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Dynamics of investments in Russia under the conditions of sanction restrictions: Forecast based on an agent-based model

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Abstract

The situation of a trade war between Russia and Western countries is unprecedented in recent history, both in terms of the scale of the restrictions being introduced and because of their mutually dangerous nature, as a result of which the entire world economic system is experiencing difficulties. An urgent task is to develop an economic policy for Russia that will allow for a quick reorientation to Eastern markets and the use of new growth drivers. Evaluation of the effectiveness of the measures taken should be carried out using modern tools, one of which is agent-based economic models. Since Russia is not considered as a key player in the models of international trade relations developed in a

number of countries, in order to assess the sanctions imposed against it, it was necessary to develop a new tool – an agent-based model of trade wars between Russia, the USA, China and the European Union. The purpose of the study presented in this article is to assess the need of the Russian economy for additional investments in various industries for large-scale import substitution of products till now supplied from unfriendly countries. To achieve this, the agent-based model reproduces the sectoral structure of the considered economies of the countries and trade relations among them that existed before the start of the special military operation, compiles scenarios of possible sanctions, and simulates the corresponding changes in international trade relations. As part of the scenario calculations, three series of experiments were carried out. In the first series, for each scenario the expected dynamics of Russia's GDP in 2022 was estimated in the context of organizing import substitution programs in key industries, and the cost of these programs was calculated. In the second series, the dependence of GDP dynamics on the volume of investments was studied. The third series simulated the dynamics of trade relations for the period up to 2025 for two investment policy options in each scenario. The results of the experiments also show that the impact of investments on the economy is stronger, the more severe the sanctions are, and under these conditions, the implementation of investment programs can accelerate economic recovery on average by 0.5% of GDP per year.

Keywords: trade wars, agent-based model, sanctions, scenario calculations, investment

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Introduction

Since the start of Russia's special military operation in Ukraine, the world has faced the imposition of economic sanctions that are unprecedented in many respects. Firstly, this is the scale of restrictions, affecting more than half of the trade turnover in a number of industries with countries that are not directly involved in the military conflict and are not in agreements on military cooperation with the conflicting countries; in some cases, they completely block this turnover. Secondly, we see the mutually dangerous nature of the restrictions introduced, as a result of which not only the Russian economy suffers, but also the economies of the United States, the EU and neutral countries, due to global shortages of fuel, food and metals provoked by the sanctions, as well as inflation, suspension of production and related unemployment. In the current conditions, the low-income segments of the population suffer the most. Even in developed countries, they are under the threat of hunger, and the question arises, what is it: underestimation of the consequences of the measures being introduced, or deliberate neglect of their impact on the lives of ordinary citizens? History can shed light on the motives of the governments of countries that are now introducing these restrictions, and the task of the current moment is to develop an economic policy for Russia that will minimize the damage caused, and in the future even lead to emerging growth drivers.

To solve this problem, computer models of the economy that integrate the available data on production, employment, and economic relations between countries can serve as an effective tool. The most famous project in the field of developing tools for quantitative assessment of trade wars is The Global Trade Analy-

sis Project (GTAP), which brings together scientific researchers from different countries [1, 2]. GTAP uses a generic modeling methodology based on computable general equilibrium (CGE) models. GTAP has developed a number of model complexes, including:

1. WorldScan, which simulates the trade of 29 products among 30 countries that have the largest weight in world GDP, and enlarged regions that include several states. Goods and services in the model are produced using labor, capital and intermediate products, the contribution of which is determined by the parameters of the corresponding production function. Supply and demand for a particular product in a particular country is formed taking into account supply and demand of this product in other countries, and the price depends on substitution opportunities, transport costs, trade barriers and other factors. Using WorldScan, the impact of tariff increases on certain types of products and on the industry as a whole was assessed, both for individual countries sequentially and for all at the same time. Based on the results of these calculations, the sectors most sensitive to trade wars in the United States and China were identified. Based on the simulation results, it was concluded that in the case of bilateral symmetrical impacts between the US and China, the latter bears the greatest losses, but in the event of a large-scale trade war, China also suffers the most [3].

2. The GLOBE multisectoral model [4], developed by specialists from the University of Hohenheim and the US Naval Academy, was used to assess the consequences of trade wars among the countries of the North American Free Trade Area, regulated by the North American Free Trade Agreement.

3. Multi-country multi-sector model MIRAGRODEP, developed at the International Food Policy Research Institute (Washington, USA), based, in addition to the GTAP methodology, on MIRAGE model (modeling of international relations under applied general equilibrium). The focus of this model is on trade in goods between the US, China, and Mexico [5].

4. The Center for International Trade and Economics and the Institute of World Economics and Politics of the Chinese Academy of Social Sciences have developed a global model for assessing the consequences of a trade war between the United States and China [6].

The models listed above focus on consideration of the world's largest players, most often the United States and China, sometimes also the EU countries. Despite the fact that in some of the presented model complexes Russia stands out as a participant, the available publications do not provide any assessments of the impact of economic sanctions on Russia which have been regularly imposed against it since 2014. At the same time, the world's leading agencies began very quickly to give negative forecasts for the Russian economy: JP Morgan on February 28 predicted a 20% drop in GDP in the second quarter, the World Bank in April suggested an annual drop of 11.2%, and Bloomberg in May spoke of a drop of 12%. To counteract such a negative informational impact on public opinion, it is necessary to have our own model complexes that can quickly update forecasts in changing conditions, and include Russia as one of the key participants in world trade. This task is being implemented by the CEMI RAS team using an agent-based approach [7–11]. The model developed simulates trade interactions among Russia, the USA, China, the European Union and the united rest of the world [12]. The series of calculations carried out in 2021 did not assume the scenario of such a global trade war against Russia, which we are currently witnessing, so the adaptation of the model to new realities becomes an urgent task. In particular, the purpose of this work is to assess the needs of the Russian economy for additional investments in various industries for large-scale import substitution of products hitherto supplied by unfriendly countries.

