Evaluation of optimal international economic policy based on both the parametric control theory and global computable general equilibrium model

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Abstract

Based on the GLOBE model global dynamic computable general equilibrium model (to describe functioning and interaction of the Customs Union (CU) of Belarus, Kazakhstan, and Russia with Armenia, Kyrgyzstan, the European Union and the rest of the world) is developed and calibrated. The calibrated model is tested for the possibility of practical application and on its base the possibility of optimal economic policy both within the CU and within functioning and interaction of the CU, the EU, Armenia, Kyrgyzstan and the rest of the world is assessed using methods of the parametric control theory.

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1. Introduction

Necessity of new adequate instruments of macroeconomic analysis and effective economic policy within the framework of regional unions as well as within the framework of world economy is highlighted by latest global crisis.
Possible way to search for the development of effective measures in economic policy is the use of mathematical models of macroeconomic systems\textsuperscript{1,2}.

Class of computable general equilibrium models (CGE models) is a common tool of macroeconomic analysis of macroeconomic systems, evaluation of effective economic policy version\textsuperscript{3,4,5} and, according to Dixon and Parmenter “Considered class of mathematical models, most probably, will more and more influence on the development of government economic policy and business strategy\textsuperscript{5}.” Among the models in this class there is a static GLOBE model\textsuperscript{6}, which does not describe the dynamics of the macroeconomic system evolution.

It should be noted that the models used for the macroeconomic analysis and evaluation of economic policy versions are generally verified on the test sample by evaluating the retroprognosis quality\textsuperscript{7}, and in fact they are not tested for the possibility of their practical application.

Recently developed parametric control theory provides effective instruments to test mathematical models for the possibility of their practical application and techniques to make recommendations in the sphere of economic policy, taking into account the effects of uncontrollable economic factors\textsuperscript{8}.

In this paper we develop a static GLOBE model\textsuperscript{6} to describe the dynamics of functioning and interaction of the countries of the Customs Union (CU) of Belarus, Kazakhstan, and Russia within the CU, as well as with the European Union (EU), Armenia, Kyrgyzstan, and with the rest of the world (hereinafter the Model).

The developed calibrated Model is tested for the possibility of its practical application and on its base the possibility of macroeconomic analysis and methods for estimating optimal values of regional and global economic policies targeted at economic growth and reducing disparities of countries’ economic development are demonstrated using the parametric control theory methods.

2. The Model

2.1. General features of the Model

The Model describes functioning and interaction of economies of seven Regions (countries): Kazakhstan, Russia, Belarus, Armenia, Kyrgyzstan, the European Union, the rest of the world.

Economy of the each Region in the Model includes the following 16 Sectors (producer agents): Agriculture, Production and transmission of electricity, gas and hot water, Mining, Oil and petrochemicals production, Metallurgy industry, Chemical and petrochemical industry, Metalworking industry, Construction materials production, Textile manufacture, Food industry, Construction, Education, Public health, Public administration, Other industries, Other Services.

In addition to these producers, in each Region consumer agents exist: Households and Government. Each Region has an agent Banks.

The Model also has another special agent Globe, earning income from transport margins in the export and import of products between Regions.

Model compared to the baseline variant of GLOBE\textsuperscript{6} is developed as follows:

- Taking into account the existing agreements of the Customs Union, GLOBE model structure is bound to seven selected Regions (including countries), covering the global economy, as well as 16 economic Sectors and two factors (labor and capital) in each Region;
- It is added to the Model the financial blocks of Regions, including indicators of the monetary sphere: monetary base and monetary aggregates M0 and M3;
- It is added to the Model the banking Sectors, describing the mechanisms of forming loans and deposits of legal entities and individuals (Industries and Households in the Regions);
- It is added to the Model a description of forming and service of government debts of the Regions;
- The Model has taken a dynamic structure, there are added a number of dynamic equations for the computation of the following variables: technological factors of production functions for GVA (gross value added) of all industries in the Regions, factor supply by the Regions’ Households, levels of government debts of the Regions.
2.2. Conceptual description of economy of the Model

It is assumed that Producer agents, Household agents and Government agents are perfect rationality agents.

