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## Analyzing the Industry Structure and Dynamics of Commodity Exchange between Russia, China, the USA and the EU under Trade Restrictions



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**Abstract.** In the context of large-scale economic sanctions against Russia, it becomes an urgent task to design model complexes for assessing their impact on the economies of various countries. To this end, we use an agent-based approach and select China, the United States, the European Union, and the rest of the world as the main participants in trade relations with Russia. We design the trade wars model with the help of analyzing available data on the economies of the abovementioned countries and trade relations between them, and by assessing the imposed sanctions restrictions in quantitative and sectoral aspects. The information content of the developed model faced difficulties caused by the coordination of data on cross-industry supplies, imports and exports of goods in different countries. The article presents an

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algorithm that determines the sequence of processing the initial statistical data and bringing them to a unified form with detailed elaboration necessary for the model. The formation of arrays of initial data is carried out on the basis of the Federal State Statistics Service of Russia, Federal Customs Service, Eurostat, U.S. Bureau of Economic Analysis, National Bureau of Statistics of the People's Republic of China and the World Bank. To unify the information of these agencies, eleven enlarged industries are created in the model; each of the industries corresponds to one or more industries or commodity groups. The target result of applying the algorithm is construction of cross-country tables of industry supplies of intermediate and investment goods, containing data on trade in Russia, the USA, the EU, China and the rest of the world. In the course of data processing, we also analyzed the sectoral structure of international commodity exchange in 2021, which indicates a close relationship between the economies of the European Union and Russia before the introduction of large-scale sanctions, and relatively low indicators of commodity exchange between Russia and the United States. An analysis of the dynamics of trade exchange between Russia and the countries that imposed sanctions restrictions in 2022 showed that Russia's imports from the EU countries fell by 38%, and exports in value terms increased by 24%, which is primarily due to a sharp increase in energy prices. For the United States, the drop in exports and imports with Russia was 70% and 50%, respectively.

**Key words:** international commodity exchange, trade wars, economic sanctions, input-output tables, agent-based model.

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### Introduction

With the beginning of the special military operation (SMO) in Ukraine, Russia faced the imposition of unprecedented financial, trade and transport sanctions against it (Timofeev, 2022). A distinctive feature of the West's sanctions policy in relation to Russia is the double-edged nature of the restrictions, not only as a result of retaliatory measures, but also due to the provoked shortage of resources on world markets and price shocks (Afontsev, 2022). Under the circumstances, it becomes urgent to analyze the impact of the imposed sanctions and possible strategies for Russia's economic development (Belozеров, Sokolovskaya, 2022; Tenyakov et al., 2022).

An effective tool for solving this problem is computational economic models that allow

integrating data on production, employment and economic relations between countries. Such models are developed most often according to the methodology of the Global Trade Analysis Project (GTAP) (Aguiar et al., 2016; Corong et al., 2017) and include from two to thirty countries participating in world trade. The most well-known examples of implementation of the GTAP methodology are WorldScan model (Bollen, Rojas-Romagosa, 2018), GLOBE multisectoral economy model<sup>1</sup> (McDonald, Thierfelder, 2014) and MIRAGRODEP model (Bouët, Laborde, 2017). Within the framework of these models, the

<sup>1</sup> McDonald S., Thierfelder K. (2014). GLOBE v2: A SAM based global CGE model using GTAP data. Available at: [http://cgemod.org.uk/globev2\\_2014.pdf](http://cgemod.org.uk/globev2_2014.pdf)

USA and China are considered key participating countries, and EU countries, Canada, Japan and Mexico may also be considered. WorldScan defines Russia as a participant in international trade, but the available publications lack the results of calculations that would allow us to assess the impact of the sanctions imposed against it. For this reason, it becomes necessary to develop model complexes that consider Russia as a key player in trade wars. This model, developed by a team of researchers at the Central Economic Mathematical Institute RAS with the use of agent-based approach, considers trade interactions between Russia, the European Union, China, the USA, and the united rest of the world (Mashkova, Bakhtizin, 2021; Mashkova, 2023).

The purpose of the work is to analyze the most recent data on the economies of the countries participating in the model and trade relations between them, as well as to assess the imposed sanctions restrictions in quantitative and sectoral aspects for the information content of the developed agent-based model of trade wars.