The processes of investment in the Russian economy have been studied from various points of view: the impact of the investment and state monetary policy [13–15], foreign investment [16], and distribution of investment between old and new technologies [17]. Despite the relatively lower efficiency of public investment compared to private investment, as shown in [13], under the current conditions, the role of public investment in the affected sectors of the economy is increasing.

Calculations on the model developed will make it possible to assess not only the required investment volumes, but also their impact on the reorganization of supply chains and dynamics of the country's domestic product, as well as the risks associated with insufficient investment activity of organizations and the state.

1. Methods

Agent-based modeling was chosen as the main research method. This makes it possible to evaluate the dynamics of the global system as a result of the interaction of various agents: countries, organizations and residents [18, 19]. Compared to such a widespread approach to building computer models of the economy as computable general equilibrium models (CGE), agent-based models have a number of features that determine their ability to reproduce complex socio-economic processes:

1. Heterogeneity of agents and their characteristics, which allows us to use different behavior models for them.

2. Direct interaction between agents that influences their decisions.

3. Bounded rationality of agents.

Based on these principles, agent-based economic models (ACE) can serve as a kind of computer laboratory for assessing the impact of policies on macroeconomic dynamics [20]. The ACE approach is used to model tax [21], monetary [22, 23] and macroprudential policy [24, 25], as well as regulation of the labor market [26].

In the model developed for trade wars, the interaction between agents determines the direction and structure of commodity-money flows between countries and their change under the influence of demand and government regulation. The study presented in this paper was carried out in accordance with the following methodology:

1. Reproduction in an agent-based model of the existing sectoral structure of the economies of the countries under consideration and trade relations between them (modeling "as is"). In conditions that are constantly changing at the moment, it seems correct to clarify that the existing structure is understood as the structure that existed before the start of the special operation and the international sanctions that followed.

2. Drawing up scenarios for the external economic situation, taking into account both packages of sanctions already introduced and those planned.

3. Modeling structural changes in trade relations between countries under conditions of the scenarios developed on the assumption of unlimited investment opportunities for organizations.

4. Estimating the amount of investment required to increase output in the sectors affected by the sanctions, based on the output of the simulation.

5. Modeling changes in trade relations in the context of limited investment opportunities for organizations and countries.

2. Structure of the model

The use of an agent-based approach makes it possible to achieve a high degree of detail in the model and reflect their consequences for the budgetary system, production, employment and incomes of residents in the model of trade wars. For each country considered in the model, the population is recreated in accordance with its gender and age structure (*Fig. 1*). The created agents-residents participate in the processes of production (like employees at workplaces) and consumption of products produced by agents-organizations.

Organizations in the model are enlarged and represent a group of organizations in the same industry in the country for which their indicators are aggregated: output, number of workplaces and volume of fixed assets characterizing production capacities.

Trade relationships in the model are defined through the supply chain of organizations, while export and import supplies form the international trade exchange. Supplies in the model are divided into three types:

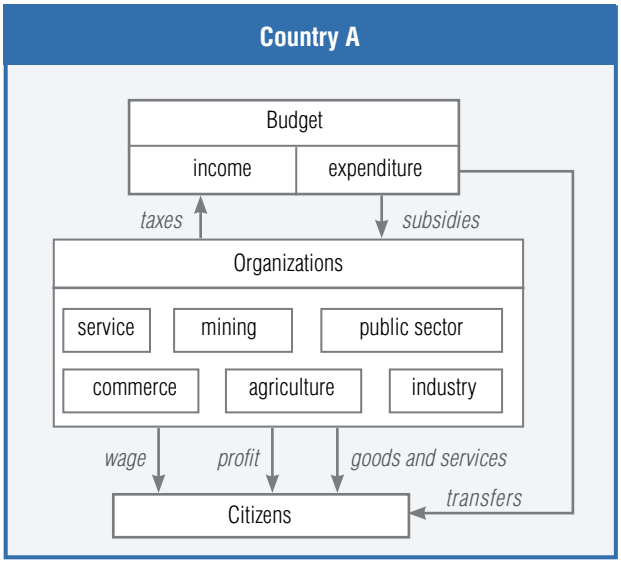

Fig. 1. Relationships between model objects within one country.

- intermediate supplies of raw materials and components to other organizations, for the convenience of further calculations, are divided into current (directly dependent on output volumes) and static;
- investment supplies of fixed assets, in which the main (purchase of machinery, equipment and buildings) and additional (purchase of products of other industries, reflected in the accounting as investments) are distinguished;
- supplies of final products, the buyers of which are agents-residents.

Supply of each type can be realized (in the past period) and planned (calculated for the next period). Planned deliveries are used to regulate and calculate changes in trade relations. For each supply, the identifier of the supplier and buyer, date, delivery volume, sale and purchase price are specified. The sale price is set in the currency of the state where the supplier agent-organization is located, without taxes. The purchase price consists of the sale price, sales taxes, export and import taxes (for international supplies), and is converted into the currency of the state in which the buying agent-organization is located.

States have a national currency, the rate of which is set relative to the currencies of other countries. The budgetary system of each state receives revenues through the tax system and makes expenditures, including paying benefits to the population and subsidies to organizations, and also finances the public sector of the economy. For the states, a budget is built for each model year; this includes revenue and expenditure parts presented in aggregated form (*Table 1*). Furthermore, the functions of the state in the model involve the introduction of restrictions on the import and export of products of certain industries.

Table 1.

Budget structure in the model

Income	Expenditure
Wage taxes	Public sector financing
Domestic production taxes and excises	
Export taxes and excises	Subsidies for the national economy
Import taxes and excises	
Government loans	Government loan servicing
Other income	Other expenditures

The developed model of trade wars considers the dynamics of trade relations among a number of countries and their associations: Russia, the USA, China, the European Union and the rest of the world (*Fig. 2*). Trade among countries is determined, on the one hand, by the needs of their economies, and, on the other hand, by the current sanctions restrictions on imports and exports. In light of recent events, the countries in the model can be divided into three groups:

1. The initiators of the economic war which introduced the largest number of sanctions: the US and the European Union (in *Fig. 2* on the left).