**Producer agents.** Each Sector in each Region of the Model in its activities each year:
- Produces one type of product (from the condition of cost minimization);
- Forms GVA (using factors: labor and capital of Households);
- Exports part of output (from the condition of profit maximization);
- Imports intermediate and investment goods from other Regions;
- Consumes intermediate and investment goods;
- Pays net tax payments to its Government.

Sectors solve the following two pairs of nested optimization problems:
- Minimizing Sector costs for the purchase of intermediate products and GVA costs of industry for a given production output;
- Minimizing the Sector costs for the purchase of production factors for a given output of the final product;
- Maximizing profits from sales within the Region and beyond for a given production output;
- Maximizing profits from exports to different Regions for a given level of exports.

**Households** in each Region in their activities each year:
- Receive income from factors (labor and capital) on the basis of demand for factors by producers in their Region;
- Consume consumer products (according to the problem of maximizing their utility function under the budget constraint);
- Carry out savings in the form of investment products based on their income and consumption;
- Pay net tax payments to the Government of their Region.

**Government** in each Region in its activities each year:
- Defines the effective tax rates and receives revenues in the form of net tax revenues (including revenues from customs duties);
- Consumes the final product (Government spending);
- Carries out savings in the form of investment products based on its income and spending;
- Determines the monetary base, monetary aggregates and the refinancing rate in its Region;
- Generates and services the Government debt of its Region.

**Sectors, Households and Government** of each Region yearly jointly solve the following optimization problems:
- Determination of the optimal share of imports in the consumption of each product by minimizing the cost of domestic and imported components of this product;
- Determination of the optimal regional structure of each type of imported products by minimizing the cost of this kind of imported products.

**Banks** determine interest rates on loans and deposits and carry out banking functions on lending and receiving deposits in their Region.

**Pricing and balances.** The Model uses a composite system of endogenous prices for all 16 types of products of each Region, including prices of both buyer and seller, the prices of both exporter and importer and so on.

Calculated price values provide implementation of the annual balance relationship, providing:
- Equilibrium in factor markets (labor and capital);
- Equilibrium in markets of each kind of product;
- Bilateral current balance of payments for each pair of Regions;
- Equilibria of savings (Households, Governments) and their investments in Sectors of the Regions.

The conceptual description of economy contains statements of previously mentioned optimization problems with the relevant first-order conditions, equations describing rules for agent activities, balance relations for prices and quantities (real variables measured in producer prices), the internal balances on the government accounts and the external balances on the trade accounts.
2.3. Mathematical Model and its solution

Taking into account the conditions of agent rational behavior, the dynamic Model has been developed (based on foregoing formalization) by combining following equations into a single system:
- First-order conditions for optimization problems;
- Rules for agent activities;
- Balance relations for prices and quantities;
- Dynamic equations noted in section 2.1;
- Auxiliary equations (intended for finding aggregate values and calculating scenarios).

This Model is generally represented by the following system of relations, composed of two subsystems.

1) Subsystem of differential equations, linking dynamic endogenous variables \( x_1(t) \) values for two consecutive years:

\[
x_1(t + 1) = f_1(x_1(t), x_2(t), u(t), a(t)).
\]

Here \( t = 0, 1, \ldots, n - 1 \) is a number of year, discrete time; \( n = 18; t = 0 \) corresponds to the year 2001;
\( x_1(t), x_2(t) \) are vectors of endogenous variables of the system. \( x_1(t) \) set include shift parameter values (technological coefficients) of CES production functions for GVA of Sectors, labor and capital supplies for Sectors, Government debt amount in Regions. \( x_2(t) \) vector coordinates include values of all endogenous variables of the Model (demands and supplies for various goods, prices and others), excluding those in \( x_1(t) \);
\( u(t) \in U(t) \subset R^q \) is vector function of controllable (regulated) parameters. Coordinate values of this vector correspond to various Governmental economic policy instruments, for instance: various tax rates, Government spending shares, required for consumption and others. In below mentioned parametric control problem \( Pr_W: q = 238; \)
\( a(t) \in A \subset R^s \) – is vector function of uncontrollable parameters. Coordinate values of this vector characterize various external and internal social and economic parameters: production function coefficients and aggregation function coefficients, amounts of minimum product consumption by consumers and others. Further in the paper in parametric control problem \( Pr_W: s = 12117; \)
\( X_1(t), X_2(t), U(t), A \) are compact sets with nonempty interiors, \( X_1(t), X_2(t) \) sets determine phase constraints, \( U(t) \) sets specify constraints on control of solving parametric control problems on the basis of the Model; \( X_1 = U_{t=0} U_{t=n} X_1(t), i = 1, 2; U = U_{t=0} U_{t=n} U(t); \)
\( f_1: X_1 \times X_2 \times U \times A \to R^{m_1} \) – differentiated mapping.