Much attention has been paid to the analysis of imports and exports of various sectors of the Russian economy in recent years; in particular, researchers assess the dependence of exports of services, high-tech and agricultural products on the volume of investments and expenditures on R&D (Lyubimov, 2021; Borisov, Pochukaeva, 2021; Altiner et al., 2022; Derunova et al., 2021); dependence on equipment imports (Kolpakov, Saenko, 2023; Golikova, Kuznetsov, 2021) and the effectiveness of import substitution mechanisms (Partsvaniya, 2022), as well as the implications of restricting grain exports (Kheifets, Chernova, 2022). Of particular interest were the prospects for Russia's exports to the EU countries in connection with its planned transition to green energy (Bashmakov, 2022; Chupina, 2022).

Relatively few more publications consider the dynamics of Russia's international trade since the beginning of the SMO, they are mainly related to

the changes that have occurred and are expected in the export of resources (Andreyev, Polbin, 2023; Gordeev, Pyzhev, 2023). The impact of the imposed sanctions for entrepreneurship is considered in the work (Egorova, Chepurensko, 2022), and the need for expanding investments, including public ones, that emerged as a result of the sanctions, is investigated in the works (Kovalin, 2022; Shirov, 2023).

The above works analyze the structure and dynamics of imports and exports of individual sectors of the Russian economy, while the unification of data on cross-industry supplies, imports and exports of products of various industries in the countries under consideration presents the greatest difficulty for the information content of the trade wars model. The key source of such data is input-output tables, which are widely used both for forecasting economic processes within individual countries (Chernyavsky, 2021; Edinak et al., 2022) and for the analysis of international trade (Strizhkova et al., 2022; Vnukov et al., 2023).

The use of input-output tables to form arrays of initial modeling data is fraught with several difficulties. First, the industry classifiers used to form the tables differ across countries, therefore it is impossible to directly compare industries and goods. Second, the time periods for which the input-output tables are presented are also different. Third, countries reflect the structure of their commodity exchange to varying degrees. Another task is to reproduce the economy of the rest of the world (with the exception of the USA, China, the EU and Russia), considered in the model as a whole.

In order to harmonize the available information on international trade, we propose an algorithm that determines the sequence of bringing the initial statistical data to a unified form with the degree of detail necessary for the model. The target result of the algorithm is cross-country tables of intermediate and investment industry supplies containing data on trade in Russia, the USA, the EU, China, and the rest of the world.

Practical significance of our research lies in creating an information base necessary for the analysis and forecast of the dynamics of international trade under sanctions restrictions, taking into account the existing structure and volumes of import and export flows between countries. The initial information structured with the help of the method we propose makes it possible to model, with a high degree of accuracy, the change in production volumes when restrictions imposed by unfriendly countries on trade in various types of goods.

Scientific novelty of the work lies in the development of a method for unifying data on international trade and a way to present the information obtained in cross-country tables of industry supplies, reflecting the structure of commodity exchange between countries in relation to the sectoral structure of the production needs of their economies.

### Materials and methods

We form initial information arrays for the agent-based model of trade wars on the basis of data from official statistical agencies: Federal State Statistics Service of Russia<sup>2</sup>, Eurostat<sup>3</sup>, U.S. Bureau of Economic Analysis<sup>4</sup>, National Bureau of Statistics of China<sup>5</sup>, and World Bank<sup>6</sup>. Samples by key parameters and their uploading in Excel document format are available for all the countries under consideration, except for China, since the National Bureau of Statistics of China publishes statistical yearbooks in the form of images of the corresponding pages.

The main source of data on production relationships are the input-output tables published for each of the countries represented in the model (Russia, China, USA), as well as the countries of the European Union, considered both individually and as a whole. Also, the input-output tables provide information on the volume of exports and

Table 1. Comparison of the structure of production, import and export data in different countries

Data type	Russia	EU	USA	China
Number of industries in the input-output model	60	63	71	17
Units of measurement	Million rubles	Million euro	Million USD	Million yuan
Detailing the input-output structure of import supplies	Available	Available	Available	Not available
Detailing the sectoral structure of import and export with individual countries	Available for a number of countries, including the USA, China, EU countries	Available for all countries of the world	Available for a number of countries, including China, EU countries; not available for Russia	Not available
Commodity codes representing the structure of import-export with individual countries	Commodity nomenclature for foreign economic activities (TN VED)	Standard international trade classification (SITC)	Industry structure (similar to the input-output balance)	Not available
Compiled according to: Federal State Statistics Service of Russia, Eurostat, U.S. Bureau of Economic Analysis, National Bureau of Statistics of China.				

