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MODELING THE QUALITATIVE DEVELOPMENT OF INDUSTRIAL ENTERPRISES UNDER SANCTIONS PRESSURE: AN AGENT-BASED APPROACH

Abstract: *In this paper we address the task of forecasting consequences of sanctions for economies of the involved countries by creating the agent-based model of trade wars. The developed model considers trade relation among Russia, European Union, China and the United States, and using it we study dynamics of demand for products and availability of supplies under sanctions. The model was programmed in MS Visual Studio; its information support is based on international statistical data. Two main scenarios were considered: (1) Western countries impose sanctions against Russia, the rest world is neutral; (2) severe sanctions are imposed against Russia and China. The first scenario showed that Russian enterprises are mostly sensitive to fluctuations in demand, while European enterprises suffer from reduction of fuel and material supplies. In the second scenario Chinese enterprises are affected by decrease of demand and American enterprises struggle to substitute supplies of materials and components.*

Keywords: *agent-based model; trade wars; sanctions; industrial enterprises; supplies*

1. Introduction

Introduction of sanctions by Western countries has led to a number of shocks for Russian enterprises: cessation of supplies, decrease in sales volumes, reduction in foreign investment, currency instability, loss of personnel due to mobilization and emigration (Kalinin, 2024). The current situation, along with the problems that have arisen, also creates opportunities and incentives for qualitative development of enterprises due to increased domestic demand, departure of foreign competitors and government investment (Zemtsov, 2024; Frolov et al., 2023). The most acute problem for Russian enterprises associated with economic sanctions against Russia has become difficulties in obtaining imported raw materials and components (Shirov, 2023). According to a survey of Russian enterprises conducted by the Institute of Economic Forecasting of the Russian Academy of Sciences, 67.4% of respondents faced this problem in the spring of 2022, and 59.5% at the end of 2023. The second most important problem was rise in prices of imported components (Kuvalin et. al., 2024). At the time of introduction of sanctions, reduction in opportunities for exporting products affected only 17.1% of enterprises, which is largely due to the organization of intermediary channels in the implementation of foreign economic transactions (Plakhin et

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al., 2024).

New opportunities for development of Russian enterprises are based on import substitution programs, primarily in the manufacturing industry (Golovanova & Krekhovets, 2024; Gusev & Yurevich, 2023; Malyshev & Pechenskaya-Polishchuk, 2024). However, the implementation of these investment programs takes time, and in the first year after introduction of sanctions, enterprises inevitably face a decline in sales volumes, which is partly mitigated by government support measures.

The restructuring of global supply chains caused by sanctions affects not only Russia, but also other countries. Enterprises in the EU countries are facing shortages and rising prices for energy resources, as a result of which many enterprises are closing or moving production to other countries (Roginko, 2024; Sapir, 2023). The United States, on the contrary, is a beneficiary of the current situation, capturing the European energy market, where they previously could not compete in price with Russian natural gas (Kopytin, 2023). China and India are also winners, having gained access to energy resources from Russia at a significant discount, and also expanded the sales volumes of their enterprises' products to Russia.

In the current international situation, the task of forecasting consequences of sanctions for economies of individual countries and the global economy as a whole is becoming especially relevant. Large-scale computer models that reproduce the processes of production, consumption, employment, and international economic relations are a suitable tool for solving this problem. Such models have been developed since the 1990s both for the global economy (Hof et al., 2009; Timmer, 1998 Francois et al., 2013; Egger et al., 2015) within the framework of the GTAP standard (Aguiar et al., 2016; Corong et al., 2017; Van Tongeren et al., 2017) and for individual trade zones (Li et al., 2018; Bolt et al., 2019). Russia is considered as a participant in international trade only in the global model WorldScan (Lejour et al., 2006), however, publications presented on it do not contain calculated data on the consequences of sanctions that have been introduced for 10 years already.

The agent-based model of trade wars developed by our team considers Russia as one of the key global players, along with the European Union, China and the United States. The results of its work are presented in a number of publications:

- (Mashkova & Bakhtizin, 2022) examines effect of introduction of new sanctions against Russia in various scenarios of global epidemiological situation on volumes of imports and exports;
- (Mashkova, 2023) assesses the need of the Russian economy for additional investments in various industries for large-scale import substitution of products supplied from unfriendly countries;
- in (Mashkova & Bakhtizin, 2024) we examine four scenarios of sanctions against Russia and China in the coming years and assess their impact on economies of the countries involved through GDP indicators.

The purpose of this work is a more detailed analysis of the consequences of sanctions for manufacturing enterprises. Based on the developed model, the dynamics of two factors that determine possibility of qualitative development of industrial enterprises are studied: demand for products and availability of raw materials and components. In addition to the scenario of sanctions against Russia, the experimental studies also considered a potential scenario of large-scale sanctions against China introduced by Western countries, which is likely in case of military action around Taiwan (Mikheev, 2023; Bolgova et al., 2022).

2. Materials and methods

The agent-based model of trade wars includes two main blocks: formation of model objects and dynamic modeling procedure (Figure 1).

The objects are created at the start of work based on the source data files, and then saved in the model database.

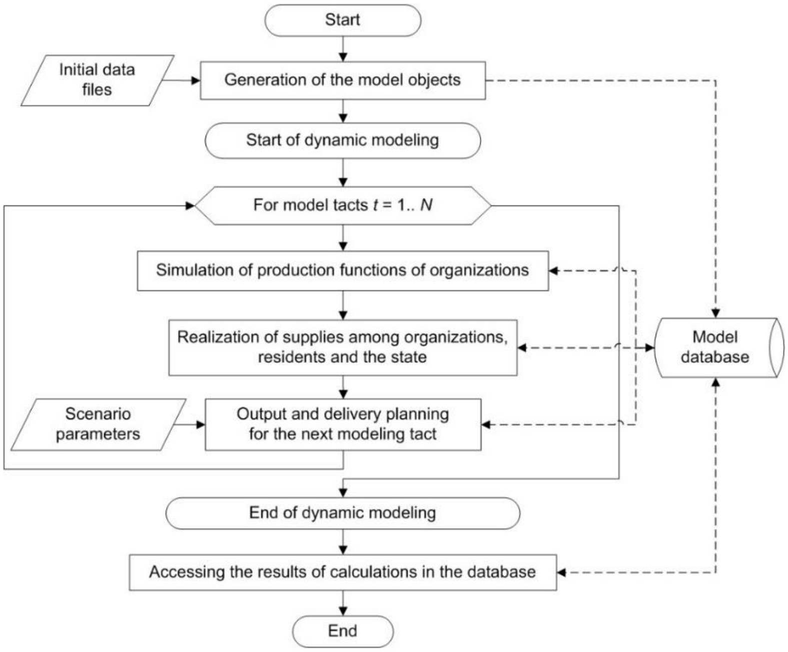

Figure 1. Order of simulation in the agent-based model of trade wars

The dynamic modeling procedure includes simulation of production processes of organizations (industrial enterprises as well as mining, agriculture, construction and service), supplies trade among contractors of various types (organizations, residents, countries), recalculation of output and redistribution of sales taking into account changes in the external economic environment using the scenario parameters of the model. The dynamic modeling procedure is repeated at each cycle of the model time, corresponding changes in the state of the model objects are saved in the database. At the end of the simulation, access to the results of the calculations is carried out through special queries to the model database.

The source data required to create model objects is loaded as the following files:

- list of countries containing identifiers and names of each country in the model;
- list of industries, including identifiers and names of industries in the model;
- list of organizations with the identifier of the country where the organization is located, the industry to which it belongs, general information about the annual output, price and cost of fixed assets.
- files of supplies of four types: basic intermediate, additional intermediate, basic investment and additional investment, filled on the basis of official input-output balances of countries.

Model objects are created in the following sequence:

1. Creation of countries and industries based on the data in the relevant files.
2. Creation of organizations, establishing links with the countries and industries; filling in data on the output, price and cost of fixed assets based on information from the list of organizations; calculating the initial volume of stocks of own products in the warehouse:

$$V_z = V_m * kZ \quad (1)$$

where V_z – initial stock volume, V_m – the volume of the organization's output per month according to the initial data, kZ – a coefficient that determines the ratio of the average volume of stocks of products in a warehouse to the monthly output of the organization based on statistical data for various industries.