2) Subsystem of algebraical equations (relatively unknown \( x_2(t) \)), describing the behavior and interaction of agents in different markets during the selected year, in particular the first order conditions of optimization problems of agents, rules of Governments behavior, Globe agent and balance equations:

\[
f_2(x_1(t), x_2(t), u(t), a(t)) = 0.
\]

Here \( f_2: X_1 \times X_2 \times U \times A \to R^{m_2} \) – differentiable mapping.

Computable Model (1), (2) for given fixed values \( u(t) \) and \( a(t) \) functions for each time \( t \) determines the values of \( x(t) \) endogenous variables, corresponding to the equilibrium price of demand and supply in goods and factors markets within the next algorithm.

1) It is assumed \( t = 0 \) and the initial values of \( x_1(0) \) variables are set.
2) Calculate the values of \( x_2(t) \) for the current \( t \) by solving the system (2).
3) Based on obtained equilibrium solution at time \( t \) using the dynamic equations (1), the values of \( x_1(t + 1) \) variables are found. \( t \) value increases by unity. Go to step 2.

The number of iterations of steps 2 and 3 of the algorithm are defined in accordance with the objectives of the forecast and parametric control on the pre-selected time intervals.
Solving the system of equations of the Model (1), (2) according to the abovementioned algorithm is performed using software implemented in the GAMS IDE, using embedded MCP solver “PATH”.

3. Forming and processing of statistical database for Model calibration

The central core of the Model database are social accounting matrices (SAM) for each Region, illustrating how product flows are distributed between Sectors, Households, Governments, importers and exporters.

Statistical database for the Model calibration consists of the following three components:
- Some indicators of financial blocks, Banking sectors and Government sectors in selected regions for 2001-2012.
- The extracted by a special converter from the GTAP in accordance with an accepted structure of the Model the part of four-dimensional SAM, which is a set of two-dimensional SAM numbered by the index of time (year) and the index of the Region for 2001, 2004 and 2007.

In accordance with the SAM forming algorithms and SAMs obtained from GTAP, new matrices are formed for the years, missing in the GTAP database. Statistical data specified in sections above are used. Some data (Investment, Foreign trade, Transfers) if necessary, adjusted to eliminate the existing discrepancies in them with requirements to the SAMs.

As a result of this stage, we have the final four-dimensional SAM, containing all the necessary data for the years 2001-2012, which is then used for calibration stage.

4. The Model calibration

At the stage of calibration, calculation of exogenous variables values of in the Model for points in time from 2001 to 2012 according to the following steps:
- Substitution coefficients values of various factors in the Sector production functions; substitution coefficients of different kinds of products in functions of Sector outputs, Households utility functions and aggregation functions, which describe consumption of agents, are taken straight from the literature.
- The values of the rest exogenous parameters in the Model are calculated using special expressions based on the formed SAMs for the mentioned regions for 2001 – 2012, which are the expansion of Leontief tables of intersectoral balance by adding to them the results of financial activities of economic agents.

Consequently, calibrated Model precisely reproduces used in its calibration statistical data from GTAP and other sources. Obtained values of all its exogenous parameters were extrapolated to prognosis period 2013-2018 to get the basic miscalculation of the Model until 2018.

5. Testing the Model for the possibility of its practical application

The possibility of practical application of calibrated Model has been tested by three techniques.
- Estimation of stability indicators of the mapping given by the model. In these experiments, as a stability indicator is used an indicator equal to the maximum number of percent change in values of all endogenous variables in the Model for chosen point in time (2001 to 2018) compared to the base variant given the change of the Model input parameters within a sphere of radius 1% centered at the base point of the Model parameters in relative values.