2. Sub-sanctioned countries with large economies: first of all, Russia, against which the largest number of restrictions apply, as well as China, against which the United States has imposed economic sanctions since 2018 (in *Fig. 2* on the right).

3. The rest of the world (ROW), which is considered to be a conditionally neutral enlarged country in the model, although it includes both countries that also imposed sanctions against Russia, and countries that did not support the imposition of restrictions, as well as countries under Western sanctions.

The software structure of the agent-based model of trade wars includes algorithms for the formation of the population and organizations, the dynamics of the economic environment, and the implementation of sanctions restrictions. In the first group of algorithms, the initial generation of resident agents, organizations (with the definition of output volumes, supplies, fixed

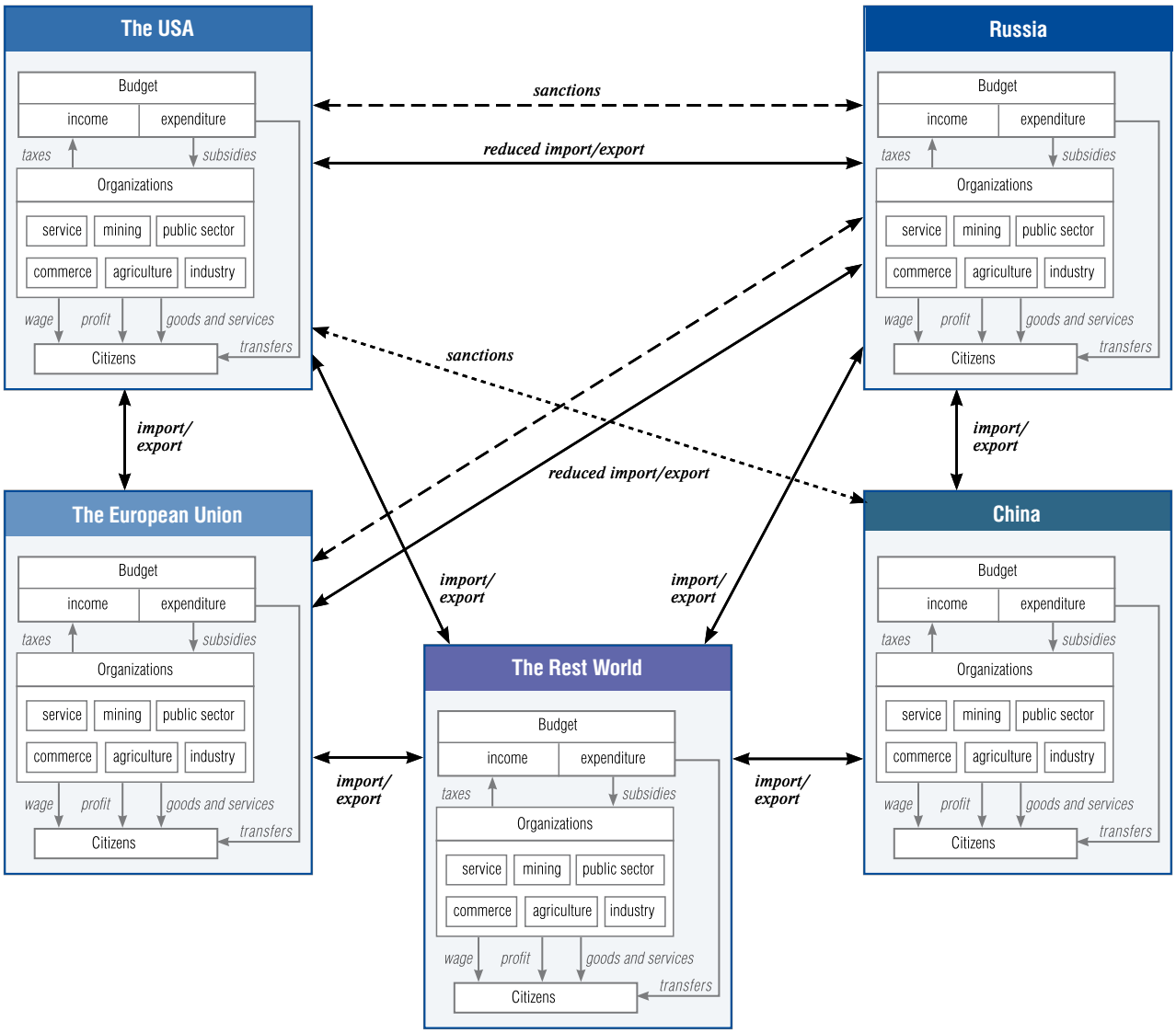

Fig. 2. Conceptual structure of the agent-based model of trade wars.

assets) and jobs are created, where resident agents are fixed. These issues are considered in detail in [27, 28]. The second group of algorithms includes implementation of the following processes:

- production: purchase of raw materials, production delay, wholesale of products;
- consumption: receiving wages and purchasing final products;
- public administration functions: payment of benefits to the population, financing public sector organizations and investments in the national economy through organizations of agriculture, mining and manufacturing industries;
- change in the supply chain as a result of sanctions restrictions;
- calculation and planning of necessary investments.

Model events in the sphere of production and consumption of products in the model of trade wars are considered in [12]; functions of the budgetary system are presented in [29].

Trade restrictions in the model are considered from two sides: restrictions on the import of certain types of products from a number of countries and restrictions on exports to other countries. Each restriction is presented by the following data set:

$$TR = <S_1, S_2, t, i, r, y>,$$

where S_1 – country in the model;

S_2 – trade partner country of S_1;

t – type of trade relationship subject to restrictions (import or export);

i – industry whose products are subject to restrictions;

r – the value of the trade restriction in shares relative to the volume of trade relations in the previous period;

y – model year in which the trade restriction was introduced.