3. Creation of planned supplies of organizations, while for each supply is set seller's ID, buyer's ID, type of supply (1 – basic intermediate, 2 – additional intermediate, 3 – basic investment, 4 – additional investment), type of buyer (organization, state or population), tact = 0 (scheduled supply), supply volume equal to the value from the source data file.
4. Formation of a production plan defining the norms for use of raw materials for production of the required volume of products.
5. Initialization of stocks of raw materials in the warehouses of organizations, for each organization and industry of supplies, the stock is calculated as follows:

$$Z_i = PP_i * kZ_i \quad (2)$$

where Z_i – initial volume of raw materials stocks by industry i, PP_i – volume of raw materials used by industry i according to the production plan, kZ_i – a coefficient that determines the ratio of the average volume of raw materials stocks by industry i in the warehouse to the monthly needs of the organization based on statistical data.

The generated model objects are stored in the database, while the necessary relationships among objects are established through foreign keys (Figure 2).

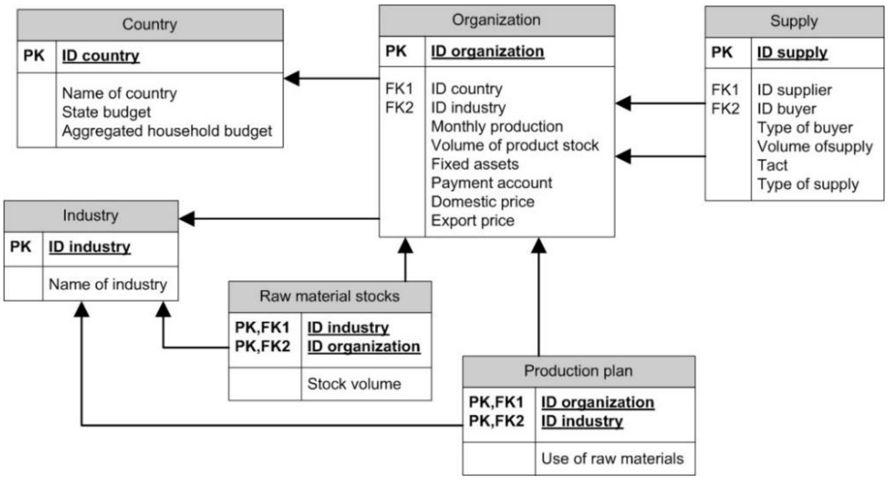

Figure 2. Conceptual scheme of the trade wars model database

The implementation of production functions of organizations is carried out on the basis of planned values set at the stage of generation of model objects (at the first tact of model time) or recalculated based on scenario parameters (starting from the second tact). In both cases, the following steps are performed for each organization:

- all lines from the table "Production plan" are selected, and for each selected line, the stock of the component in the corresponding industry in the warehouse is reduced;
- the stock of finished products of the organization in the warehouse increases by the volume of its monthly output;
- wages are paid to employees and credited to the total budget of households;
- taxes are calculated and paid to the country's budget.

At the end of the modeling of the production process, sales of the organization's products are made in accordance with the algorithm shown in Figure 3.

For each organization in the model, its planned supplies as a seller are selected and the following actions are performed:

- the stock of products in the warehouse of the selling organization is reduced by the volume of the supply;
- the supply cost without taxes is calculated:

$$S = V_{post} * Price \tag{3}$$

where S – cost of supply, V_{post} – volume of supply in conventional units of products, $Price$ – price of products set by the seller (if the buyer is in another country, then the price of exported products may differ from that set on the domestic market).

- the supply cost is credited to the seller's payment account.

Further actions depend on the type of buyer (organization, state or population) and the type of supply. If the buyer is a state, then the cost of the supply is written off the state budget, thus reflecting costs of the public sector of the economy (education, healthcare, administration, defense and security). For resident buyers, the final products and services purchased are recorded as an aggregate supply from the trade sector, the cost of which is written off the aggregated budget of households. If the buyer is an organization, then the cost of supply is debited from the buyer's payment account. If the seller and the buyer are located in different countries, then the cost of supply is converted into currency of the country where the organization-buyer is located:

$$S^* = S * CurrencyRate \tag{4}$$

where S^* – cost of supply in the currency of the buyer, S – cost of supply in the currency of the seller, $CurrencyRate$ – exchange rate of currency of the seller relative to the currency of the buyer.

Basic intermediate supplies (type 1) are accounted by increasing stock of raw materials in the buyer's warehouse, and upon receipt of investment supplies (type 3 or 4) cost of fixed assets of organization-buyer increase.

After all the above actions, the amount of sales taxes is calculated, debited from the buyer's payment account and credited to the country's budget, and if the seller and the buyer are in different countries, then taxes are credited to the budgets of both countries in accordance with the current rates of taxes and excises.

Recalculation of output and supplies for the next period is carried out at the end of each tact of model time in accordance with scenario parameters loaded from the corresponding files. For the trade wars model, the following are set as scenario parameters:

- exchange rates of currencies relative to each other;
- expected inflation in each country;

- expected dynamics of final demand in each country;
- share of countries in substituting of supplies - a parameter that characterizes possibility of substituting supplies in the industry with the help of domestic producers or suppliers from friendly countries; the sum of the shares of countries in one industry cannot exceed one, the sum of less than one means limited possibilities for substituting of resources;
- trade restrictions set for each pair of countries as a percentage of trade turnover by industry.

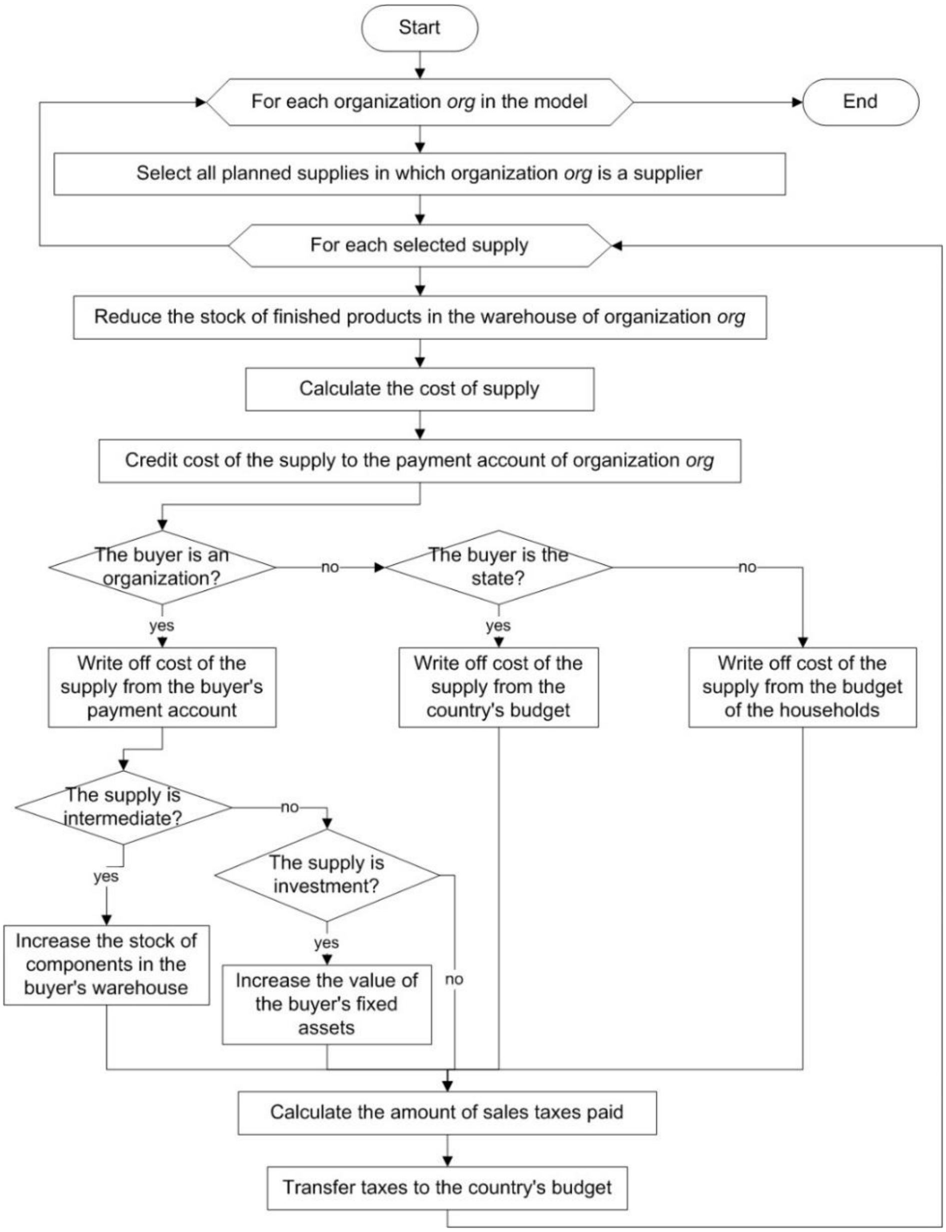

Figure 3. Algorithm for implementation of supplies

Recalculation of output and supplies is carried out in four stages:

1. Redistribution of non-basic supplies among sellers under the influence of sanctions. At this stage, changes in additional intermediate and investment supplies are processed, which do not have direct impact on output volumes in the current modeling cycle.
2. Recalculation and redistribution of orders for basic intermediate supplies of raw materials and components, the shortage of which directly affects output volumes. The supplies required by organizations are calculated taking into account changes in final and intermediate demand and recorded in the required supplies submitted for consideration by the sellers.
3. Recalculation of sales. At this stage, received orders for the products of organizations are compared with production capacities of organizations, available volume of raw materials and components. Based on these factors, available supplies are formed, information about which is returned to organizations-buyers.
4. Final recalculation of supplies and output. At this stage, for each organization-buyer, the supplies required by it are compared with those available from suppliers. The bottlenecks in the supply chain and the final volume of purchases of raw materials and components are determined.

Further we consider each stage in more detail. At the stage of redistribution of additional and investment supplies under sanctions for each organization trade restrictions on suppliers are checked, and if such restrictions exist, then volume of supplies from sellers from unfriendly countries is reduced, and the lacking supplies are replaced by sellers from neutral countries. Actions at this stage affect volume of orders of organizations, and these changes are stored in the variable Z_m. The algorithm for redistributing supplies under trade restrictions is considered in more detail in (Mashkova & Bakhtizin, 2022).

At the stage of redistribution of basic intermediate supplies, the order in which organizations are processed is determined by their industry, with organizations that produce final products and provide services are processed first, and organizations of mining and agriculture are processed last. This calculation procedure allows to take into account changes in intermediate supplies among organizations and recursively make changes in output volumes caused by changes in supplies. For each organization, the following actions are performed (Figure 4):

- Demand for the organization's products is recalculated, taking into account changes in final and intermediate demand:

$$V_d = S_0 + Z_m + D_0 * kD \quad (5)$$

where V_d – estimated demand for products in the next cycle, S_0– organization’s planned sales to organizations- buyers, Z_m – accumulator of changes in the volume of orders for products from buyers, D_0 – organization’s planned sales to residents and the state, kD – expected dynamics of the final demand (scenario parameter).

- The coefficient of demand dynamics is calculated relative to the values of the current cycle:

$$k_d = \frac{V_d}{V_m} \quad (6)$$

where k_d –demand dynamics coefficient, V_d – estimated demand for products in the next cycle, V_m – output in the current cycle.

- The supply reduction factor kU is set equal to one.

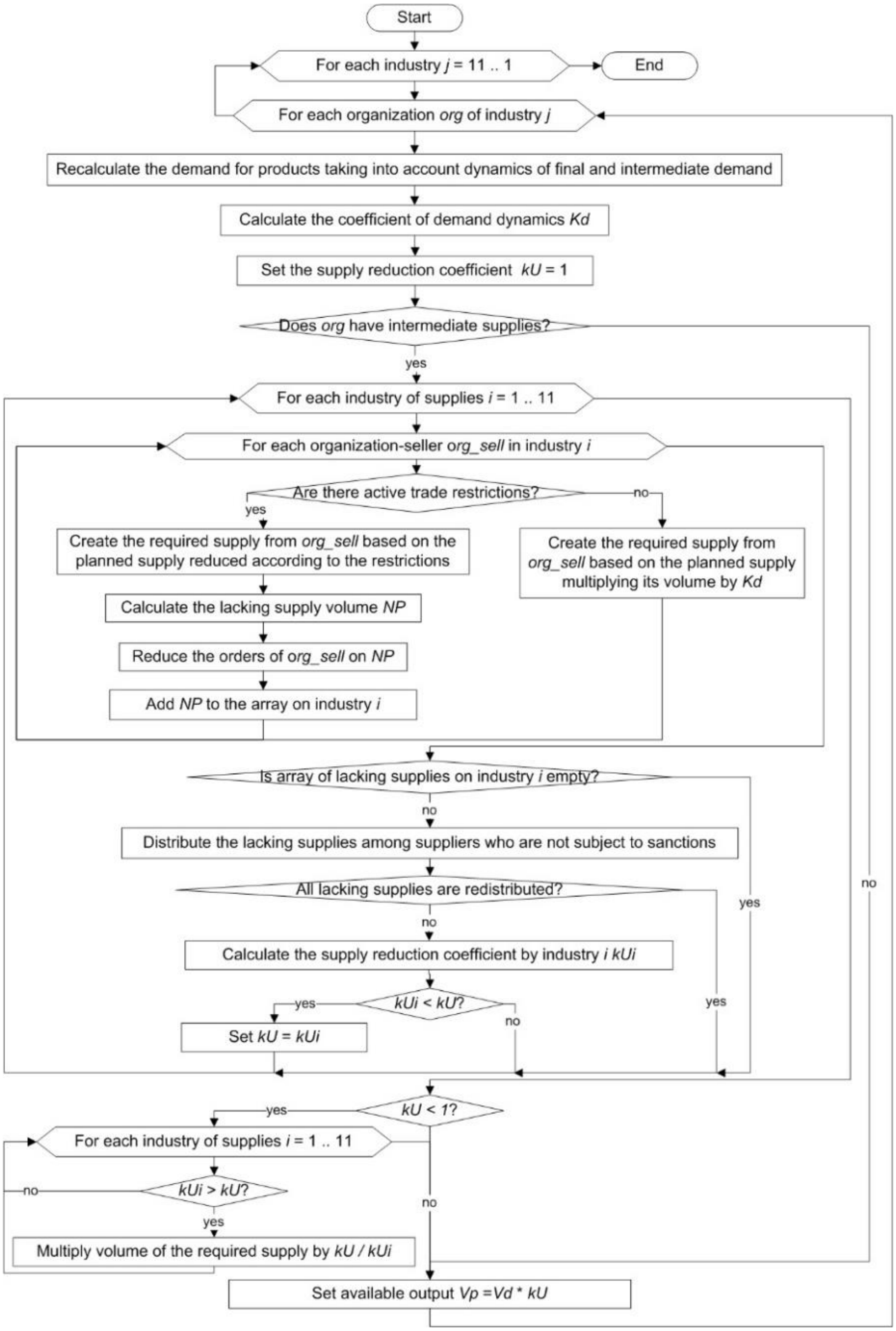

Figure 4. Algorithm for redistribution of basic supplies

A number of further actions are performed only for organizations that have basic intermediate supplies of raw materials and components, access to which directly affects the volume of output. For each supply by industry i, supply reduction factor kU_i is initialized to one, and for each supplier organization the current trade restrictions on imports and exports are checked and the required supply is created from the current supplier. If there are no restrictions, then the volume of the required supply is calculated as follows:

$$VP^{demand} = VP^{plan} * k_d \quad (7)$$

where VP^{demand} – required supply volume in the next period, VP^{plan} – planned supply volume in the current period, k_d – demand dynamics coefficient.

If trade restrictions exist, then the amount of required supply is calculated as:

$$VP^{demand} = VP^{plan} * TR_i^{imp} * TR_i^{exp} \quad (8)$$

where VP^{demand} – volume of required supply in the next period, VP^{plan} – volume of planned supply in the current period, TR_i^{imp} – trade restrictions on imports of industry i products by the country of the organization-buyer, TR_i^{exp} – trade restrictions on the export of products of industry i by the country of the organization-seller.

Also, if there are trade restrictions, the following actions should be performed:

- Decrease supplier's Z_m by the difference in volumes between planned and required supplies
- Calculate the amount of the lacking supply as:

$$VP^{unavail} = VP^{plan} * k_d - VP^{demand} \quad (9)$$

where $VP^{unavail}$ – the lacking supply, VP^{plan} – the planned supply in the current period, k_d – demand dynamics coefficient, VP^{demand}– the required supply in the next period under trade restrictions.

