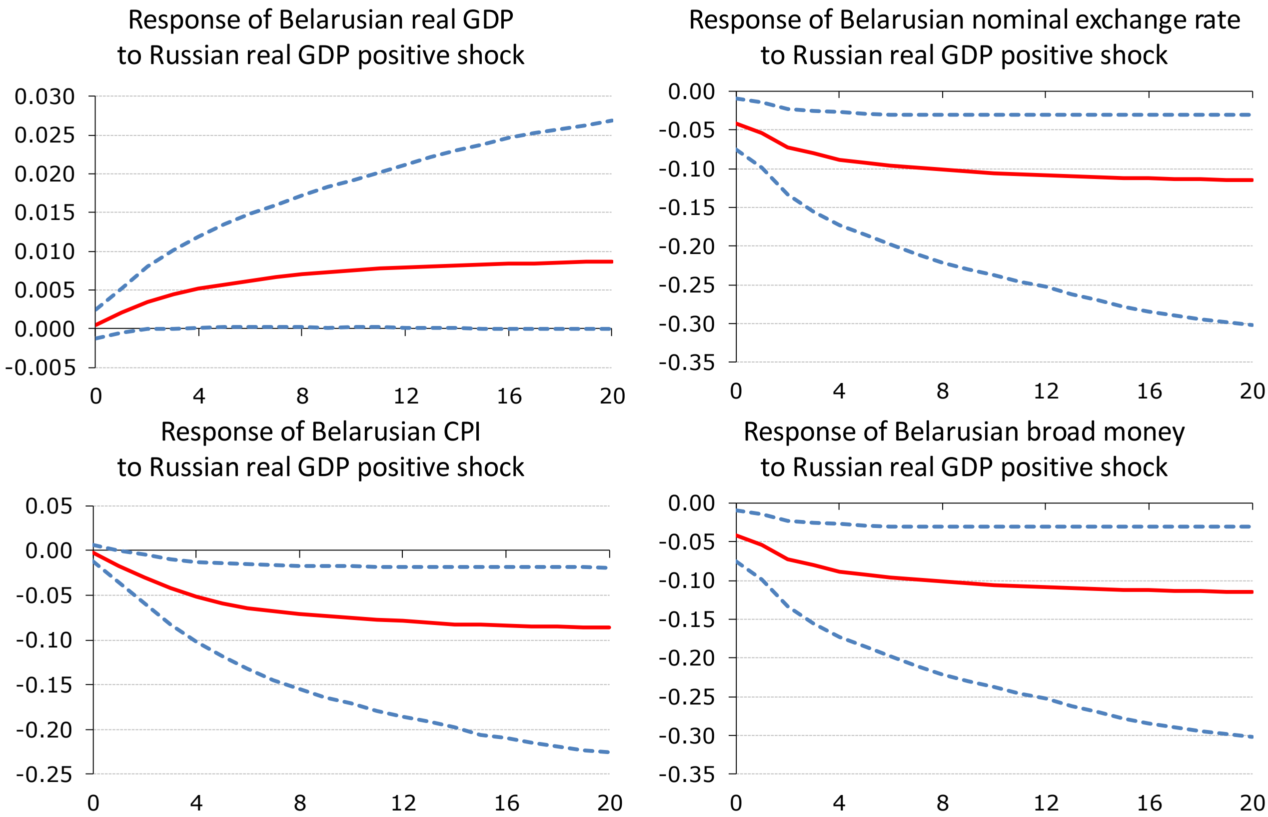
Dynamic analysis by means of the GVAR-EAEU model shows similar results to a large world-wide model. The shock of an oil price increase has a positive effect on economic growth in Belarus that is sustainable in the long-run (Figure 5). The oil price increase implies a terms of trade improvement for Belarus, but it does result in appreciation of the Belarusian ruble and has no impact on the price level. In other EAEU countries, the effect of the oil price shock on the exchange rate is statistically significant, which fully corresponds to the results of the world-wide model.

Figure 5. Impact of oil prices shock on Belarusian macroeconomic variables and Russian real GDP: EAEU model



Note: Red solid line represents bootstrap median estimates of the generalized impulse response function (GIRF) of appropriate variable due to positive one standard deviation oil price shock. GIRF is calculated by a standard bootstrap procedure with 2000 replications. Blue dashed lines depict 90% bootstrap confidence intervals.
Source: own estimates.

Figure 6. Impact of Russian GDP shock on Belarusian macroeconomic variables: EAEU model

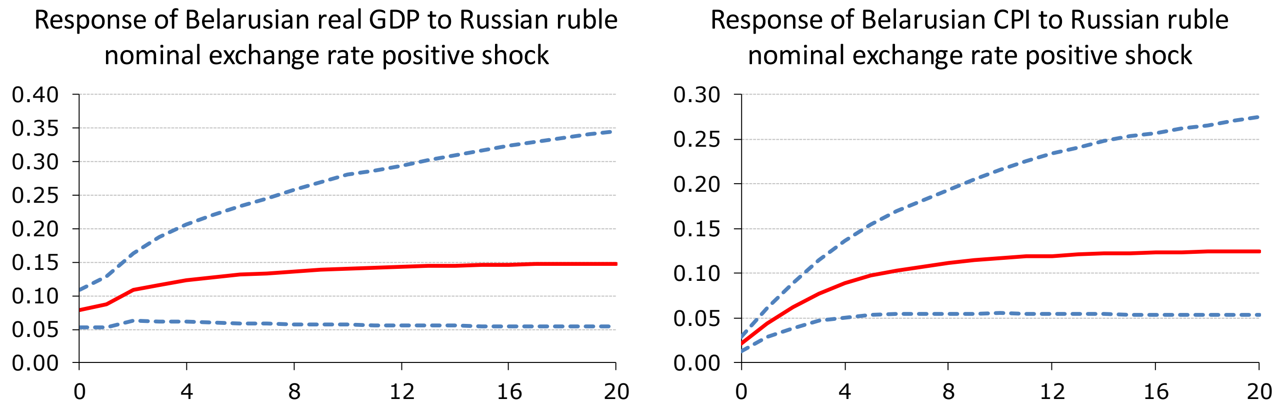


Note: Red solid line represents bootstrap median estimates of the generalized impulse response function (GIRF) of appropriate variable due to positive one standard deviation shock of Russian real GDP. GIRF is calculated by a standard bootstrap procedure with 2000 replications. Blue dashed lines depict 90% bootstrap confidence intervals.
Source: own estimates.