<sup>2</sup> Federal State Statistics Service of Russia. Available at: <https://rosstat.gov.ru/> (accessed: April 28, 2023).

<sup>3</sup> Eurostat. Available at: <https://ec.europa.eu/eurostat> (accessed: April 22, 2023).

<sup>4</sup> U.S. Bureau of Economic Analysis. Available at: <https://www.bea.gov/> (accessed: April 25, 2023).

<sup>5</sup> National Bureau of Statistics of China. Available at: <http://www.stats.gov.cn/english/> (accessed: March 24, 2023).

<sup>6</sup> World Bank. Available at: <https://www.worldbank.org/en/home> (accessed: March 25, 2023).

imports for each industry. For Russia, the USA, and the EU, the structure of import cross-industry supplies is additionally detailed; the National Bureau of Statistics of China publishes only general information on the volume of imports of goods for each industry.

Data from statistical agencies are used to reflect commodity flows between countries, if they provide such information (Eurostat and the U.S. Bureau of Economic Analysis); in Russia, such data are published by the Federal Customs Service.

Table 1 presents a comparison of the structure of information on production, import and export published by official statistical agencies in different countries.

The classifiers of the European Union and Russia have a lot in common, while the USA and China differ significantly from them. Also, the branches of the model are compared with the standard international trade classification (SITC) and the commodity nomenclature for foreign economic activities (TN VED) to aggregate data on imports and exports.

Data for 2019 are available for all countries except China, for which the latest input-output tables refer to 2017. In order to ensure the use of the most up-to-date information for all countries, data on the output and supply of industries are updated until 2021 using GDP growth coefficients for the corresponding period.

Countries reflect the structure of commodity exchange with each other to varying degrees: China – only the volume of imports and exports by country, Russia and the USA – the commodity structure of commodity exchange with individual countries, and only the EU – with all countries of the world.

The unification of the presented data on international trade is carried out within the framework of an algorithm that determines the sequence of their processing with the degree of

detail necessary for the model. The algorithm includes the following steps:

1. Establishing relationships between different nomenclatures and the industry structure of the model. The data in input-output tables are presented in various industry classifiers in different countries: 63 industries in the EU countries, 60 industries in Russia, 71 industries in the USA and 17 industries in China.

To unify these data, 11 aggregate industries are created in the model, each of which corresponds to one or more industries or commodity groups: (1) agriculture, food production; (2) mining; (3) fuel production; (4) public sector; (5) chemical production; (6) production of materials; (7) manufacture of equipment and transport; (8) light industry; (9) services; (10) trade; (11) construction. Appendix shows an example of bringing various classifiers to the aggregate industry “Equipment and transport”.

2. Transformation of the most relevant input-output balance sheets of countries to the base year of the modeling according to data on the sectoral structure of GDP. The year 2021, immediately preceding the introduction of large-scale sanctions against Russia, was chosen as the base year of modeling. The most relevant input-output balances for Russia, the EU, and the USA are presented for 2019, for China – for 2017. Data on the output and supply of industries are updated until 2021 based on the GDP growth coefficients of industries in each country. For Russia, the reduction formula is as follows:

$$x_{ij}^{RU-2021} = x_{ij}^{RU-2019} * \frac{va_i^{RU-2021}}{va_i^{RU-2019}}, \quad (1)$$

where  $i, j$  – branches of the Russian economy in the input-output balance;  $x_{ij}^{RU-2019}$  – supplies of industry  $i$  for the organization of industry  $j$  according to the input-output balance data for 2019;  $va_i^{RU-2021}$  and  $va_i^{RU-2019}$  – added value of industry  $i$  in 2019 and 2021, respectively.

3. Bringing the input-output balances for countries to the sectoral structure of the model. All sections of the balance sheet are being transformed: the first quadrant of cross-industry supplies (domestic and imported), the second quadrant of final goods (including export and investment columns), the third quadrant of conditionally net goods (wages, amortization and profit).

We should note that during the implementation of transformations, the system of coefficients changes: standard coefficients  $i$  and  $j$  corresponding to the supplier and buyer industries in the input-output balances of countries are replaced by coefficients  $k$  and  $l$  corresponding to the aggregate supplier and buyer industries in the model, while each aggregate industry includes one or more source industries. Thus, the values in the first quadrant of the transformed balance have a set of indices  $kl$ , in the second quadrant –  $k$ , in the third quadrant –  $l$ .