- Add lacking volume of supply $VP^{unavail}$ to industry i array.

If, after checking all sellers in industry i, the array of lacking supplies is not empty, then it is necessary to distribute the lacking supplies in industry i among the sellers that are not subject to sanctions in proportion to the shares of countries in substituting of supplies, increase of required supplies and accumulators of change in orders Z_m for these suppliers. If the sum of countries' shares in substitution is less than one, that means it is impossible to fully replace the need for raw materials and components as a result of the introduction of trade restrictions, then the following actions are performed:

- check the stock of components for industry i in the warehouse;
- calculate the reduction factor for industry i:

$$kU_i = \min\{1, \frac{(\sum VP_i^{demand} + W_i)}{(\sum VP_i^{plan} * k_d)}\} \quad (10)$$

where kU_i – supply reduction factor for industry i, $\sum VP_i^{demand}$ – sum of the required supplies for industry i in the next period under trade restrictions, W_i – stock of raw materials of industry i in the warehouse of the organization, $\sum VP_i^{plan}$ – sum of planned supplies of industry i in the current period, k_d– demand dynamics coefficient.

- if $kU_i < kU$, then set $kU = kU_i$.

If, after checking sellers in all industries of basic intermediate supplies, the supply reduction factor kU turned out to be less than one, then it is necessary to proportionally reduce orders for all sectors of basic intermediate supplies. To do this, for each industry the reduction factor kU_i is compared with the final reduction factor for the organization kU, and if $kU_i > kU$, then the volume of all required supplies of industry i is recalculated:

$$VP_i^{demand\prime} = VP_i^{demand} * \frac{kU}{kU_i} \quad (11)$$

where $VP_i^{demand\prime}$ – adjusted supply requirement for industry i, VP_i^{demand} – initial supply requirement for industry i, kU_i – supply reduction factor for industry i, kU – final supply reduction factor for the organization.

At the end of the stage of redistribution of orders for basic intermediate supplies, a preliminary output value is calculated:

$$V_p = V_d * kU \quad (12)$$

where V_p – preliminary value of output in the next cycle, V_d– estimated demand for products in the next cycle, kU – reduction factor for the organization's basic intermediate supplies.

At the sales recalculation stage, received orders for the products of organizations are compared with their production capacities and available supplies of raw materials and components (Figure 5). The order in which organizations are processed in this algorithm is also determined by their industry, but here mining and agriculture organizations are processed first, followed by manufacturing, trade and services organizations. The actions performed within the framework of the algorithm depend on whether the organization has basic intermediate supplies.

For organizations that do not need raw materials and components from other industries, the estimated demand for products in the next cycle $V_d$is compared with the maximum possible output in terms of production capacity PL. If demand does not exceed production capacity, then available supplies are created based on required supplies, where the current organization is the supplier.

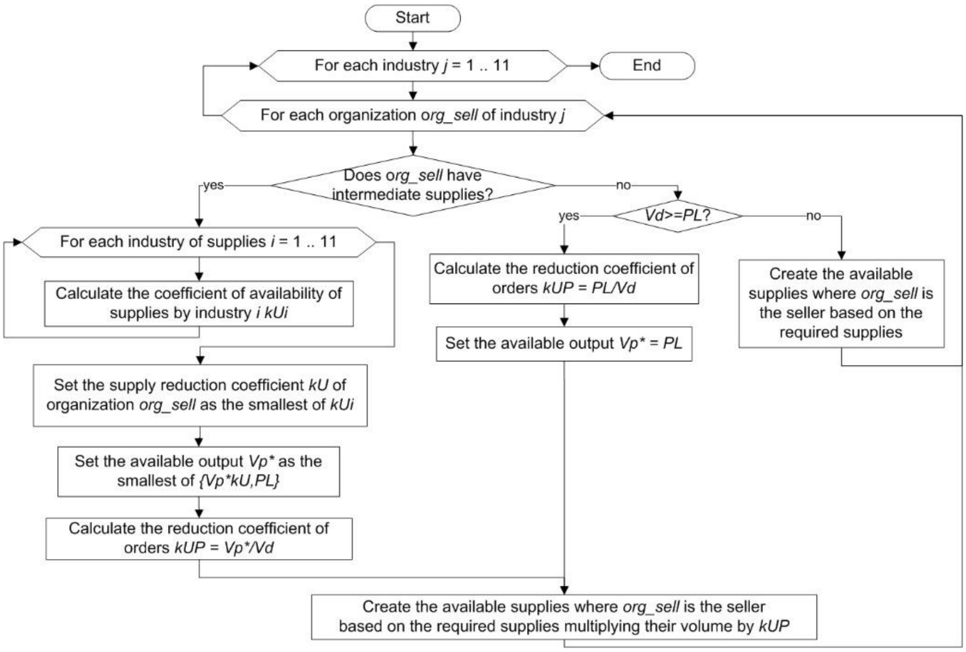

Figure 5. Sales recalculation algorithm

Otherwise, the following actions are performed:

- orders reduction coefficient is calculated:

$$kUP = \frac{PL}{V_d} \quad (13)$$

where kUP – orders reduction coefficient, PL – the maximum possible output in terms of production capacity, V_d– estimated demand for products in the next cycle.

- available volume of output is set equal to the production capacity $V_p^* = PL$;

- volume of available supplies is calculated, where the organization is a seller:

$$VP^{avail} = VP^{plan} * kUP \tag{14}$$

where VP^{avail} – volume of available supply, VP^{plan} – volume of planned supply in the current period, kUP – orders reduction factor.

If the organization needs to buy raw materials and components, then the following actions are performed:

- for each industry of basic intermediate supplies i, supply reduction factor is calculated:

$$kU_i = \frac{\sum VP_i^{avail}}{\sum VP_i^{demand\prime}} \tag{15}$$

where kU_i – supply reduction factor for industry i, $\sum VP_i^{avail}$ – sum of available supplies by industry i in the next period, $\sum VP_i^{demand\prime}$ – sum of required supplies by industry *i*.

- the supply bottleneck is determined through the final supply reduction factor:

$$kU = \min\{kU_i\} \tag{16}$$

- the available output volume is set in accordance with the limitations of production capacities and components:

$$V_p^* = \min\{V_p * kU, PL\} \tag{17}$$

where V_p^*– adjusted output in the next cycle, kU – supply reduction factor, V_p – preliminary output in the next cycle, PL – the maximum possible output in terms of production capacity.

- order reduction factor is calculated:

$$kUP = \frac{V_p^*}{V_d} \tag{18}$$

where kUP – order reduction factor, V_p^*– adjusted value of output in the next cycle, V_d – estimated demand for products in the next cycle.

- the volume of available supplies is calculated, where the organization is a supplier:

$$VP^{avail} = VP^{demand\prime} * kUP \tag{19}$$

where VP^{avail} – amount of available supply, $VP^{demand\prime}$ – amount of required supply, kUP – order reduction factor.

At the last stage of the recalculation of supplies and output, the organization compares the required supplies with the available ones (Figure 6).

The procedure for processing organizations starts from organizations with the largest number of basic intermediate supplies. For each organization, an adjusted output is calculated, taking into account changes in the volume of orders at the last stage:

$$V_p^{**} = V_p^* + Z_m^* \tag{20}$$

where V_p^{**} – adjusted value of output calculated at the stage of recalculation of output and supplies, V_p^* – adjusted value of output calculated at the stage of recalculation of sales, Z_m^* – change in the volume of orders at the stage of recalculation of output and supplies.

Next, the adjusted coefficient of output dynamics is calculated relative to the output value V_p^*at the previous stage:

$$k_d^* = \frac{V_p^{**}}{V_p^*} \tag{21}$$

where k_d^* – adjusted coefficient of output dynamics, V_p^{**} – adjusted value of output calculated at the stage of recalculation of output and supplies, V_p^* – adjusted value of output calculated at the stage of recalculation of sales.

A number of further actions are performed for organizations that have basic intermediate supplies:

- For each industry of supply *i* sums of required basic intermediate supplies PD_i, where the organization is a buyer are calculated.
- For each supply industry *i* sums of available circulating supplies PA_i, in which the organization is a buyer, are calculated.