Here all possible tax rates of the Model for 2001 are considered as input parameters, and as output variables – GDP, exports, imports, Government debt in all Regions of the Model for the current year (2001 to 2018).

Estimation results of the Model stability indicators are shown in Table. 1.

All stated in Table 1 stability indicators estimates do not exceed 7.18, which characterizes the Model stability (in the sense of stability indicators) in the calculations until 2018 as sufficiently high.
Table 1. Stability indicators values

<table>
<thead>
<tr>
<th>Year</th>
<th>Indicator (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>0.73</td>
</tr>
<tr>
<td>2002</td>
<td>1.18</td>
</tr>
<tr>
<td>2003</td>
<td>1.24</td>
</tr>
<tr>
<td>2004</td>
<td>1.89</td>
</tr>
<tr>
<td>2005</td>
<td>1.96</td>
</tr>
<tr>
<td>2006</td>
<td>1.94</td>
</tr>
<tr>
<td>2007</td>
<td>3.32</td>
</tr>
<tr>
<td>2008</td>
<td>3.04</td>
</tr>
<tr>
<td>2009</td>
<td>2.73</td>
</tr>
<tr>
<td>2010</td>
<td>3.51</td>
</tr>
<tr>
<td>2011</td>
<td>3.76</td>
</tr>
<tr>
<td>2012</td>
<td>4.76</td>
</tr>
<tr>
<td>2013</td>
<td>5.01</td>
</tr>
<tr>
<td>2014</td>
<td>6.13</td>
</tr>
<tr>
<td>2015</td>
<td>5.31</td>
</tr>
<tr>
<td>2016</td>
<td>4.39</td>
</tr>
<tr>
<td>2017</td>
<td>7.18</td>
</tr>
<tr>
<td>2018</td>
<td></td>
</tr>
</tbody>
</table>

- Stability estimation (in the sense of \(^{14}\)) of differentiable mapping defined by the Model. In computational experiments a number of mappings were investigated, that is defined by value transformations of exogenous parameters of the Model (tax rates) into the calculated values of their endogenous variables for the chosen year. As the domains of these mappings were used the parallelepipeds in spaces of corresponding tax rates in the Model Regions with the boundaries, determined by ±50% deviation of the exogenous parameters from their baseline values. The results of these experiments showed the absence of critical points of these mappings in their respective domains and their stability in all experiments.

- Conducting a number of counterfactual scenarios for 2009 to 2012. In particular, during the scenario with 10% decrease in the effective VAT rates and income taxes and 10% increase in Government consumption in each country of the CU, Armenia and Kyrgyzstan, an increase in GVA of every Sector in the corresponding country within the scope from 0.11% in 2009 to 3.56% in 2012 compared with the observed data. The results of this experiment are consistent with the provisions of macroeconomic theory that indicates an adequate response of the Model to changes in these exogenous indicators.

6. Macroeconomic analysis based on the Model for retroperiod and perspective (medium-term) period

To macroeconomic analysis in the time interval 2001 to 2018 were subjected:
- Dynamics in nominal dollar terms of such indicators as NEA and budget indicators in seven Regions of the Model as GDP, GDP per capita, Household consumption, Government consumption, exports, imports, Government revenues, Government debt;
- Dynamics in nominal dollar terms of indicators in 16 economic Sectors in all seven Regions;
- Rates of all of the above parameters.

As an example, Fig. 1 shows the calculated values of GDP per capita in three Model Regions and in the CU for retrospective and prospective periods.

Fig. 1. GDP per capita in Kazakhstan (KZ), the Customs Union (CU), the European Union (EU), and the rest of the world (ROW) in USD, in current prices
Within the framework of macroeconomic analysis based on the Model, the scenario of Armenia’s entering into the Customs Union in 2015 was calculated. Analysis of the scenario results at the level of Sectors GVA in the CU countries shows the following. In 2015 to 2018 will be an increase (compared to the base variant) of GVA in all Sectors of Armenia except Metallurgy and Production of construction materials (by 5.22-6.68% in 2018). In these two Sectors in 2018 GVA will be reduced by 0.66-0.08%. As a result, Armenia’s GDP in 2018 will grow by 5.81% compared to the base variant and reaches 13.65 billion dollars. While GDP of other three CU countries slightly (by 0.56-0.08%) increase in 2018 compared to the base variant.