A positive shock of Russian GDP, contrary to the oil price shock, is associated with Belarusian ruble appreciation and related fall in broad money and price level (see Figure 6). Belarusian inflation and ruble exchange rate are also exposed to shocks in Russian ruble exchange rate (see Figure 7). At the same time, impact that Russian GDP has on economic growth in Belarus is only marginally significant. These results also coincide with the results of the world-wide model. However, they appear to be counterintuitive in respect of oil price and Russian GDP impact on economic growth in Belarus.

According to theoretical considerations and results of previous research, oil price shock should affect Belarusian economy largely through its impact on Russian economy. Hence, Belarus is more dependent on Russian economic growth rather than oil prices themselves. But the GVAR world-wide and EAEU models suggest the opposite. In fact, the elasticity of Belarus' GDP on oil prices appears to be higher than in Russia (see Figure 5). At the same time, the reaction of Belarus' GDP to changes of the GDP of other CEE countries is less pronounced than the reaction of Russian GDP. Contemporaneous effect of foreign GDP change by 1% on domestic GDP is 0.22% in Belarus and 0.77% in Russia. This contradiction may be explained by correlation of oil prices and Russian GDP, which affects quality of the results if they are both included in a country model. Exclusion of oil prices from GVAR model results in impulse response functions of Belarusian macroeconomic variables on Russian GDP that corresponds to theoretical expectations, but it inevitably affects overall quality of GVAR model. In this regard, a country SVAR model can provide better results than the GVAR model.

Figure 7. Impact of Russian ruble exchange rate shock on Belarusian macroeconomic variables: EAEU model



Note: Red solid line represents bootstrap median estimates of the generalized impulse response function (GIRF) of appropriate variable due to positive one standard deviation shock of Russian ruble nominal exchange rate. GIRF is calculated by a standard bootstrap procedure with 2000 replications. Blue dashed lines depict 90% bootstrap confidence intervals.
Source: own estimates.

4. Single country SVAR vs. GVAR: Is there a difference?

In this section we compare the impulse responses coming from GVAR models presented above with the results obtained from standard SVAR model, augmented with some relevant exogenous variables. The results from the GVAR modeling may be used in SVAR model: we can include in the model weighted foreign variables and individual foreign variables as well. This provides necessary flexibility in the construction of the SVAR model with different types of exogenous variables and permits analyzing of various kinds of external shocks. In SVAR model exogenous variables are usually included in the form of additional X-variables that taking into account the contemporaneous effects and lagged structure. In this case, it is impossible to obtain the corresponding impulse responses of endogenous variables while shocking the exogenous variables (one can only use dynamic multipliers, which are not directly comparable with the impulse response functions). In this paper a different approach has been used. Initially, all variables of interest were included in unrestricted VAR model as endogenous and then necessary restrictions on lag structure were imposed to make the variables considered as external exogenous relative to domestic endogenous variables.

Further, we consider the SVAR model with exogenous variables in the context of monetary transmission mechanism analysis in Belarus. Based on traditional approaches to the analysis of the transmission mechanism of monetary policy (see Mishra, Montiel, 2013), the SVAR models usually include the following set of variables: 1) target variables (for example, real GDP and CPI), 2) operational monetary policy targets (e.g., interest rate of the central bank, the monetary base, the exchange rate), and 3) intermediate targets (e.g., monetary aggregates), 4) external variables (e.g., world oil prices). In Belarus, the monetary policy targets have changed over time from exchange rate targeting in the recent past to currently introduced monetary targeting. Therefore, the exchange rate can be considered in the SVAR model as the operating target, and as a variable, which characterizes the openness of the economy as well (especially in the floating exchange rate regime). In addition, the economy of Belarus has strong economic and political ties with the Russian economy, so economic situation in Russia has a strong impact on Belarusian economy. Thus, Russian real GDP or weighted real GDP could be a relevant exogenous variable in the model. Additionally, nominal exchange rate of Russian ruble is also very important variable for the Belarusian economy and should enter into the SVAR model. The price of oil is also a crucial exogenous variable for Belarus.

Before specification of the SVAR model, we replaced some variables in comparison with the GVAR models, namely nominal short-term interest rate (nsr) has been replaced by nominal refinancing rate ($NIRR$) and broad money (m) has been replaced by monetary base (mb).[11] This replacement is needed to take into account current monetary targeting regime in Belarus, analyzed in Pelipas, Kirchner (2015).[12]

Taking into account the above-mentioned considerations, we estimated the SVAR models for the analysis of monetary transmission channels in Belarus with the following five endogenous variables: nominal refinancing rate ($NIRR$), the monetary base (mb),[13] the real GDP ($rgdp$), the consumer price index (cpi) and the nominal exchange rate of the Belarusian ruble against the US dollar (ner). Three exogenous variables included in the SVAR model are as follows: oil prices (oil), weighted foreign real DGP ($gdpx$) and nominal exchange rate of Russian ruble against the US dollar (ner^{ru}). All variables except $NIRR$ were expressed as natural logarithms.

We use the following strategy while specifying and estimating the SVAR model:

1) Initially, unrestricted VAR with potentially exogenous variables is used. Then the appropriate restrictions are imposed on lag structure of the unrestricted VAR so to make these variables exogenous in relation to the rest of the system. In this case endogenous variables cannot affect endogenous variables, while exogenous variable can be part of the system. This trick permits us to use exogenous variables in impulse response analysis.

In the SVAR model we use the logarithmic levels of variables, which are non-stationary with the order of integration *I*(1), Such an approach is common in the literature, and based on Sims, Stock, Watson (1990), where authors showed the possibility of using non-stationary (with unit root) and potentially cointegrated variables in the VAR models. Since our objective is to analyze the response of some variables on the other variables shocks, such an approach seems justified, and the usage of non-stationary variables the levels (instead of their first differences) allows taking into consideration implicitly the potential cointegration between the analyzed variables.