- The ratio of available supplies and stocks to the required supplies for industry *i* is calculated:

$$K_i^{AD} = \frac{PA_i + W_i}{PD_i} \quad (22)$$

where K_i^{AD} – coefficient that determines ratio of available raw materials of industry *i* to the required one, PA_i – amount of available basic intermediate supplies, W_i– stock of raw materials of industry *i* in the warehouse of the organization, PD_i– amount of required basic intermediate supplies.

- The supply adjustment coefficient k^* is defined as the smallest of the adjusted output dynamics coefficient k_d^* and coefficients $K_i^{AD}$for all sectors of basic intermediate supplies:

$$k^* = \min\{K_i^{AD}, k_d^*\} \quad (23)$$

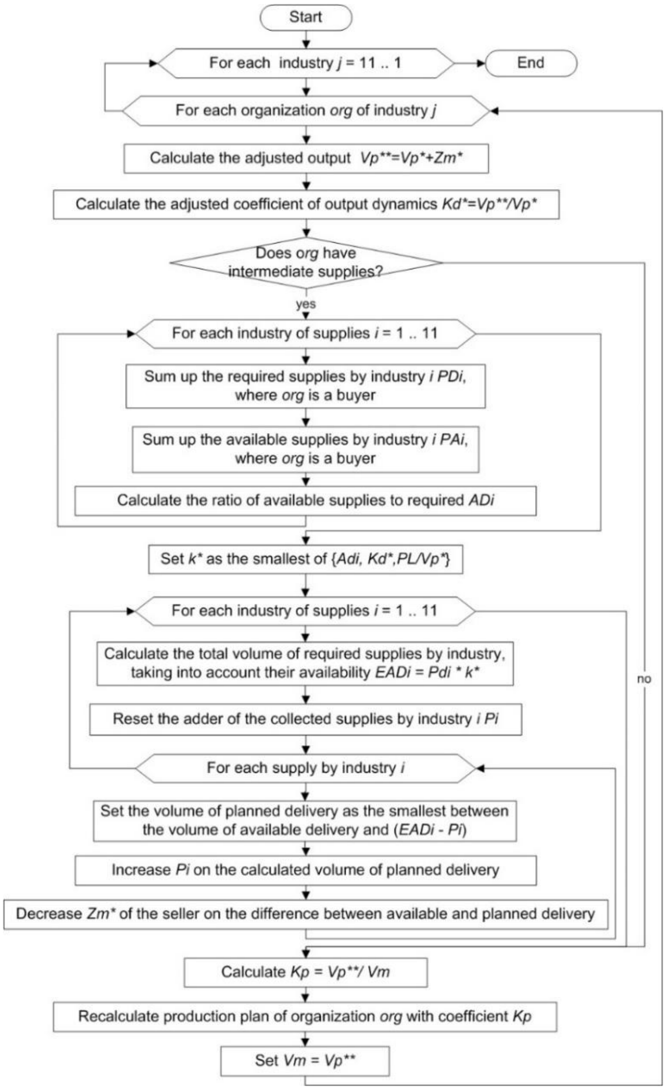

Figure 6. Algorithm for recalculating supplies and output

Further, for supply industry i, the total amount of required basic intermediate supplies is calculated taking into account the supply adjustment coefficient:

$$PD'_i = PD_i * k^* \quad (24)$$

where PD'_i – total amount of required supplies of industry i, PD_i – pre-calculated amount of required basic intermediate supplies for industry i, k^* – organization's supply adjustment coefficient.

The totalizer of accumulated supplies for industry P_i = 0 is reset, and for each supply of industry i, the following actions are performed:

- The planned supply volume is recalculated:

$$VP^{avail\prime} = \min\{VP^{avail}, (PD'_i - P_i)\} \quad (25)$$

where $VP^{avail\prime}$ – adjusted amount of available supply, VP^{avail} – amount of available supply calculated at the previous stage, PD'_i – total amount of required supplies for industry i, P_i – sum of accumulated supplies for industry i.The totalizer of accumulated supplies for the industry P_i is increased by the calculated volume of the planned supply

- Z_m^* of the supplier is reduced by the difference in volumes between available and planned supplies.

After completing the processing of supplies, it is necessary to recalculate the production plan of the organization in accordance with the changed output volume. To do this, the coefficient of output change relative to the previous period is calculated:

$$k_p = \frac{V_p^{**}}{V_m} \quad (26)$$

where k_p – adjusted coefficient of output dynamics, V_p^{**} – adjusted value of output calculated at the stage of recalculation of output and supplies, V_m – output in the current cycle.

Use of raw materials and components by industry are multiplied by the calculated coefficient k_p in the organization's production plan. At the end of the algorithm, the value of the monthly output V_m is set equal to the adjusted output volume V_p^{**} and thus the output, basic intermediate supplies and use of raw materials and components are coordinated.

Agent-based model of trade wars was programmed in Microsoft Visual Studio using C# and PostgreSQL as the database management system. Choice of this software instead of any multi-agent simulation platform is justified by its computational capacities and ability to work with large data arrays. The software architecture of the agent-based model of trade wars consists of the database and two main program modules: module of the model objects generation and module of dynamic simulation. Within procedure of generation objects of the model are created, including agents, organizations and countries. The created objects are stored in the model database and used in scenario calculations within procedures of dynamic simulation. Experimental results are loaded into the model database and accessed via the PostgreSQL database management system interface.

Information support of the agent-based model of trade wars is based on official data presented on websites of Eurostat (Eurostat, 2024), Bureau of Economic Analysis of the United States Department of Commerce (BEA, 2024), National Bureau of Statistics of China (NBSC, 2024), the Russian Federation Federal State Statistics Service (FSSS, 2024) and World bank (World bank, 2024). Main information tables are input-output balance, sectoral structure of gross domestic product and import and export flows among countries included in the model.

As countries considered in the model implement different sectoral classifiers in their economic statistics, we identified a set of aggregated industries, each of those represents a significant commodity group in international trade and correlates with one or a few industries. For the model eleven aggregated industries have been chosen: agriculture and food production, mining, fuel production, chemical production, production of materials, production of equipment and transport, production of consumer goods, service, trade, construction and public sector. Each organization in the model presents organizations of an aggregated industry in one country. Consequently, in the model of trade wars there are 55 organizations, standing for eleven industries in five countries, and more than 2000 trade flows of different products among them. The issues of coordinating data from various sources and bringing them to the form required for loading into the model are considered in the work (Mashkov &, Bakhtizin, 2023).

3. Results and Discussion

As part of the scenario experiment, the impact of sanctions pressure on demand for products and availability of raw materials and components for industrial enterprises was studied. A short-term period of one year after introduction of sanctions was chosen for consideration, and the possibilities of enterprises' adaptation to the shock were studied, primarily by restructuring logistics chains. It should be noted that the series of calculations did not take into account impact of investments, the effect of which is noticeable over a longer period. This aspect of enterprise development and its impact on the adaptation of the Russian economy to sanctions is considered in (Mashkova, 2023). The purpose of conducting a series of calculations on the developed trade war model was to assess the dynamics of output of enterprises in four aggregated industries: chemical production, materials production, equipment and transport production, and production of consumer goods. To conduct scenario modeling, coefficients were established that characterize decrease in import and export volumes between countries in a trade confrontation. Based on the analysis of international statistical data for 2022, it can be concluded that in the first year after introduction of sanctions against Russia, its trade turnover with the United States and the European Union countries decreased by half (Eurostat, 2024), therefore, in calculations to assess consequences of existing and potential trade confrontations, the coefficient of decline in trade turnover was taken as 0.5.

The calculations also used the parameter of substitutability of materials and components from suppliers subject to sanctions. This parameter was set in the range from 0 to 1, where 1 indicates complete replacement of resources with supplies from other countries, 0 indicates complete inability of replacing them, and intermediate values characterize the share in the total volume of supplies under sanctions that can be replaced by supplies from other countries. As part of the experimental studies, three levels of substitutability were selected for the model: 1; 0.9 and 0.8, with the substitutability level equal to 1 taken as the base scenario.

Production and supplies were modeled in physical terms (in conventional units of production), to reflect monetary settlements between enterprises, the volume of supplies was multiplied by the price per unit of production and the exchange rate of the currency of the buyer country relative to the currency of the seller country. Further on, the graphs show dynamics of the output of enterprises also in physical terms.