To adjust the existing structure of trade relations in the context of introduction of new sanctions, an assessment is made of the availability of import supplies for purchasing organizations from each country and supplier organizations from trading partner countries. If new restrictions are introduced in the pair of countries and industry under consideration, then the volume of supply is reduced, and the difference is entered into the array of missing supplies for the supplier's industry. After considering all supplier countries, the formed array of missing supplies is distributed between domestic suppliers and suppliers from countries that did not impose trade restrictions. The algorithm for implementing trade restrictions is presented in more detail in [7]. The implementation of this algorithm leads to a change in sales and output of organizations from countries involved in a trade war, and an increase in trade flow with friendly and neutral countries.

3. Modeling investment dynamics

The planning of the necessary investments of organizations consists of regular costs for maintaining the fixed assets (FA) fund and the costs of increasing production capacities in accordance with the expected dynamics of output (*Fig. 3*). The cost of maintaining the fixed asset fund is assumed to be equal to the depreciation allowance known from country and industry statistics.

To estimate the costs of increasing production capacity, data on the cost of fixed assets of the organization of the industry i in the country j E_i^j are used. As a result of the algorithms described above for adjusting sales volumes, the output growth coefficient for each organization KV_i^j is known. The volume of investments for the increase of production is calculated as:

$$IP(t+1)_i^j = E_i^j \cdot KV_i^j,$$

where $IP(t+1)_i^j$ – investments in the increase of production in the period $(t+1)$.

The growth rate of the organization's investments in the next period is calculated relative to the investments of the current period :

$$KI(t+1)_i^j = \frac{IP(t+1)_i^j + IA(t+1)_i^j}{IP(t)_i^j + IA(t)_i^j},$$

where $KI(t+1)_i^j$ – the growth rate of investments of the organization of the industry i in the country j in period t;

$IA(t)_i^j$, $IA(t+1)_i^j$ – depreciation charges in periods t and $(t+1)$;

$IP(t)_i^j$ – investments in the increase of production in the period t.

According to the calculated coefficient $KI(t+1)_i^j$ the plan of investment supplies of organizations is corrected, then the sequential processing of supplier organizations takes place, within which the values of their sales and intermediate supplies are adjusted. The procedure for checking supplier organizations is determined by their industry affiliation: first, organizations producing final products (light industry), then intermediate (production of fuel, materials and chemical products) and finally – raw materials (agriculture and mining).

To exit the algorithm from the recursion of recalculation of mutual deliveries, an assumption is introduced into the model that separates current (depending on the volume of output) and static intermediate supplies by industries of suppliers and buyers. Supplies are divided in such a way that in the terminal sectors of the algorithm (agriculture and mining) all intermediate supplies are static. This assumption makes it possible to avoid looping the algorithm, since the organizations of industries that do not need to adjust the circulating supplies of raw materials from other industries after output changes are processed last.

4. Initial data

The information content of the agent-based model of trade wars is carried out on the basis of data from official statistical agencies: the All-Russian State Statistics Service [30], the US Bureau of Economic Analysis [31], the National Bureau of Statistics of China [32] and Eurostat [33], as well as the World Bank [34]. In all the sources presented, selections by key parameters and their download in Excel document format are available, with the exception of the National Bureau of Statistics of China, which publishes statistical yearbooks in the form of pictures of the corresponding pages.

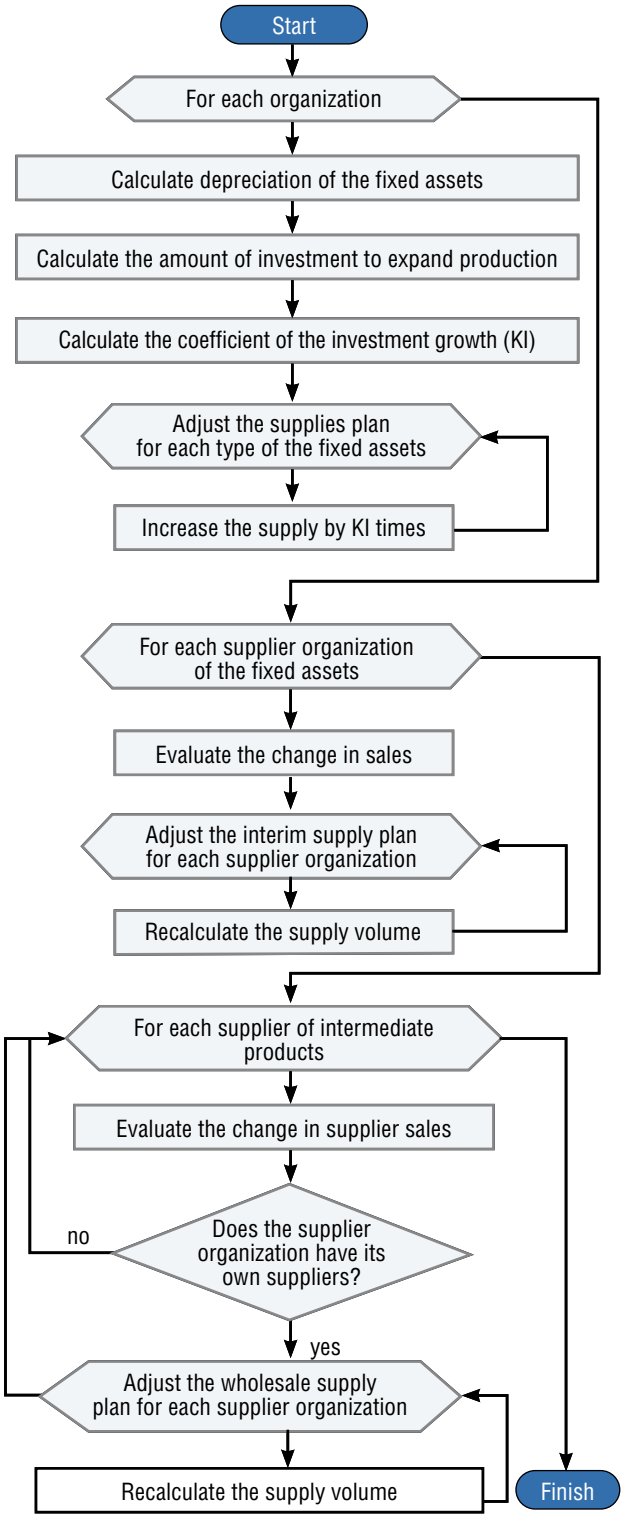

Fig. 3. Algorithm for calculation of investments.