After estimation of the VAR model with the restriction on lag structure for exogenous variables, identification restriction on the matrix of short-run contemporaneous effects is imposed in order to isolate individual shocks and make them structural (SVAR). For these purposes, **AB**-type model is used (see Breitung, Bruggemann, Lutkepohl, 2004).

2) An important procedure in the framework of the SVAR model is the identification of the matrix of short-run contemporaneous effects. Typically, a recursive identification scheme or one based on economic theory is used. In the first case it is generally assumed that the more exogenous variables are put first and the more endogenous variables put last that can lead to ambiguity and arbitrariness in the identification of SVAR model. In the second case, restrictions are set on the basis of economic theory (see Kim, Roubini, 2000). It should be noted, that the imposition of restrictions based on economic theory (both recursive and non-recursive identification schemes), is not always acceptable from a statistical point of view. This means that restrictions can be rejected on the basis of statistical tests, or many of the estimated coefficients in the matrix of short-run contemporaneous effects can be statistically insignificant.

This problem can be solved by using formal statistical methods based on graph theory to identify the SVAR model (see Demiralp, Hoover, 2003; Hoover, Demiralp, Perez, 2009). In this case, the identification is based on the correlation/covariance matrix of VAR residuals and the algorithms for constructing Directed Acyclic Graphs (Spirtes, Glymour, Scheines, 2000). This approach allows to identify statistically significant contemporaneous causal relationships between variables and to carry out the identification of SVAR model based on the real properties of the data used. It is important that the use of a Directed Acyclic Graphs (DAG), as a rule, allows obtaining statistically significant coefficients of the matrix of short-run contemporaneous effects while identifying the SVAR model.[14]

3) On the basis of the identified SVAR models, it is possible to determine the effect of orthogonal (structural) shocks. Such analysis is carried out on the basis of the impulse response functions. To assess the signifi-

[11] The monetary base variable was seasonally adjusted, using JDemetra+ software.
[12] The monetary transmission mechanism in Belarus is discussed in Mironchik (2015) and Bezborodova, Mikhalionok (2015).
[13] The usage of monetary aggregates M1 and M2 gives similar results. Inclusion of M3 (where deposits in foreign currencies are dominated in Belarusian rubles) in the SVAR model leads to counterintuitive results (M3 growth leads to CPI reduction).
[14] We use TETRAD 5.3.0-0 software for GAD construction, http://www.phil.cmu.edu/tetrad/.

cance of the impact of the shocks we used confidence intervals obtained using the bootstrap method. This approach is particularly relevant when using SVAR models in levels, where statistical conclusions based on the asymptotic behavior can be problematic. The SVAR estimation and impulse response analysis is performed with using econometric software JMulTi 2.24.[15]

Table 8. SVAR: non-recursive identification scheme

(1) Inclusion of exogenous variables: restrictions on lag structure

$$
\begin{bmatrix} oil(t) \\ gdpx(t) \\ nerru(t) \\ NIRR(t) \\ mb(t) \\ gdp(t) \\ cpi(t) \\ ner(t) \end{bmatrix}
=
\begin{bmatrix}
* & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
* & * & 0 & 0 & 0 & 0 & 0 & 0 \\
* & * & * & 0 & 0 & 0 & 0 & 0 \\
* & * & * & * & * & * & * & * \\
* & * & * & * & * & * & * & * \\
* & * & * & * & * & * & * & * \\
* & * & * & * & * & * & * & * \\
* & * & * & * & * & * & * & *
\end{bmatrix}
\begin{bmatrix} oil(t-1) \\ gdpx(t-1) \\ nerru(t-1) \\ NIRR(t-1) \\ mb(t-1) \\ gdp(t-1) \\ cpi(t-1) \\ ner(t-1) \end{bmatrix}
+
\begin{bmatrix}
* & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
* & * & 0 & 0 & 0 & 0 & 0 & 0 \\
* & * & * & 0 & 0 & 0 & 0 & 0 \\
* & * & * & * & * & * & * & * \\
* & * & * & * & * & * & * & * \\
* & * & * & * & * & * & * & * \\
* & * & * & * & * & * & * & * \\
* & * & * & * & * & * & * & *
\end{bmatrix}
\begin{bmatrix} oil(t-2) \\ gdpx(t-2) \\ nerru(t-2) \\ NIRR(t-2) \\ mb(t-2) \\ gdp(t-2) \\ cpi(t-2) \\ ner(t-2) \end{bmatrix}
+
\begin{bmatrix} * \\ * \\ * \\ * \\ * \\ * \\ * \\ * \end{bmatrix}
\begin{bmatrix} CONST \end{bmatrix}
$$

(2) Structural shocks identification

restriction on A matrix

oil	gdpx	nerru	NIRR	mb	gdp	cpi	ner
1	0	0	0	0	0	0	0
*	1	0	0	0	0	0	0
*	0	1	0	0	0	0	0
0	0	0	1	0	0	0	0
0	*	0	0	1	0	0	0
*	*	0	0	0	1	0	0
0	*	*	*	0	0	1	*
0	0	*	0	0	0	0	1

restriction on B matrix

oil	gdpx	nerru	NIRR	mb	gdp	cpi	ner
*	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	0	0	0	0	*	0	0
0	0	0	0	0	0	*	0
0	0	0	0	0	0	0	*

(3) SVAR over-identification LR test: $\chi^2(18)$ = 19.4054 (p = 0.3673)

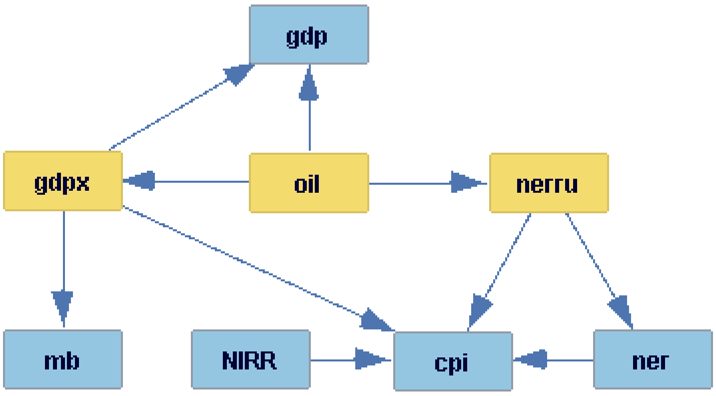
*Note: * means freely estimated parameter; 0 is imposed zero restriction; CONST is a constant.*
Source: Compiled and estimated by the authors using JMulTi 4.24 software.