Two main scenarios were considered in a series of calculations:

1. Western countries (USA and EU) impose sanctions against Russia, while China and the rest of the world take a neutral position, continuing to trade with all countries.
2. Along with the current sanctions against Russia, similarly severe sanctions against China are introduced, while the rest of the world maintains a neutral position, and Russia and China strengthen trade cooperation.

Figure 7 shows the forecast of dynamics of output of chemical production organizations, materials production, equipment and transport production, and production of consumer goods under the conditions of the baseline scenario of sanctions against Russia (with the possibility of full resource substitution). Under these conditions, output volumes are affected exclusively by dynamics of demand, and the affected party are Russian enterprises, which are faced with a reduction in output by 2-4%. It should be clarified here that this picture is observed taking into account targeted state support and the growth of defense spending, which provide significant growth drivers for the entire manufacturing industry; without this factor, the decline would be more noticeable. Enterprises in China, the USA, and the EU, on the contrary, increase output by 0.5-1%.

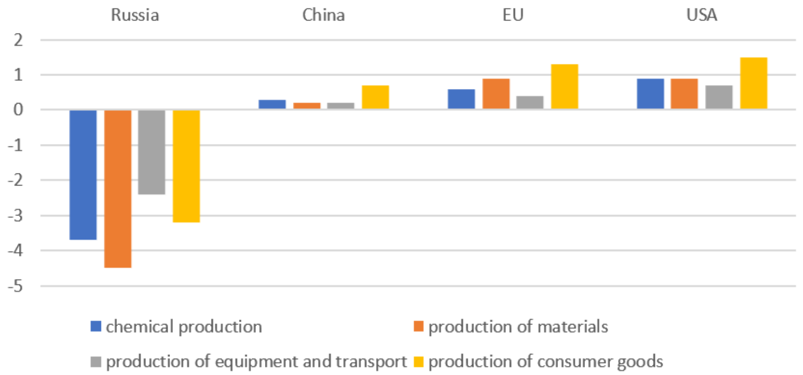

Figure 7. Dynamics of output of industrial enterprises in various industries and countries under sanctions against Russia with full substitution of resources, in percent

Figure 8 shows deviations in dynamics of output of organizations in the considered industries from the baseline scenario under conditions of sanctions against Russia and 90% substitutability of resources. Calculations show that Russian enterprises in this case reduce output by 0.3-1% relative to the baseline scenario, and European enterprises by 3.5-5%. Chinese enterprises face an insignificant decrease in output by 0.1-0.3%, and American enterprises by 0.4-0.8%.

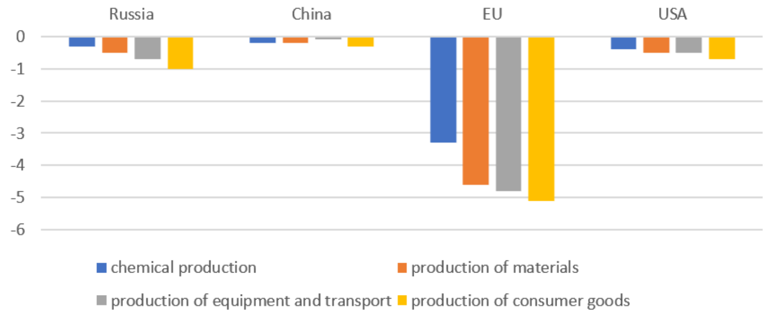

Figure 8. Dynamics of output of industrial enterprises in various industries and countries under sanctions against Russia with 90% resource substitution relative to the baseline scenario, in percent

A reduction in resource substitution to 80% leads to a doubling of enterprise losses relative to the baseline scenario in all the countries under consideration: a decrease in output of 0.5-2% is observed in Russia; 0.2-0.5% in China; 6.5-10% in the Eurozone; 0.6-2% in the USA (Figure 9).

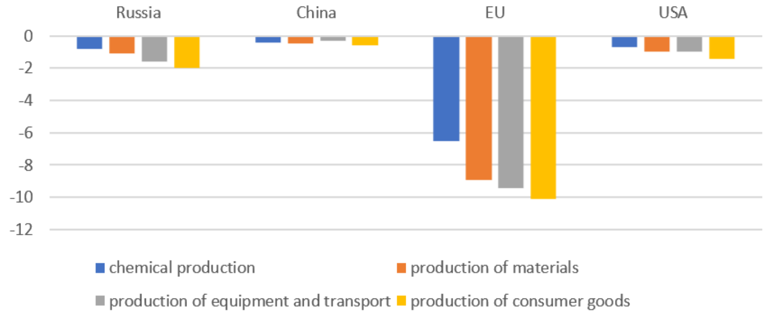

Figure 9. Dynamics of output of industrial enterprises in various industries and countries under sanctions against Russia with 80% resource substitution relative to the baseline scenario, in percent

Since enterprises in the European Union countries show the greatest sensitivity to the possibility of resource substitution, we will consider deficit for individual industries in more detail. In the baseline scenario (with full resource substitutability), total supplies do not decrease, but only the geography of suppliers changes. With 90% substitutability, European enterprises face a deficit of 1.3-1.9% of the total required supplies; with 80% substitutability, the deficit increases to 2.6-3.7% (Figure 10).

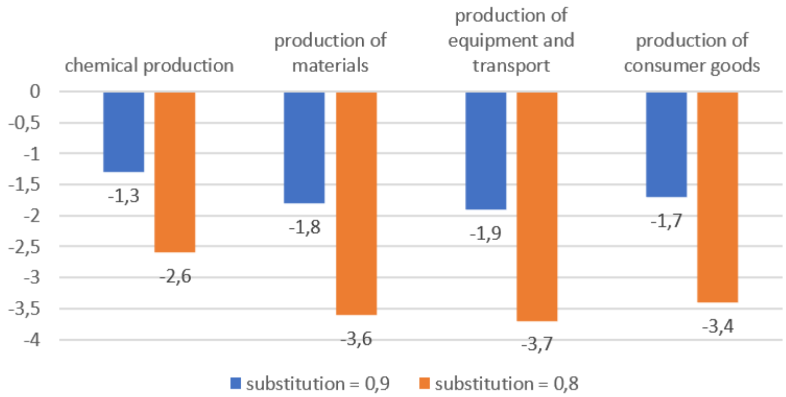

Figure 10. Reduction in resource supplies for European enterprises in various industries under sanctions against Russia, in percent

It should be noted here that deficit is not observed in all supply sectors, but to the greatest extent in raw materials and fuel (Table 1), however, according to the logic of the model, if there is a deficit of at least one of the resources, the enterprise proportionally reduces purchases in all supply sectors (formula (24)), which leads to a chain reaction in the economy, and the resulting decrease in the output of enterprises turns out to be more significant than decrease in available supplies.

Table 1. Reduction in supplies of materials and fuel for European enterprises in various industries under sanctions against Russia, in percent

Industry of the supplier enterprise	Industry of the purchasing enterprise			
	chemical production	production of materials	production of equipment and transport	production of consumer goods
mining	-2.6	-3.6	-3.7	-3.4
fuel production	-0.9	-0.8	-0.9	-0.9
chemical production	0	-0.1	-0.1	-0.1
production of materials	0	0	-0.2	-0.2

The second series of calculations considered the case when, along with the sanctions against Russia, Western countries also introduce sanctions against China, similar in strength, i.e. affecting half of the trade turnover between China, the US and the EU. In this case, the picture for Russian industrial enterprises is largely similar to the first series of calculations, with the difference that the production of equipment and transport demonstrates a smaller decrease (0.5% compared to 2.5%). Under the imposed sanctions, with full substitutability of resources, Chinese industrial enterprises are forced to reduce production by 0.7-2.8%, while EU and US enterprises, on the contrary, show an increase in output by 1-4% (Figure 11).