7. Formulation and solution of some parametric control problems based on the Model

A number of parametric control problems was formulated and solved within the framework of estimating optimal values of economic policy instruments of Regions of the Model for 2013-2018. We give informal definition of such nine problems $Pr_i$, $(i = 1, ..., 7, CU, W)$ of economic policy directed to the economic growth and reducing regional development disparities. In these problems, the values of all uncontrolable exogenous variables of the Model correspond to the baseline forecast of these variables. Further indices $i, j = 1, ..., 7$ correspond to the Region number: 1 – Kazakhstan, 2 – Russia, 3 – Belarus, 4 – Armenia, 5 – Kyrgyzstan, 6 – European Union, 7 – the rest of the world. $CU$ index corresponds to the Customs Union, $W$ – the world economy.

**Statements of $Pr_i$ parametric control problems.** To find for each $Pr_i$ problem, based on the Model, the control parameter values (effective tax rates on producer revenues (Corporate Income Tax), sales tax (VAT), and customs duties; Government spending shares, which are for consumption) for 2013-2018, those provide the maximum $K_i$ criterion value (4-6) given appropriate constraints on control instruments ($\pm 10\%$ from their baselines) and constraints (3) on some endogenous variables.

For $Pr_i$, $(i = 1, ..., 7)$ problems, control parameters are the mentioned Government policy instruments in $i$-th Region, for $Pr_{CU}$ problem – in three countries of the Customs Union, and for $Pr_W$ problem – in all seven Regions of the Model in aggregate.

The constraints on endogenous variables in the Model in $Pr_i$ problems are as follows.

$$\text{CPI}_j(t) \leq \bar{\text{CPI}}_j(t), \; GD_j(t) \geq \bar{GD}_j(t), \; QVAP_j(t) \geq \bar{QVAP}_j(t), \; j = 1, ..., 7, \; t = 2013, ..., 2018. \tag{3}$$

Here: $\text{CPI}_j(t)$ is consumer price level in the Region $j$ with parametric control; $GD_j(t)$ is an amount of Government debt in the Region $j$ with parametric control; $QVAP_j(t)$ is GDP per capita in the Region $j$ with parametric control; sign $\bar{\text{...}}$ denotes basic values of corresponding indicator (without parametric control).

In stated problems the criterion $K_i$ $(i = 1, ..., 7)$ characterizes the average GDP rate value (in current USD) in the Region $i$ for the period 2013-2018:

$$K_i = \frac{1}{6} \sum_{t=2013}^{2018} TQVA_i(t), \tag{4}$$

where $TQVA_i(t)$ is annual GDP rate in the Region $i$ in the year $t$.

$K_{CU}$ and $K_W$ criteria of $Pr_{CU}$ and $Pr_W$ problems characterize correspondingly the average GDP rate value in the Customs Union and World economy (in current USD), as well as relative deviations in GDP per capita in the Model Regions from GDP per capita in the European Union (the Region that has the highest value of GDP per capita among all of the Model Regions) for the period 2013-2018:

$$K_{CU} = \frac{1}{6} \sum_{t=2013}^{2018} TQVA_{CU}(t) - \frac{1}{6 \sum_{t=2013}^{2018} TQVA_{CU}(t)} \times \left( \frac{\sum_{t=2013}^{2018} QVAP_{CU}(t) - \sum_{t=2013}^{2018} QVAP_{CU}(t)}{\sum_{t=2013}^{2018} QVAP_{CU}(t)} \right), \tag{5}$$

$$K_W = \frac{1}{6} \sum_{t=2013}^{2018} TQVA_W(t) - \frac{1}{6 \sum_{t=2013}^{2018} TQVA_W(t)} \times \left( \frac{\sum_{t=2013}^{2018} QVAP_W(t) - \sum_{t=2013}^{2018} QVAP_W(t)}{\sum_{t=2013}^{2018} QVAP_W(t)} \right). \tag{6}$$
Here: $TQVA_{CU}(t)$, $TQVA_{W}(t)$ are correspondingly annual GDP rates of the Customs Union and World economy in the year $t$; $QVAP_{i}(t)$ is GDP per capita in the Region $i$ in the year $t$; $\varepsilon_i$ is weight coefficient, its value is $\varepsilon_i = 1$ for less developed Regions (Belarus, Armenia, Kyrgyzstan, and the Rest of the World), $\varepsilon_i = 0.1$ for mid-developed Regions (Kazakhstan and Russia).