In the first part of Table 8, the restriction on the lag structure of the SVAR model is presented. As one can see, the oil price is the most exogenous variable in the system. It influences all other variables, whereas these variables have no effect on variable oil. The second near exogenous variable is foreign real GDP. This variable is exogenous related to all variables except oil, that can affect $gdpx$. The third near exogenous variable is nominal exchange rate of Russian ruble. This variable is exogenous related to all variables except oil and $gdpx$. All other variables are domestic; they are endogenous and can interact with each other.

The model includes a constant (trend variables appeared to be statistically insignificant in all equations and were excluded from the model). To be more or less comparable with the lag structure of the GVAR models, we choose two lags. In such a specification the SVAR model suffers from residual autocorrelation. However, inclusion of one additional lag solves the problem but the final results (impulse response function) in fact are similar for model with 2 or 3 lags. Therefore, we preferred a more parsimonious model, which is more comparable with the GVAR model discussed earlier.

[15] http://www.jmulti.de/.

Figure 8. Directed acyclic graph (DAG) for SVAR model



Note: exogenous and variables endogenous variables are marked in yellow and blue respectively.
Source: compiled and estimated by the authors using Tetrad 5.3.0-0 software.

An identification of the SVAR model has been done on the basis of DAG. The CPC method was used in the TETRAD software with parameter ∝ = 0.2.[16] It should be noted that in our case algorithms delivers inter linkages among variables but does not discover all necessary directions. Since we have in the model three exogenous variables, this permits us to determine all casual short-run contemporaneous effects, using the following rule: Endogenous variables cannot cause exogenous variables but exogenous can affect both endogenous and near exogenous variables. The final results are depicted in Figure 8.

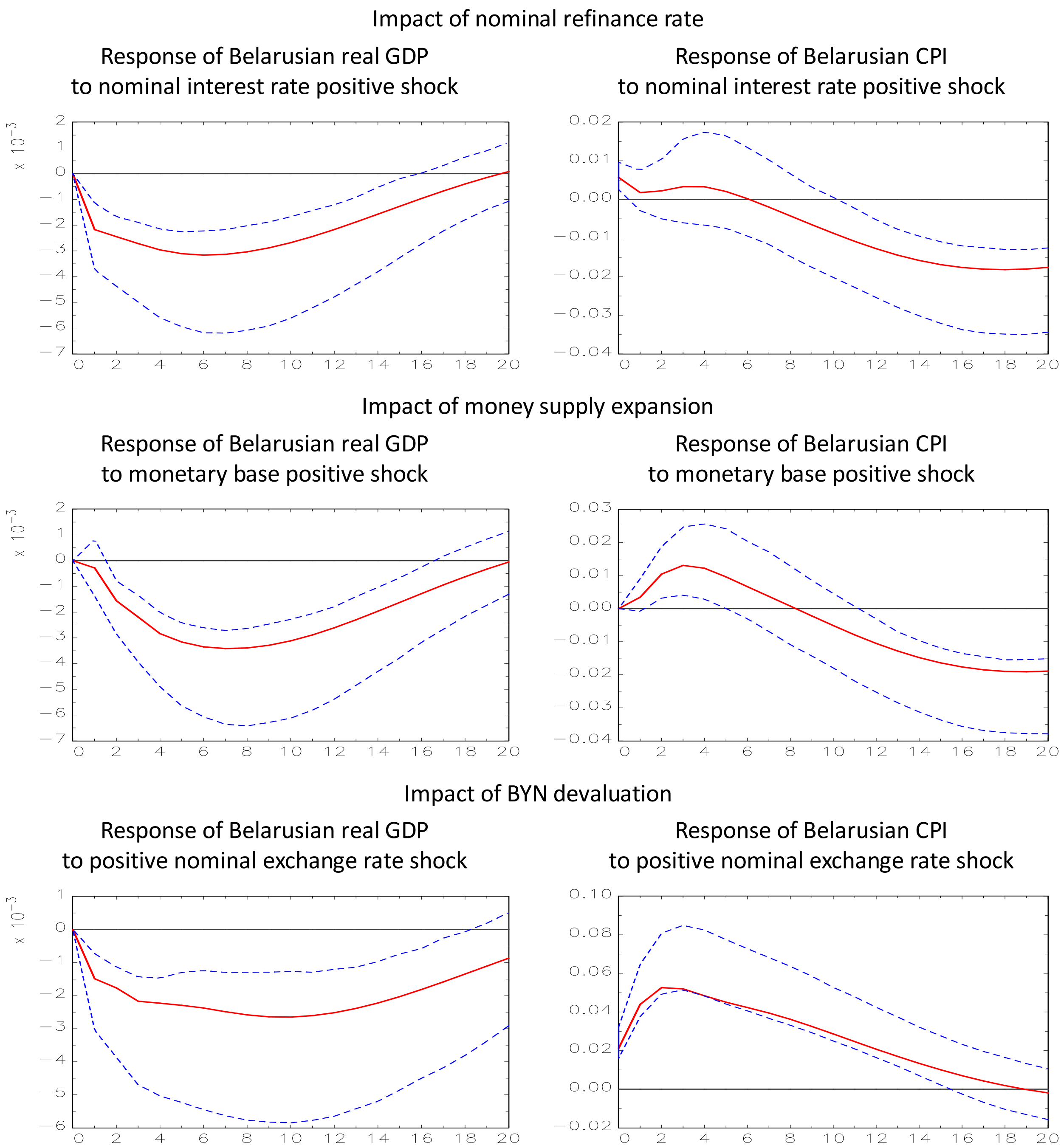
According to the obtained results, contemporaneous casual linkages take place between the oil prices and foreign and domestic real GDP, and nominal exchange rate of Russian ruble; between foreign real GDP and domestic real GDP, monetary base and consumer price index; between nominal exchange rate of Russian ruble and nominal exchange rate of Belarusian ruble and consumer price index; between nominal refinancing rate and consumer price index. All this directed linkages seem sensible and do not contradict theoretical considerations.