The greatest difficulty at the stage of information content of the model is the collection and unification of data on the economic relationships of organizations in different countries, including intersectoral supplies, imports and exports of various types of products. An indispensable source of such data are input-output tables, which are published for each of the countries represented in the model (Russia, China, USA), as well as the countries of the European Union, considered as a whole. There are two difficulties in using official input-output tables to generate simulation input tables. First, the industry classifiers used to generate input-output tables vary from country to country, and therefore direct comparison of industries and products is not possible. While the classifiers of the European Union (63 industries) and Russia (60 industries) are quite similar, the United States (71 industries) and China (17 industries) have significant differences from

Table 2.

Value added of consolidated industries in various countries, in units of the national currency

Industry in the model	Country in the model				
	Russia, billion rubles	USA, billion dollars	EU, billion euro	China, billion yuan	ROW, billion dollars
Agriculture, food production	5865.7	441.3	511.8	10755.6	4015.6
Mining	12622.5	293.3	42.2	3194.1	1192.5
Fuel production	2545	157.4	60.6	2486.1	928.2
Public sector	13827.5	4522.7	1384.8	8947.6	3340.6
Chemical production	2080.6	534	433.2	4586.8	1712.5
Production of the materials	3993.9	383.8	393.1	3831.9	1430.6
Production of transport and equipment	3166.9	860.4	874.9	7558.7	2822
Light industry	432.9	136.8	168	3983.9	1487.4
Service	35350.8	10503.9	8275.7	27388.2	10225.3
Commerce	12737.8	1934.9	1642.4	13941.8	5205.1
Construction	5340.6	890.6	852.1	6241.6	2330.3
Total in national currency	97964.2	20659.1	14638.8	92916.3	34690.1
Total in USD	1687	20659.1	15689	14280	34690.1

Calculated by the author on the basis of data from the FSSS, the US Bureau of Economic Analysis, Eurostat, the National Bureau of Statistics of China and the World Bank.

them. To solve this problem, the model creates 11 aggregated industries, each of which corresponds to one or more industries from the input-output tables of countries (*Table 2*). Also, the industries of the model are compared with the Standard International Trade Classification (SITC) to aggregate countries' imports and exports.

Secondly, the time periods for which input-output tables are presented differ: data for 2019 are available for all countries, with the exception of China, for which the latest input-output tables refer to 2017. To ensure that the most up-to-date information for all countries is used, industry output and supply data are updated to 2019 using China's GDP growth rates available on the World Bank website [34]:

$$a_{kl} = \sum_{ij=1}^{n}\sum_{=1}^{m} a_{ij} \cdot \frac{va_i^{2019}}{va_i^{2017}},$$

where k – an aggregated industry in the model that includes a number of industries of the economy $i = \overline{1,n}$;

l – an aggregated industry in the model that includes a number of industries of the economy $j = \overline{1,m}$;

a_{kl} – supplies of the organization of an aggregated k from the organization of an aggregated l;

Table 3.

Information on fixed assets (FA) of organizations in Russia

Industry in the model	Cost of FA, billion rubles	Commissioning of new FA, billion rubles	Depreciation of FA, billion rubles
Agriculture, food production	9948.1	1045.2	408.8
Mining	29774.9	3085.4	1115.1
Fuel production	3532.9	340.7	237.3
Public sector	23560.3	1348.3	2847.9
Chemical production	3460.8	333.7	255
Production of the materials	6388.7	616.1	420.7
Production of transport and equipment	5289.8	510.1	482.9
Light industry	744	71.8	70.1
Service	258369.6	14136.8	6005.5
Commerce	5567.8	560.9	2288.7
Construction	3094.1	459.9	138.2
Total:	349731	22508.9	14270.2

Calculated by the author on the basis of data from the FSSS.

a_{ij} – supplies of industry i from the organization of industry j according to the data of the input-output balance;

va_i^{2019} and va_i^{2017} – value added of industry i in 2017 and 2019 respectively.

The GDP of the rest of the world is calculated based on the World Bank data as the difference between the global GDP ($87 trillion) and the GDP of the countries considered in the model ($52.3 trillion). We consider the sectoral structure of the economy of the rest of the world to be similar to that of China, which is the largest among developing countries. The results of the calculations are presented in *Table 1*.

Information about fixed assets available to organizations, their depreciation and commissioning of new ones is also presented for aggregated industries in the model (*Table 3*).

5. Scenarios

Until 2020, when building forecasts for the development of the Russian economy, the price of Urals oil, the exchange rate of the ruble against the US dollar, inflation, GDP dynamics, exports and imports of goods were taken into account as the main scenario parameters [35]; at the same time, the decline in energy prices and the depreciation of the ruble against the US dollar were considered traditional risk factors.

Serious adjustments to the formation of forecast scenarios were made due to the coronavirus pandemic, which caused such difficulties as a slowdown in the global economy; decrease in demand for raw materials, goods and services; decline in trade, tourism, public catering. The maintenance and introduction of epidemiological restrictions has become a new risk factor in the global economy, affecting the volume and structure of final demand and, as a result, output and employment in a number of industries. In this context, two scenarios have been developed: an optimistic one, which assumes the stabilization of the epidemiological situation, and a pessimistic one, in which bursts of incidence are regularly repeated, causing the introduction of new restrictions [12]. At the moment, a conservative epidemiological scenario seems more likely, in which the repetition of waves of coronavirus infection does not lead to a further slowdown in the global economy, and the epidemiological restrictions introduced affect only certain regions.