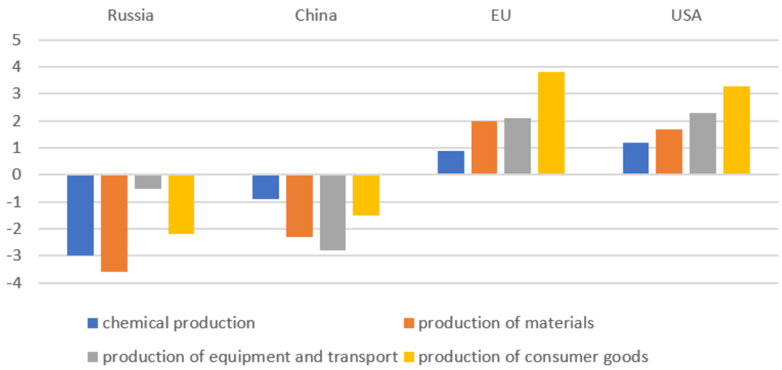

Figure 11. Dynamics of output of industrial enterprises in various industries and countries under sanctions against Russia and China with full substitution of resources, in percent

Analysis of the modeling results with incomplete resource substitutability yields a picture similar to the first series of calculations: enterprises in the European Union suffer the most from the lack of resources (a drop of up to 5% relative to the baseline scenario with 90% substitutability, and up to 10.5% with 80% substitutability). For Russian enterprises, decrease in output relative to the baseline scenario does not exceed 1% with 90% substitutability at and 2% with 80% substitutability; for American enterprises, this figure is at the level of 1.4% and 2.5%, respectively; the decrease in output at Chinese enterprises does not exceed 0.5% (Figures 12 and 13).

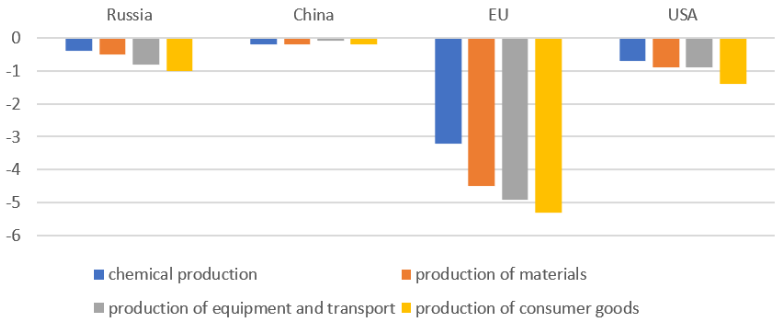

Figure 12. Dynamics of output of industrial enterprises in various industries and countries under sanctions against Russia and China with 90% resource substitution relative to the baseline scenario, in percent

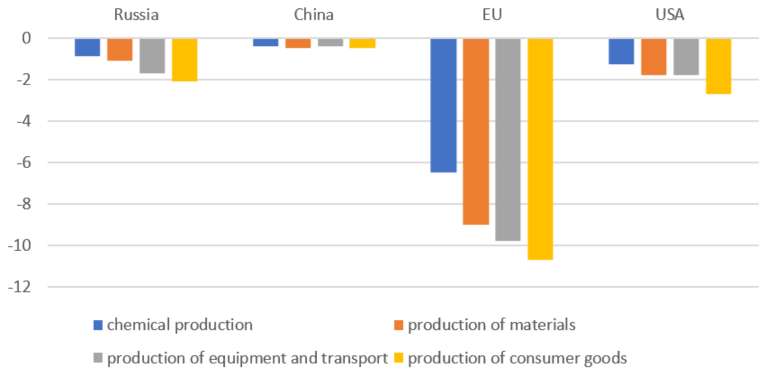

Figure 13. Dynamics of output of industrial enterprises in various industries and countries under sanctions against Russia and China with 80% resource substitution relative to the baseline scenario, in percent

For EU companies, there are no significant differences in the reduction of supplies under additional sanctions against China compared to sanctions against Russia alone. With a 90% substitutability, European companies also face a deficit of 1.3-1.9% of the total required supplies; with a 80% substitutability, the deficit increases to 2.6-3.8% (Figure 14).

US enterprises are more sensitive to the substitution of supplies from China. After introduction of sanctions against Russia, their supply deficit was no more than 0.2%, under the sanctions against China, this figure grows to 0.6% for production of consumer goods enterprises with 80% substitutability (Figure 15).

In general, it can be noted that when sanctions are imposed on China, its economy suffers seriously, the output of enterprises in a number of industries decreases by 2-3%. The main reason for the decline is decrease in demand for products from Western countries, sensitivity to resource substitution remains low (decrease in raw material supplies does not exceed 0.1%). Also, in the second series of calculations, the case was considered when China, the EU and the USA can substitute supplies of minerals and fuel, and incomplete substitutability occurs only for materials and components (Figures 16 and 17).

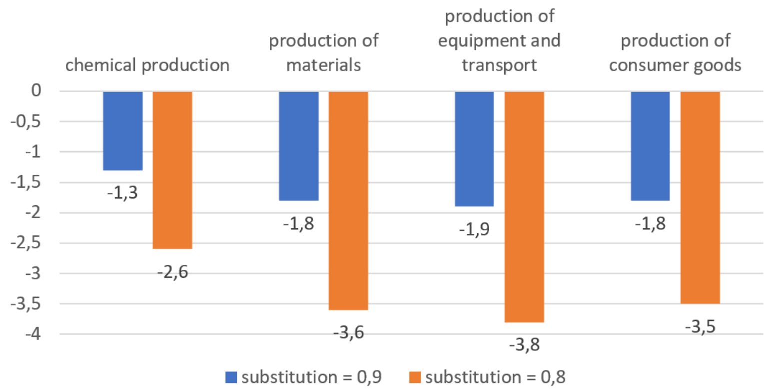

Figure 14. Reduction in resource supplies for European enterprises in various industries under sanctions against Russia and China, in percent

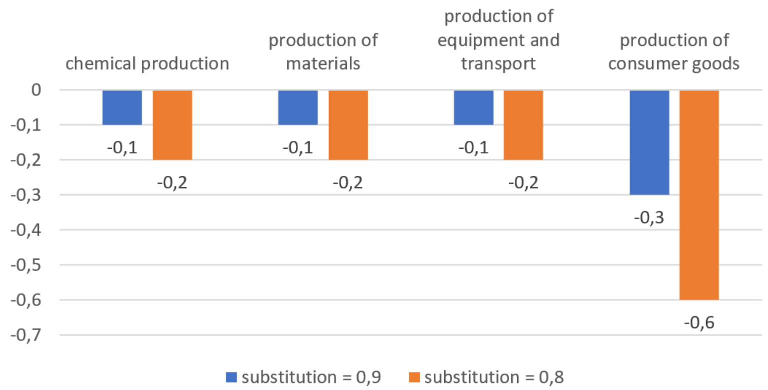

Figure 15. Reduction in resource supplies to US enterprises in various industries under sanctions against Russia and China, in percent

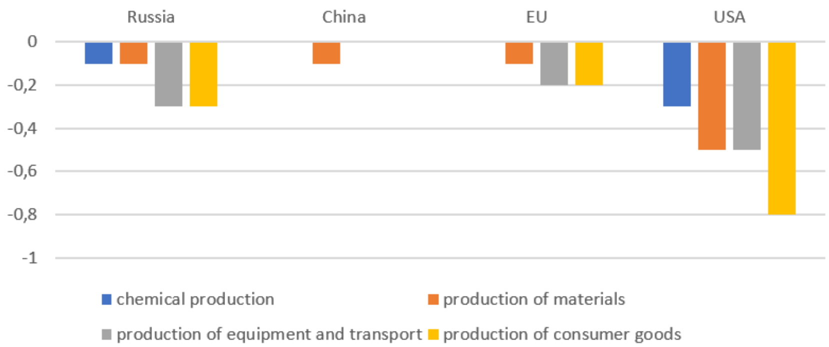

Figure 16. Dynamics of output of industrial enterprises in various industries and countries with 90% substitution of materials and components relative to the baseline scenario, in percent

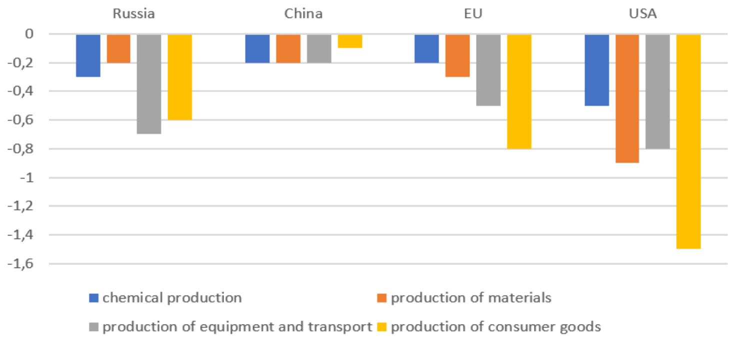

Figure 17. Dynamics of output of industrial enterprises in various industries and countries with 80% substitution of materials and components relative to the baseline scenario, in percent

In these conditions, US enterprises suffer more than others from the shortage of resources: a decrease in supplies to 0.6% (similar to that shown in Figure 15); a decrease in output to 1.5% in a number of industries. For European enterprises, the decrease in supplies does not exceed 0.2%; the decrease in output with 80% substitutability is within 0.8%.