The results from Figure 8 are used for restrictions identification in matrix **A** (part 2 of Table 8). Together with diagonal elements of the matrix equal to 1, it gives 18 filled cells. All other cells of the **A**-matrix are restricted to be zero. Combined with **B**-matrix, where only diagonal elements are estimated, **AB**-model permits to identify structural shocks. It is important that imposed identification restriction is supported by the data. Over-identification restrictions are not rejected in accordance with the appropriate LR test (part 3 of Table 8). Thus, the SVAR model can be used for impulse response analysis of structural shocks.

<u>Belarusian internal shocks</u>. Figure 9 shows monetary transmission in Belarusian economy: the impact of nominal refinance rate, money supply expansion and BYN devaluation shocks on the main macroeconomic variables – real GDP and CPI. In accordance with theoretical expectations, monetary policy tightening through increasing nominal interest rate should lead to a reduction in real output and inflation. Additionally, money supply expansion is supposed to be positive related with CPI growth. Finally, BYN devaluation should lead to a price increase.

[16] For samples less than 100 observations this parameter significantly exceeds the standard significance levels, and it is usually chosen as 0.2–0.3.

Figure 9. Monetary transmission in Belarus: SVAR model



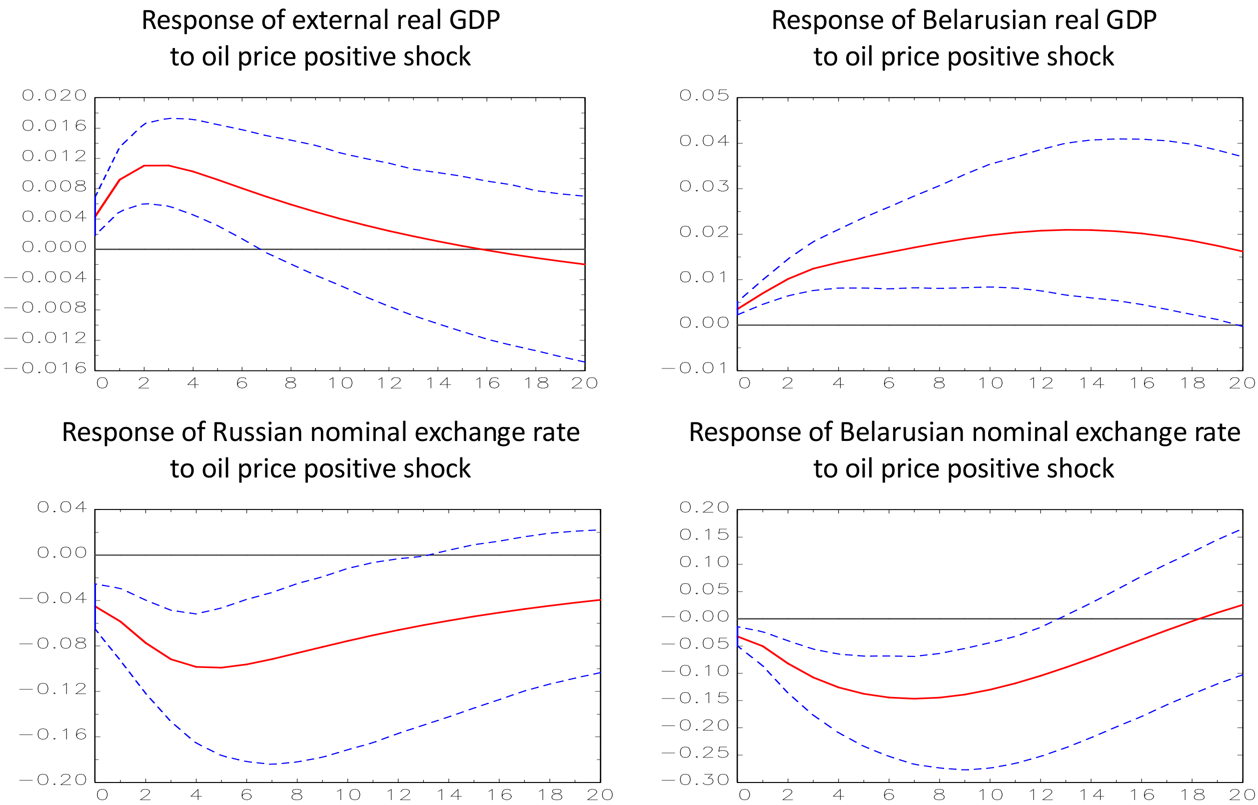
Note: Red solid line represents impulse response function of appropriate variable due to positive one standard deviation structural shock of nominal interest rate, monetary base or nominal exchange rate; blue dashed lines depict 90% Hall percentile bootstrap confidence intervals (1000 pseudo samples were used for bootstrapping).
Source: own estimations.

In general, the results are consistent with theoretical expectations. Growth of nominal refinancing rate leads to a statistically significant reduction in real GDP, which peak is observed after about 5–6 quarters. The consumer price index is also tending to be reduced as a result of a restrictive monetary policy, although this effect is insignificant during any reasonable time period.

The shock of the monetary base leads to a reduction in real GDP after about 2 quarters (earlier on the results are uncertain, because the confidence intervals are both in the positive and the negative area), and to an increase in the consumer price index, which reaches a peak in about 3–4 quarters. The impact of these shocks is statistically significant and in line with the results from a large scale GVAR model (see sub-section 3.1 for more detail). The reaction of real GDP growth to the shock in the monetary base seems too large, but in general, these results are consistent with theoretical expectations that expansionary monetary policy is not a relevant stimulus economic growth in the medium or long-run. The shock of the nominal exchange rate (depreciation of the Belarusian ruble) leads to a statistically significant reduction in real GDP and the growth of consumer prices that in fact coincide with the results obtained earlier on the basis of a large scale GVAR model.