After the start of Russia's military special operation in Ukraine, the formation of forecast scenarios for the global economy became an even more difficult task. The United States and the European Union are introducing unprecedented sanctions, the consequences of which affect not only Russia, but the whole world. The phenomena observed in recent months show the need not only to consider new risk factors for the Russian and global economy, but also their new combinations; in particular, the ruble exchange rate has shown stability which was not observed earlier in crisis periods. At the same time, one of the significant risk factors is inflation, which arose against a background of fluctuations in the ruble exchange rate; but after its stabilization, prices did not return to their original level due to pressure from the supply side, a break in international supply chains and an expected shortage of various goods and components.

In these conditions, within the framework of calculations on the agent-based model of trade wars, the exchange rate of the ruble to the US dollar, the dynamics of energy prices and expected inflation are taken into account as scenario parameters. In the context of the political situation, three scenarios are proposed:

1. Reinforcement of US and EU sanctions up to limiting their trade exchange with Russia by 70–90%.

2. Preservation of sanctions with a decrease in trade exchange with unfriendly countries by 40–60%.

3. Reduction of sanctions up to 20–30% of imports and exports.

The proposed values of the scenario parameters are presented in *Table 4*. World energy prices are in direct correlation with the sanctions imposed, since they are growing against the background of a shortage and an increase in the cost of logistics, while in the case of reinforced sanctions, the price at which Russia can sell them decreases, due to a limited number of possible buyers. Despite the fact that the measures taken by the Bank of Russia to stabilize the ruble exchange rate have shown their effectiveness, the forecast exchange rate of

75 and 90 rubles per dollar, respectively, is used to make calculations in the context of preserving and reinforcing sanctions. If the ruble exchange rate shows its stability in the long term, then scenarios for preserving and reinforcing sanctions will require adjustments to this parameter.

The restriction of trade exchange between countries is set in the form of restrictions on imports and exports as a percentage of their volume in the previous year (in *Table 4* – as a percentage of the values of 2021). The dynamics of countries' GDP and international trade volumes are calculated based on the results of the simulation output.

6. Results and discussion

The agent-based model of trade wars was programmed in C# MicrosoftVisualStudio based on the developed algorithms. The choice of a software tool is due to the need to work with a large amount of data and the related optimization of procedures and functions, which is difficult in standard modeling environments. The scaling of the model was set at the level of 1:10 000; thus, in total, about 800 000 residents were created in five countries (Russia, the USA, China) and their associations (the EU and the enlarged rest of the world). The information support of the model is presented in the form of a database using initial data loaded in Excel format (the procedure for converting statistical data from various countries to a common format is discussed in the corresponding section). The database of the model of trade wars is managed using the PostgreSQL DBMS. Scenario parameters are also loaded from the table, and the corresponding modeling parameters (inflation, trade restrictions between countries, exchange rates) are reset.

The purpose of calculations based on the developed model is not so much to build forecasts of the dynamics of the Russian economy, which is an extremely difficult task in the current conditions, as to analyze scenario deviations with various possible combinations of external factors and control influences. The first series of experiments consisted of three calculations aimed at modeling structural changes in trade relations between countries and the increasing need for the Russian economy to invest in import-substituting projects. According to the scenario parameters, the trade turnover between Russia and Western countries (the USA and the EU) decreases by 30%, 50% and 80% year-on-year with the reduction, preservation and reinforcing of sanctions, respectively, which is partially compensated in monetary terms by price increases. Based on the output data of the first series of experiments, an assessment of the volume of investments required to increase output in industries affected by sanctions is carried out, and the cost of organizing new import-substituting production capacities is taken into account while the costs of maintaining the fixed assets of organizations

Table 4.

Scenario parameters

Scenario parameter	Scenario		
	Reinforcement of sanctions	Preservation of sanctions	Reduction of sanctions
Dynamics of energy prices, %	–20	15	20
Ruble to US dollar exchange rate	90	75	60
Restriction of trade exchange between Russia and unfriendly countries, %	80	50	30

(depreciation charges) and annual budgetary costs for the national economy are excluded. The estimates obtained for various scenarios are presented in *Table 5*.

In the second series of calculations, an assessment was made of the impact of investment volumes on the economic situation in Russia. To do this, within each scenario, six investment policy options were considered, where option #1 assumes the absence of additional investments for the implementation of import substitution programs, and option #6 – investment of the entire required estimated amount presented in *Table 5*. Intermediate options reflect options for partial additional investment: 20, 40, 60 and 80 percent of the required estimated amount in each scenario.

The graphs presented in *Fig. 4* reflect the results of 18 experiments carried out, the output of which was the forecast of the dynamics of Russia's GDP in 2022 relative to the values of the base year 2021. An analysis of the results of the second series of experiments shows that the impact of investments on the dynamics of GDP is stronger, the more severe the sanctions imposed by Western countries.

An increase in investment becomes critically important in the context of scenario No. 3 (reinforced sanctions), in which the implementation of a full range of import substitution programs makes it possible to reduce the decline in GDP from 12% to 10%. Under scenario No. 1 (sanctions reduction) in the current year, the Russian economy shows a weak dependence on the implementation of investment projects (less than 1% of GDP).

To conduct the third series of experiments within each scenario, two investment policy options were selected: option #2 (investing 20% of the required estimated amount) and option #5 (investing 80% of the required estimated amount) and modeling of trade relations for the 3-year period was carried out. The dynamics of Russia's GDP was also chosen as the output parameter of the simulation, and on the graph it is presented on an accrual basis relative to the values of the base year, which makes it possible to estimate the speed of economic recovery to pre-crisis values.