4. Conclusion

Two series of calculations were performed on the developed agent-based model of trade wars. The first series of calculations considered the scenario of introduction of sanctions against Russia by the European Union and the United States, when the rest of the world takes a neutral position, continuing to trade with all countries in full. Based on this series of calculations, it can be concluded that Russian enterprises are sensitive to fluctuations in demand for their products under sanctions from Western countries. For European enterprises, the reduction in output is primarily due to the disruption of fuel and raw material supplies. For American enterprises, the consequences of the sanctions are much less noticeable than for European enterprises, since they are independent of Russian resource supplies.

The subject of the second series of calculations was a scenario in which, along with the current sanctions against Russia, similarly harsh sanctions are introduced against China, while the rest of the world maintains a neutral position, and Russia and China strengthen trade cooperation. Based on the results of the second series of calculations, a number of conclusions can be drawn.

Firstly, Chinese enterprises are still quite dependent on exports to Western markets, so the tightening of US sanctions and the introduction of EU sanctions could lead to a slowdown in China's economy.

Secondly, the US is more sensitive to the substitution of supplies of materials and components from China than raw materials and fuel from Russia, so the introduction of serious sanctions against China in the context of incomplete resource substitutability will negatively affect industrial production and the US economy as a whole.

Thirdly, European enterprises are much less sensitive to disruptions in supplies of materials and components than raw materials and fuel, so the key task for the EU is to find alternatives to fuel supplies from Russia; the trade standoff with China, in comparison, carries fewer risks for the European economy.

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References:

Aguiar, A., Narayanan, B., & McDougall, R. (2016). An overview of the GTAP 9 data base. *Journal of Global Economic Analysis*, *1*, 181–208.

Bolgova, I. V., Mel'nikova, Yu. Yu., & Lisjakiewicz, R. (2022). The EU China policy in the making: The role of Central and Eastern Europe. *World Economy and International Relations*, *66*(6), 79–90.

Bolt, W., Mavromatis, K., & van Wijnbergen, S. (2019). The global macroeconomics of trade war: The EAGLE model on the US–China trade conflict. *DNB Working Paper*, *No. 623*. De Nederlandsche Bank. Retrieved from https://www.dnb.nl/binaries/wp623_tcm46-381884.pdf

Bureau of Economic Analysis of the United States Department of Commerce. (n.d.). Retrieved August 17, 2024, from https://www.bea.gov/

Corong, E., Hertel, T., McDougall, R., Tsigas, M., & Van der Mensbrugghe, D. (2017). The standard GTAP model, version 7. *Journal of Global Economic Analysis*, *2*, 1–119.

Egger, P., Francois, J., Manchin, M., & Nelson, D. (2015). Non-tariff barriers, integration, and the Transatlantic economy. *Economic Policy*, *30*(83), 539–584.

Eurostat. (n.d.). Retrieved August 19, 2024, from https://ec.europa.eu/eurostat https://ec.europa.eu/eurostat

Francois, J., M. Manchin, H. Norberg, O. Pindyuk, & P. Tomberger (2013). *Reducing Transatlantic Barriers to Trade and Investment: An Economic Assessment*. Final Project Report, prepared under implementing Framework Contract TRADE10/A2/A16, CEPR, London.

Frolov, I. E., Borisov, V. N., & Ganichev, N. A. (2023). Problems of transition to innovative continuous development of the Russian economy in conditions of forced import substitution. *Studies on Russian Economic Development*, *34*(4), 473–483.

Golovanova, S. V., & Krekhovets, E. V. (2024). Potential for the development of Russian plastics production against the backdrop of sanctions: Assessment for the medium term. *Studies on Russian Economic Development*, *35*(2), 276–285.

Gusev, A. B., & Yurevich, M. A. (2023). Catching-up and outstripping development of the Russian pharmaceutical industry. *Economic and Social Changes: Facts, Trends, Forecast*, *16*(6), 55–73.

Hof, B., Van Leeuwen, N., Lejour, A., & Tang, P. (1999). The informal sector in WorldScan: The underpinning and the data. *Internal CPB Memorandum*, *99/IV/03*. CPB.

Kalinin, A. M. (2024). Factors of investment activity in the Russian economy: Conclusions 2022. *Studies on Russian Economic Development*, *35*(1), 21–33.

Kopytin, I. A. (2023). European gas market restructuring: Interests of importing countries and gas exporting companies. *World Economy and International Relations*, *67*(8), 48–59.

Kuvalin, D. B., Zinchenko, Yu. V., Lavrinenko, P. A., Ibragimov, Sh. Sh., & Zaytseva, A. A. (2024). Russian enterprises at the end of 2023: Recovery growth against the backdrop of sanctions, worsening labor shortages and rising credit costs. *Studies on Russian Economic Development*, *35*(3), 440–454.

Lejour, A., Veenendaal, P., Verweij, G., & Van Leeuwen, N. (2006). *WorldScan: A model for international economic policy analysis* (CPB Document 111). CPB Netherlands Bureau for Economic Policy Analysis.

Li, C., He, C., & Lin, C. (2018). Economic impacts of the possible China-US trade war. *Emerging Markets Finance and Trade*, *54*, 1557–1577.

Malyshev, M. K., & Pechenskaya-Polishchuk, M. A. (2024). Dynamics of export-import operations in the Russian chemical industry: Current state of affairs on the threshold of geopolitical shifts. *Economic and Social Changes: Facts, Trends, Forecast*, *17*(4), 109–125.

Mashkova, A., & Bakhtizin, A. (2022). Assessment of impact of trade wars on production and exports of the Russian Federation using the agent-based model. *Advances in Systems Science and Applications*, *21*(4), 100–114.

Mashkova, A. L. (2023). Dynamics of investments in Russia under the conditions of sanction restrictions: Forecast based on an agent-based model. *Business Informatics*, *17*(1), 18–36.

Mashkova, A. L., & Bakhtizin, A. R. (2023). Analyzing the industry structure and dynamics of commodity exchange between Russia, China, the USA and the EU under trade restrictions. *Economic and Social Changes: Facts, Trends, Forecast*, *16*(3), 54–80.

Mashkova, A. L., & Bakhtizin, A. R. (2024). Assessing consequences of global trade wars for world economies: Tools and forecasts. *The Journal of the New Economic Association*, *1*(62), 12–30.

Mikheev, V. V. (2023). Crisis-containing factors of the PRC's development. *World Economy and International Relations*, *67*(5), 24–33.

National Bureau of Statistics of China. (n.d.). Retrieved August 25, 2024, from http://www.stats.gov.cn/english/

Plakhin, A. E., Ogorodnikova, E. S., & Rajab, M. (2024). Models for adaptation of foreign economic activity of Russian companies in the context of sanctions pressure. *Economic and Social Changes: Facts, Trends, Forecast*, *17*(4), 126–143.

Roginko, S. A. (2024). EU energy crisis and the European energy market. *Contemporary Europe*, *3*, 95–110.

Russian Federation Federal State Statistics Service. (n.d.). Retrieved August 29, 2024, from http://www.gks.ru

Sapir, J. (2023). The macroeconomic impact of the new geopolitical deal on the French economy. *Studies on Russian Economic Development*, *34*(3), 308–319.

Shirov, A. A. (2023). Development of the Russian economy in the medium term: Risks and opportunities. *Studies on Russian Economic Development*, *34*(2), 159–166.

Timmer, H. R. (1998). *WorldScan: A world model for long-term scenario analysis*. *CPB Report*, *98/3*.

Van Tongeren, F., Koopman, R., Karingi, S., Reilly, J. M., & Francois, J. (2017). Back to the future: A 25-year retrospective on GTAP and the shaping of a new agenda. *Journal of Global Economic Analysis*, *2*(2), 1–42.

World Bank. (n.d.). Retrieved August 25, 2024, from https://data.worldbank.org/?intcid=ecr_hp_BeltC_en_ext

Zemtsov, S. P. (2024). Sanctions risks and regional development: Russian case. *Baltic Region*, *16*(1), 23–45.

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