The formulated $P_{T_i}$ problems were solved by numerical procedure using provided by GAMS optimization algorithm. The results of their solution in the forms of changes in the average GDP value in Regions for 2013-2018 (in percentage compared to the baseline variant) are shown in Table 2, and per capita GDP graphs for Kazakhstan are in Fig. 2.

Table 2. Percentage change in average GDP values of Regions in the result of nine parametric control problems solution

<table>
<thead>
<tr>
<th>Problem</th>
<th>Change in average GDP value of Region $i$ for 2013-2018</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$i=1$</td>
</tr>
<tr>
<td>$P_{r_1}$</td>
<td>3.20</td>
</tr>
<tr>
<td>$P_{r_2}$</td>
<td>0.51</td>
</tr>
<tr>
<td>$P_{r_3}$</td>
<td>0.19</td>
</tr>
<tr>
<td>$P_{r_4}$</td>
<td>0.09</td>
</tr>
<tr>
<td>$P_{r_5}$</td>
<td>0.20</td>
</tr>
<tr>
<td>$P_{r_6}$</td>
<td>0.31</td>
</tr>
<tr>
<td>$P_{r_7}$</td>
<td>0.24</td>
</tr>
<tr>
<td>$P_{r_{CU}}$</td>
<td>3.38</td>
</tr>
<tr>
<td>$P_{r_{W}}$</td>
<td>3.39</td>
</tr>
</tbody>
</table>

The analysis of Table 2 shows that in the problem $P_{r_1}$ ($i = 1, ..., 7, CU, W$), the parametric control approach at the level of all Regions ($P_{r_{W}}$ problem) as well as at the level of three Customs Union countries ($P_{r_{CU}}$ problem) gives greater for each separate Region in comparison with parametrical regulation at level of each separate Region ($P_{r_1}$ problems, $i = 1, ..., 7$).
Moreover, by solving $Pr_{iw}$ problem, it was obtained the smoothing of economic development of Regions, characterized by decrease in relation of maximum GDP per capita to minimum one among all Regions by 2.75% in 2018 compared with 2013. It was also obtained an increase in GDP per capita indicator in 2018 compared with 2013 by 29.5%, 40.0% and 45.9%, correspondingly for Belarus, Armenia, and the rest of the world (less developed regions). GDP per capita increase in whole world is 4.59% compared with the variant without control. Quadratic mean value of deviations of GDP per capita in all Regions from GDP per capita in the European Union in 2018 decreased by 4.08% compared with the variant without control. Figure 3 presents the solution result for $Pr_{iw}$ problem – the graphs of GDP per capita for Armenia (in dollars in current prices) both without control and with parametric control. This increase in Armenia is 5.57% to 2018 compared with basic variant. Similar (however, with less effect than $Pr_{iw}$) results were obtained also by solving $Pr_{wu}$ problem.

The analysis of presented results of the problem $Pr_{i}$ solution shows high potential of parametric control approach to make recommendations for coordinated optimal government economic policy at the global level and at the level of regional economic union.

![Graph](image.png)

**Fig. 3.** Per capita GDP of Armenia, in USD, in current prices

### 8. Conclusion

1. Global dynamic computable general equilibrium Model is proposed and calibrated to describe functioning and interaction of the countries of the Customs Union (Belarus, Kazakhstan, and Russia) with Armenia, Kyrgyzstan, the European Union and the Rest Of The World.
2. The constructed Model is tested for the possibility of its practical application.
3. The possibility of macroeconomic analysis based on the Model is demonstrated.
4. The efficiency of the parametric control theory in estimating optimal values of economic policy instruments in economic growth and reducing regional development disparities is shown.
5. Proposed parametric control approach (based on accordingly built CGE models) can be recommended to countries of other economic unions for effective coordinated economic policy.

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