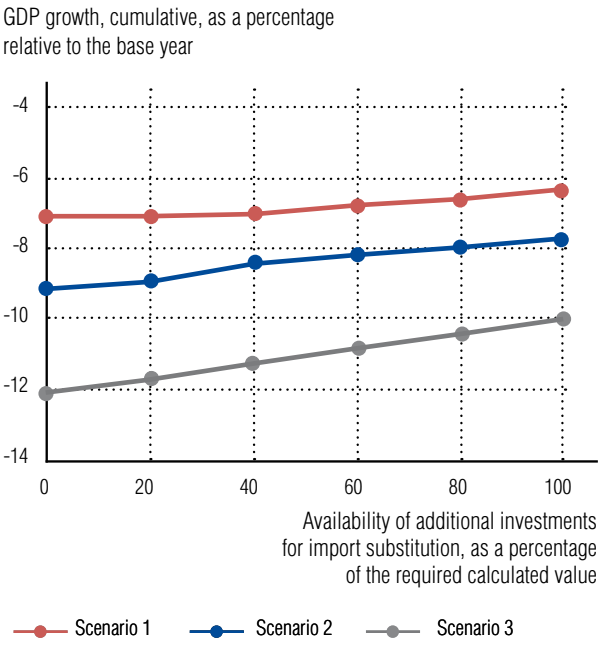

Fig. 4. Forecast of Russia's GDP dynamics under the conditions of various shares of additional investment from the required calculated values.

Figure 5 shows the forecast of GDP growth in the context of reducing international sanctions. After the fall in the current year, the Russian economy shows

Table 5.

The need of the Russian economy for additional investments in 2022, billion rubles

Parameter	Scenario 1	Scenario 2	Scenario 3
Additional investments	183	300	453

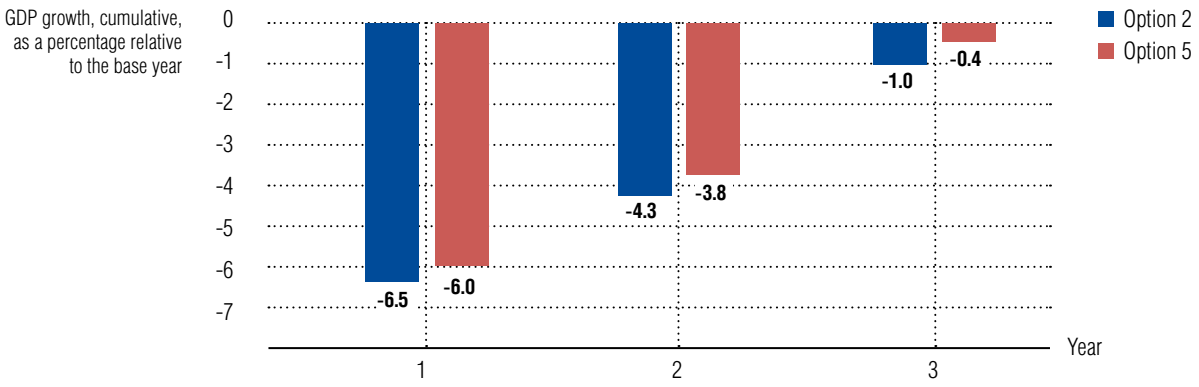

Fig. 5. Forecast of Russia's GDP dynamics in the context of the reduction of sanctions (scenario No. 1).

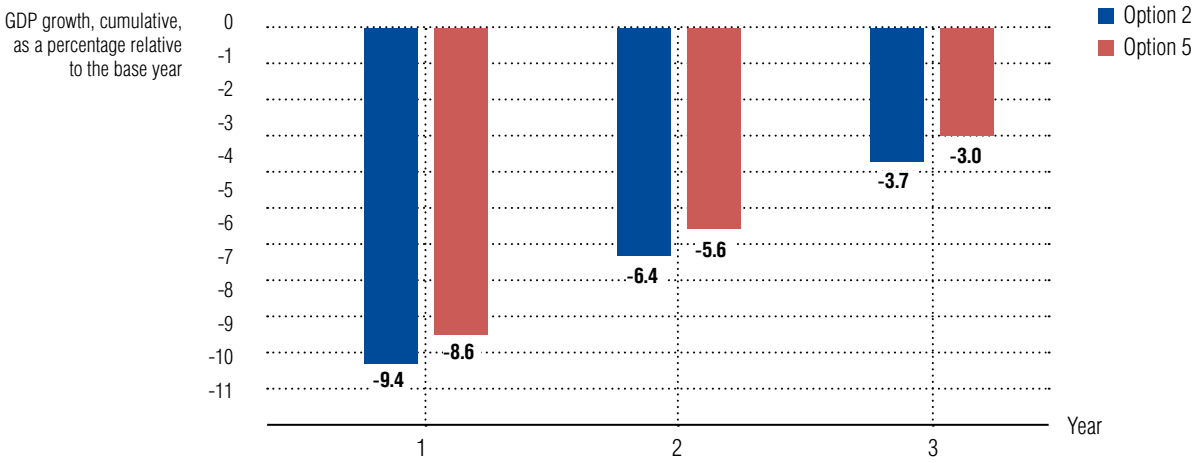

Fig. 6. Forecast of Russia's GDP dynamics in the context of preservation of sanctions (scenario No. 2).