For the first quadrant, the reduction formula is as follows:

$$x_{kl} = \sum_{i=1}^n \sum_{j=1}^m x_{ij}, \quad (2)$$

where  $k$  – aggregate industry in the model, including a number of economic branches  $j = \overline{1, n}$ ;  $l$  – aggregate industry in the model, including a number of economic branches  $j = \overline{1, m}$ ;  $x_{kl}$  – supplies of the organization of aggregate industry  $k$  for the organization of aggregate industry  $l$ ;  $x_{ij}$  – supplies of industry  $i$  for the organization of industry  $j$  according to the data of the input-output model.

The reduction of matrix of import cross-industry supplies  $imp_{kl}$  is conducted in a similar way.

Let us look at the reduction in the second quadrant using the example of the export column:

$$exp_k = \sum_{i=1}^n exp_i, \quad (3)$$

where  $k$  – aggregate industry in the model, which includes a number of economic sectors  $j = \overline{1, n}$ ;  $exp_k$  – export of goods of aggregate industry  $k$ ;  $exp_i$  – exports of goods of industry  $i$ .

We show the reduction in the third quadrant using the example of the value-added line:

$$va_l = \sum_{j=1}^m va_j, \quad (4)$$

where  $l$  – aggregate industry in the model, which includes a number of economic sectors  $j = \overline{1, m}$ ;  $va_l$  – added value of aggregate industry  $l$ ;  $va_j$  – added value of industry  $j$ .

4. Compiling a table of investment supplies. Due to the fact that the second quadrant of the input-output balance is just a common column of investment  $dom\_inv_i$ , reflecting the volume of production of industries and used as the means of production, the estimation of the distribution of these investments carried out in their industries will be conducted with the use of the data on the amortization allocations in the context of producing industries:

$$dom\_inv_{kl} = dom\_inv_k * d\_amort_l, \quad (5)$$

where  $dom\_inv_k$  – volume of investment of aggregate industry  $l$  in the means of production produced by industry  $k$ ;  $dom\_inv_k$  – volume of production of aggregate industry  $k$  used as a means of production;  $d\_amort_l$  – share of amortization allocations of aggregate industry  $l$  in the total amount of amortization allocations in the country.

Having fulfilled step 4, we obtain a square matrix of investment supplies of organizations that coincides in structure with the first quadrant of cross-industry supplies. Similarly, we obtain a matrix of imports of investment products according to the original column  $imp\_inv_k$ .

5. Distribution of import and export flows of industries between trading partner countries and the rest of the world. For each country  $c_n$ , the following actions are performed in the model:

5.1. If there is data on the commodity structure of import-export by partner countries, then:

5.1.1. If the structure of the available information coincides with the sectoral structure of the input-output balance, then the reduction

formulas from paragraph 3 are used; otherwise (the information is presented in the context of commodity groups) the following reduction formulas are used:

$$\exp_k^{c_n-c_m} = \sum_{t=1}^n \exp_t^{c_n-c_m}, \quad (6)$$

where  $k$  – aggregate industry in the model, which includes a number of commodity groups  $t = \overline{1, n}$ ;  $\exp_k^{c_n-c_m}$  – export of goods of aggregate industry  $k$  from country  $c_n$  to country  $c_m$ ;  $\exp_i$  – export of goods of industry  $i$  country  $c_n$  to country  $c_m$ .

$$\text{imp}_k^{c_n-c_m} = \sum_{t=1}^n \text{imp}_t^{c_n-c_m}, \quad (7)$$

where  $k$  – aggregate industry in the model, including a number of commodity groups  $t = \overline{1, n}$ ;  $\text{imp}_k^{c_n-c_m}$  – import of goods of aggregate industry  $k$  to country  $c_n$  from country  $c_m$ ;  $\text{imp}_i$  – import of goods of industry  $i$  to country  $c_n$  from country  $c_m$ .