Thus, the responses of key macroeconomic indicators do not contradict the theoretical expectations fundamentally. In addition, the profile of real GDP looks like a J-curve with the beginning of the recovery after about 2.5 years. In such a way, the SVAR model with exogenous variables quite properly describes monetary transmission in Belarus in the context of external shocks influencing the national economy.

Figure 10. Impact of oil price shock: SVAR model



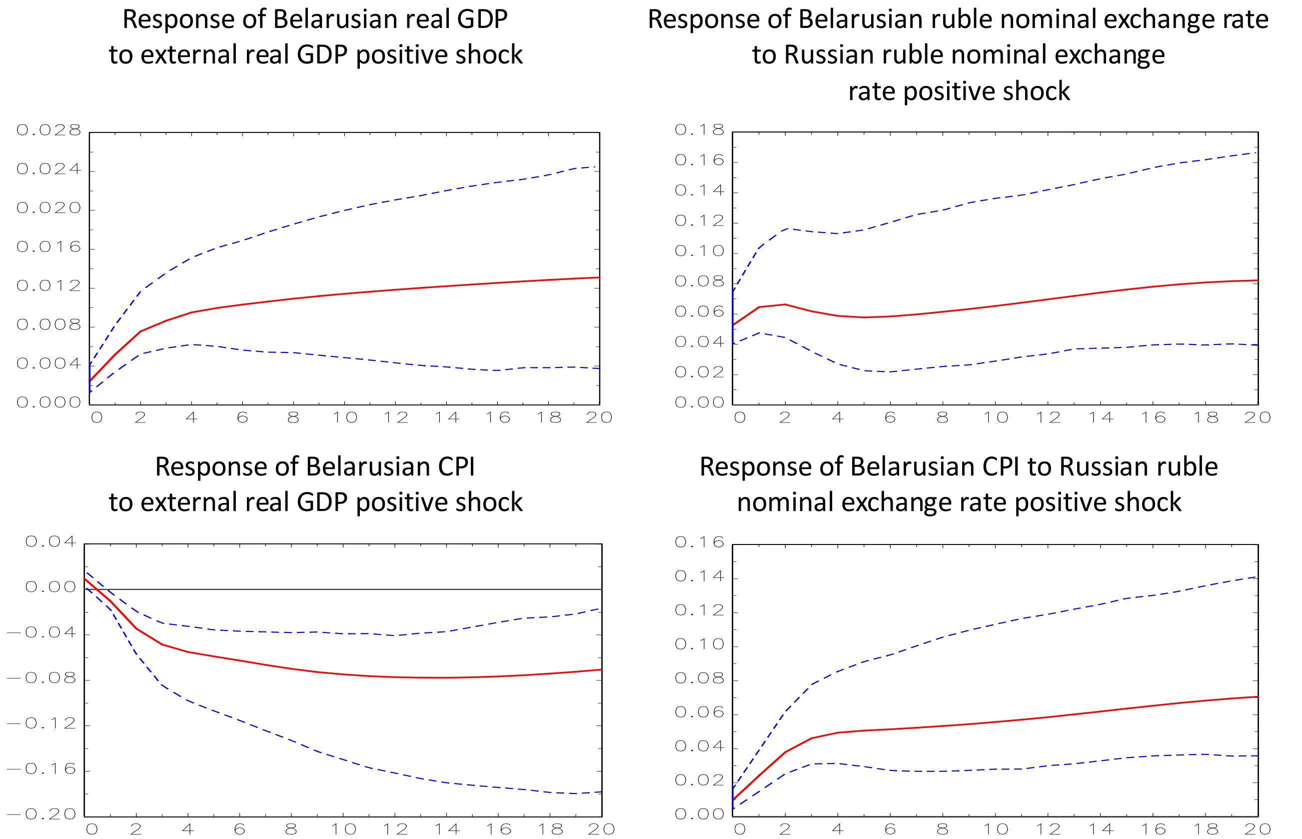
Note: Red solid line represents impulse response function of appropriate variable due to positive one standard deviation structural oil price shock; blue dashed lines depict 90% Hall percentile bootstrap confidence intervals (1000 pseudo samples were used for bootstrapping).
Source: own estimations.

<u>External shocks: oil price</u>. Figure 10 represents the impact of an oil price shock on foreign real GDP, domestic GDP, and Russian and Belarusian rubles nominal exchange rates. The obtained results are clear-cut: An increase of oil prices[17] leads to an increase of foreign real GDP[18], which reaches a peak after about 2–3 quarters. This effect disappears after 6–7 quarters and the impulse response function becomes insignificant. The reaction of Belarusian real GDP is more pronounced: The impulse response function is positive and significant throughout the analyzed period. The response profiles of nominal exchange rates in Russia and Belarus are generally the same, although the power of influence is greater in the latter case. In both countries the positive shock of oil prices reduces nominal exchange rates and this effect gradually disappears after reaching a peak in about 4 and 7 quarters in Russia and Belarus respectively.

[17] Since the impulse response functions are symmetric, a decrease of oil prices (which is more similar to the current year's situation) will lead to revise-reading graphics.
[18] A weighted foreign real GDP for Belarus to a large extend coincides with Russian real DGP (as far as Russia is one of the main trading partner), so it can be considered in this framework as a proxy of real GDP in Russia.

<u>External shocks: World and Russia</u>. Figure 11 depicts the impact of foreign real GDP and Russian nominal exchange rate shocks. Increase of foreign real GDP (and also Russian real GDP) leads to evident rise of Belarusian real DGP. At the same time this is accompanied with statistically significant CPI reduction. Growth of Russian nominal exchange rate expectably leads to increase of Belarusian nominal exchange rate and consumer prices. Thus, all impulse responses here are in line with theoretical expectations.