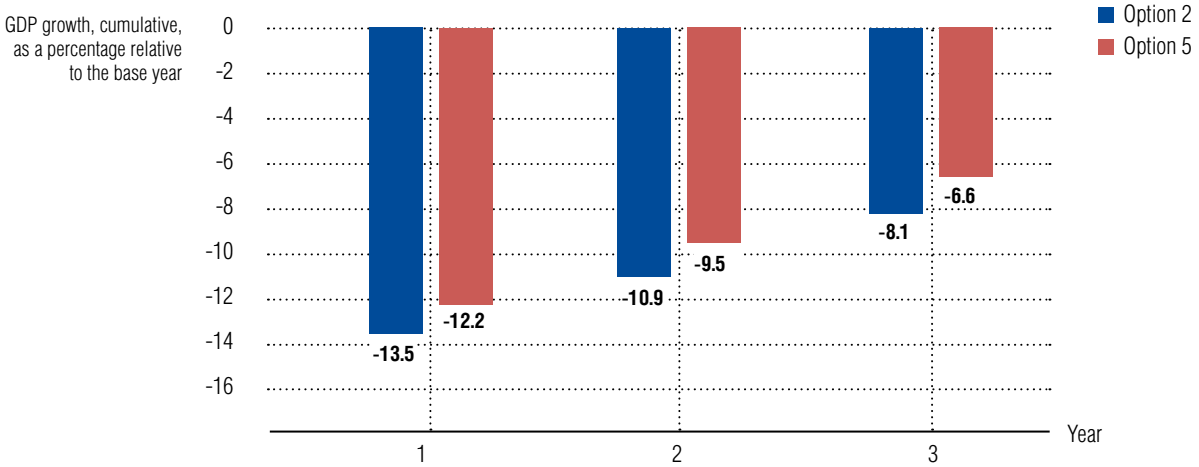

Fig. 7. Forecast of Russia's GDP dynamics in the context of reinforced sanctions (scenario No. 3).

moderate growth, and for the 3-year period it is almost returning to pre-crisis values, while the change in the volume of the import substitution program does not significantly contribute to this process (the difference is 0.6% of GDP for 3 years).

According to the calculations carried out, under the conditions of preservation of sanctions, the Russian economy is not recovering to pre-crisis values for the 3-year period, while the contribution of import substitution programs to GDP dynamics is also not very significant: the final increase over 3 years is 0.7% more when investing 80% of the required calculated value compared to investing 20% of it (*Fig. 6*).

The economic recovery is slowing down even more in the face of tougher sanctions, but the impact of investment volumes is increasing: for the 3-year period the implementation of import substitution programs by 80% of the required calculated value makes it possible to weaken the overall decline to 6.6%, which is 1.5% higher than the GDP growth relative to the expected values when implementing 20% of the investment program (*Fig. 7*).

Thus, the series of calculations we conducted show that the impact of investments on the economy, estimated through the forecast of GDP dynamics, is the strongest with the preservation and reinforcing of sanctions by Western countries. Under these conditions, the implementation of import substitution programs can accelerate the recovery of the economy and its growth rate after overcoming the crisis by an average of 0.5% per year compared to the forecast version, where investment programs are implemented on a smaller scale.

The results obtained are based on a number of assumptions embedded in the agent-based model of trade wars at the stage of its development. Firstly, it is an assumption about the complete substitutability of products of one industry, thanks to which goods and components that have fallen under sanctions can be replaced with domestic analogues or supplies from neutral and friendly countries. Secondly, logistical problems and delays that arise when changing suppliers are not taken into account, though they are especially serious due to the geographical remoteness of friendly Asian compared to unfriendly European countries; due to this assumption, production downtime is not taken into account when waiting for materials and components. Thirdly, it is assumed that there are countries in the world that have not joined the sanctions against Russia, and that they are willing and able to supply the required types of products, which in the conditions of the most negative foreign policy scenario may not be feasible. Also, due to the large number of uncertainties, the time horizon of the calculations carried out was limited to 3 years, although for a comprehensive assessment of the effect of the implementation of large-scale investment projects, it should be extended to at least 10 years.

Conclusion

This paper presents a computer model of trade wars, including Russia, the United States, China, the European Union and the united rest of the world as key participants in world trade. The model is using the agent-based approach and reflects the interaction of three types of agents: countries that introduce and remove trade restrictions, organizations that purchase and manufacture products both for the domestic market and for export, and residents living in countries working in organizations and consuming their products. The arrays of initial modeling data were formed on the basis of information from official statistical agencies of Russia, China, the USA, the European Union and the World Bank. All data loaded into the model, including inter-industry supplies, output, import and export of various types of products, were unified to 11 aggregated industries. To make forecasts, three scenarios of the external economic situation were formed: reduction of the imposed sanctions, their preservation and further reinforcement, while inflation, world currency rates and the share of trade turnover between countries falling under the imposed restrictions are set as scenario parameters.

The purpose of computer experiments on the model of trade wars in this work was to assess the need of the Russian economy for additional investments in various industries for large-scale import substitution of products hitherto supplied by unfriendly countries. To solve

this problem, three series of calculations were carried out. The first series of three experiments was aimed at modeling structural changes in trade relations between countries in the current year under the conditions of the developed scenarios, assuming unlimited investment opportunities of the state and organizations. Based on the results of this series, an estimate of the volume of investments required to increase output in the industries affected by sanctions was obtained: 183 billion rubles in the scenario of reducing sanctions; 300 billion rubles while preserving sanctions; 453 billion rubles with their further reinforcement. In the second series of 18 experiments, the impact of investment volumes on the dynamics of Russia's GDP in in the current year was assessed; for this purpose, six investment policy options with different volumes of investments in import-substituting industries were considered within each scenario. The results of the second series show that the dependence of GDP on investment is quite strong in the conditions of reinforcement of sanctions and relatively weak when they are reduced. To conduct the third series of experiments, two of the considered options were selected for each scenario, and simulation was carried out for the 3-year period. The results of the third series of experiments also show that the impact of investments on the economy is strongest when sanctions are maintained and tightened. Under these conditions, the implementation of import substitution programs in industry allows acceleration of the economic recovery by an average of 0.5% of GDP per year.

Calculations based on the model developed allow us to assess changes in trade turnover among countries under changing restrictions, the impact of this process on the production of various types of products, as well as the relationship between investment activity and the overall economic situation in different countries. In this paper, the constructed forecasts for the Russian Federation were presented, but an important area of further research is analysis of the consequences of the sanctions imposed on the Western countries that initiated this process, as well as consideration of the scenario of strengthening the trade confrontation between the United States and China under conditions of a possible new military conflict. ■

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