Figure 11. Impact of external real GDP and Russian nominal exchange rate shocks: SVAR model



Note: Red solid line represents impulse response function of appropriate variable due to positive one standard deviation structural shock of external real GDP or Russian nominal exchange rate; blue dashed lines depict 90% Hall percentile bootstrap confidence intervals (1000 pseudo samples were used for bootstrapping).
Source: own estimations.

Table 9. SVAR vs. GVAR

Positive shock to	Response of domestic variables								
	GVAR			GVAR_EAEU			SVAR		
	gdp	cpi	$nerr$	gdp	cpi	$nerr$	gdp	cpi	$nerr$
oil	++	+	+	++	−	−	++	−	−−+
$gdpx$	++	−−*	−−*	++	−−*	−−*	++	−−	−−
ner^{ru}	NA	++	++	++	++	++	−+	++	++

Positive shock to	Response of external (foreign) variables					
	GVAR		GVAR_EAEU		SVAR	
	$gdpx$	ner^{ru}	$gdpx$	ner^{ru}	$gdpx$	ner^{ru}
oil	++*	−−	++*	−−+	++−	−−
$dgpx$	NA	NA	NA	NA	NA	−−

Positive shock to	Monetary transmission					
	GVAR		GVAR_EAEU		SVAR	
	gdp	cpi	gdp	cpi	gdp	cpi
$NSR(NIRR)$	−−	+−	NA	NA	−−	−
$m(mb)$	−−	++	NA	NA	−−	++
ner	−−	++	NA	NA	−−	++

*Note: ++ is positive statistically significant response; + is positive statistically insignificant response; −− is negative statistically significant response; − is negative statistically insignificant response; NA means that such a response is not considered. * means that variable for Russia is used instead of foreign variable. Statistically significant responses are marked in gray.*
Source: own estimations.

In order to compare the results obtained from the SVAR model augmented with external variables with those of the GVAR models, we summarized the results in compact form in Table 9. As one can see, in general the results of impulse responses from different models (large scale GVAR model, small EAEU GVAR model and single country SVAR) do not contradict each other and in many cases demonstrate reasonable results. Each model has its advantages and disadvantages. In our view, all these models can complement each other. In particular, the large-scale GVAR model can be used for express analysis of international linkages and the corresponding impact of external shocks. The results of this modeling can be successfully used to build more local models that explore the interaction within the economic unions, like EAEU, as well as for in-depth analysis of various aspects of economic dynamics based on single country SVAR augmented with external variables (for instance, analysis of the monetary transmission mechanism). What methodology suits its purpose better remains, as we think, an imperial question based on careful data gathering and analysis.

5. Summary and conclusions

This policy study attempts to model international linkages of Belarus' economy using a relatively novel Global Vector Autoregression (GVAR) approach, which up to now has not been applied to the case of Belarus. The GVAR is a multi-country model that has been specifically developed to study global macroeconomic issues.

Applying the GVAR model to different large and small-scale data sets, we are able to identify the typical reaction of Belarusian macroeconomic variables like real GDP, inflation and the exchange rate to a wide array of external and domestic shocks. These patterns follow in most of the cases the underlying theoretical considerations. Other types of VAR models, like the Structural VAR (SVAR) confirm by and large the results obtained, which support their robustness.

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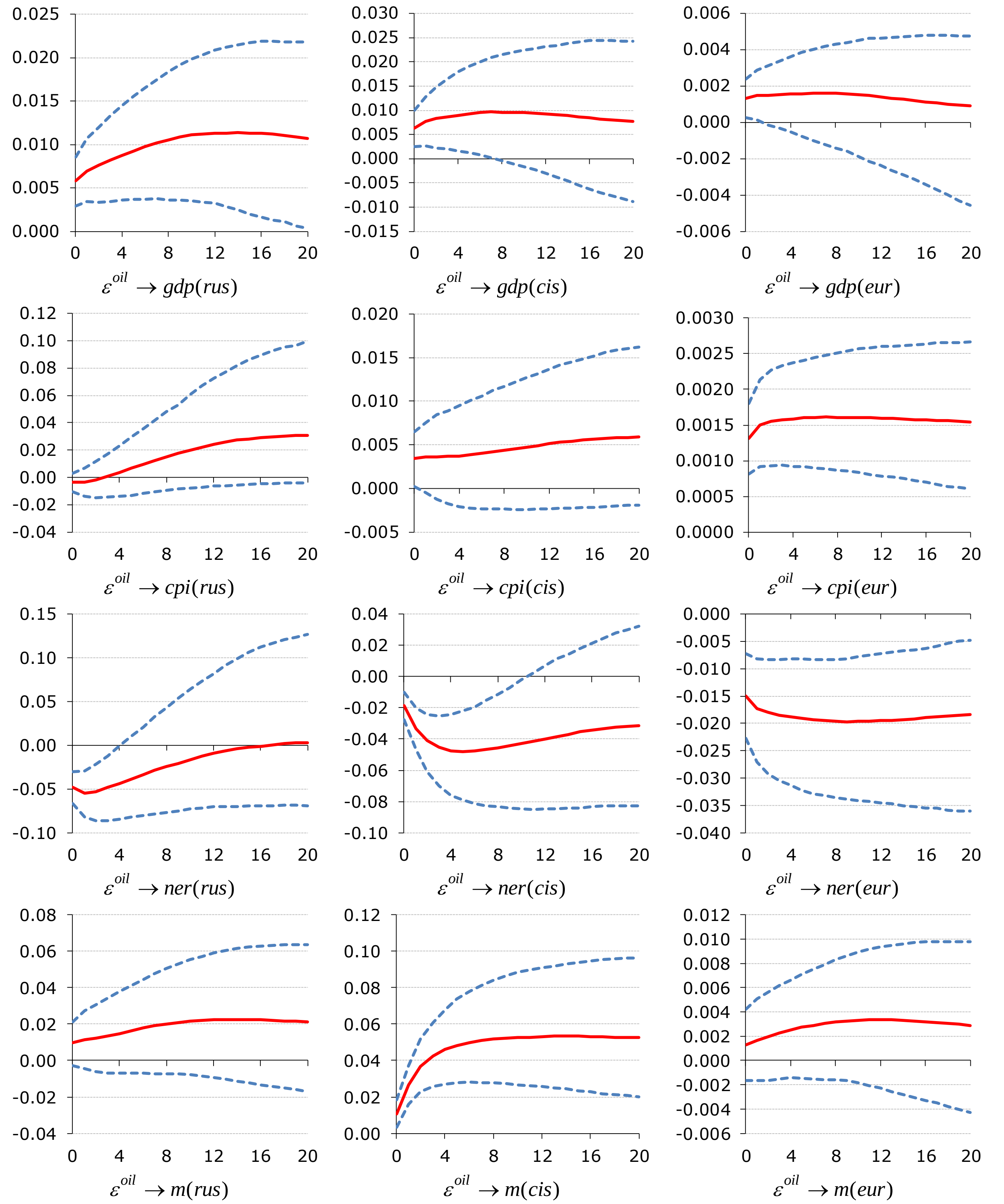
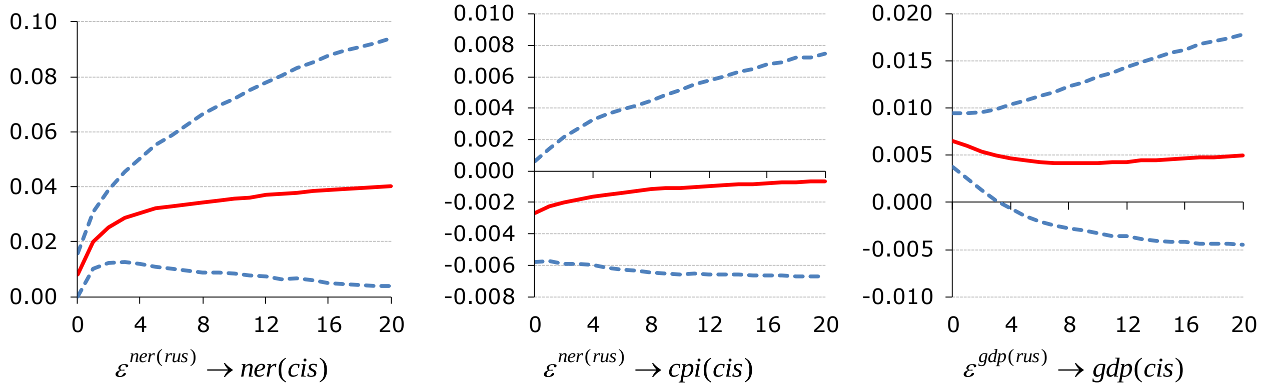
Annex. Selected GIRFs of the large-scale GVAR

Figure A1. Impact of oil prices shocks on macroeconomic indicators of Russia, other CIS countries and Euro-zone countries



Note: red solid line represents bootstrap median estimates of the generalized impulse response function (GIRF) of appropriate variable due to positive one standard deviation oil price shock. GIRF is calculated by a standard bootstrap procedure with 2000 replications. Blue dashed lines depict 90% bootstrap confidence intervals.
Source: own estimates.

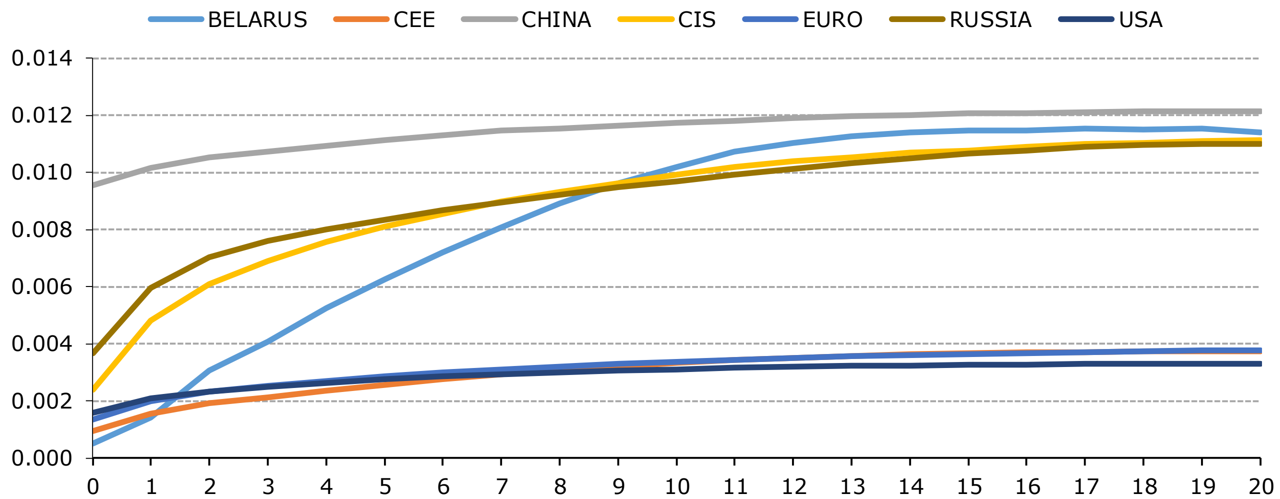
Figure A2. Impact of Russian real GDP and nominal ruble exchange rate shocks on macroeconomic variables of other CIS countries



Note: Red solid line represents bootstrap median estimates of the generalized impulse response function (GIRF) of appropriate variable due to positive one standard deviation Russian nominal exchange rate or real GDP shock. GIRF is calculated by a standard bootstrap procedure with 2000 replications. Blue dashed lines depict 90% bootstrap confidence intervals.

Source: own estimates.

Figure A3. Impact of foreign real GDP shocks on domestic real GDP



Note: Solid lines represent bootstrap median estimates of the generalized impulse response function (GIRF) of appropriate variable due to positive one standard deviation foreign GDP shock. Confidence intervals are not presented, as lower bounds for 90% confidence interval for all GIRFs are above the zero line.

Source: own estimates.

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