5.1.2. Converting the data on trade flows into the currency of partner countries by changing the flow directions accordingly:

$$\text{imp}_k^{c_m-c_n} = \exp_k^{c_n-c_m} * \text{CurrencyRate}^{c_n-c_m}, \quad (8)$$

where  $\text{imp}_k^{c_m-c_n}$  – import of goods of aggregate industry  $k$  in country  $c_m$  from country  $c_n$ ;  $\exp_k^{c_n-c_m}$  – export of goods of aggregate industry  $k$  from country  $c_n$  to country  $c_m$ ;  $\text{CurrencyRate}^{c_n-c_m}$  – exchange rate of the currency of country  $c_n$  to the currency of country  $c_m$ .

$$\exp_k^{c_m-c_n} = \text{imp}_k^{c_n-c_m} * \text{CurrencyRate}^{c_n-c_m}, \quad (9)$$

where  $\exp_k^{c_m-c_n}$  – export of goods of aggregate industry  $k$  from country  $c_m$  to country  $c_n$ ;  $\text{imp}_k^{c_n-c_m}$  – import of goods of aggregate industry  $k$  in country  $c_n$  from country  $c_m$ ;  $\text{CurrencyRate}^{c_n-c_m}$  – exchange rate of the currency of country  $c_n$  to the currency of country  $c_m$ .

Otherwise (if the necessary data for the country are not available), the data on the sectoral structure of imports and exports obtained as a result of processing the data on partner countries are used.

5.2. Calculating import-export volumes with the rest of the world (RW):

$$\text{imp}_k^{c_n-RW} = \text{imp}_k^{c_n} - \sum_{m=1}^3 \text{imp}_k^{c_n-c_m}, \quad (10)$$

where  $\text{imp}_k^{c_n-RW}$  – import of goods of aggregate industry  $k$  in country  $c_n$  from the rest of the world;  $\text{imp}_k^{c_n}$  – total import of goods of aggregate industry  $k$  in country  $c_n$ ;  $\sum_{m=1}^3 \text{imp}_k^{c_n-c_m}$  – import of goods of aggregate industry  $k$  in country  $c_n$  from three countries  $c_m$  represented in the model.

$$\exp_k^{c_n-RW} = \exp_k^{c_n} - \sum_{m=1}^3 \exp_k^{c_n-c_m}, \quad (11)$$

where  $\exp_k^{c_n-RW}$  – export of goods of aggregate industry  $k$  from country  $c_n$  to the rest of the world;  $\exp_k^{c_n}$  – total export of aggregate industry  $k$  from country  $c_n$ ;  $\sum_{m=1}^3 \exp_k^{c_n-c_m}$  – export of goods of aggregate industry  $k$  from country  $c_n$  to three countries  $c_m$  represented in the model.

5.3. Converting data on trade flows into the currency of rest of the world (US dollars) by changing the flow directions accordingly:

$$\text{imp}_k^{RW-c_n} = \exp_k^{c_n-RW} * \text{CurrencyRate}^{c_n-RW}, \quad (12)$$

where  $\text{imp}_k^{RW-c_n}$  – import of goods of aggregate industry  $k$  in the countries of rest of the world from country  $c_n$ ;  $\exp_k^{c_n-RW}$  – export of goods of aggregate industry  $k$  from country  $c_n$  to the rest of the world;  $\text{CurrencyRate}^{c_n-RW}$  – exchange rate of the currency of country  $c_n$  to the currency of the rest of the world.

$$\exp_k^{RW-c_n} = \text{imp}_k^{c_n-RW} * \text{CurrencyRate}^{c_n-RW}, \quad (13)$$

where  $\exp_k^{RW-c_n}$  – export of goods of aggregate industry  $k$  from the rest of the world to country  $c_n$ ;  $\text{imp}_k^{c_n-RW}$  – import of goods of aggregate industry  $k$  in country  $c_n$  from the rest of the world;  $\text{CurrencyRate}^{c_n-RW}$  – exchange rate of the currency of country  $c_n$  to the currency of the rest of the world.

Table 2. Structure of the cross-country table of industry supplies

Supplier country \ Buyer country	Industry	Russia				EU				USA				China				Rest of the world			
		1	2	...	11	1	2	...	11	1	2	...	11	1	2	...	11	1	2	...	11
Russia	1	CIS inside Russia				EU imports from Russia / Russia's exports to the EU				U.S. import from Russia / Russia's export to the USA				China's import from Russia / Russia's export to China				Import of the rest of the world from Russia / Russia's export to the rest of the world			
	2																				
	...																				
	11																				
EU	1	Russia's import from the EU / EU export to Russia				CIS inside the EU				U.S. import from the EU / EU export to the USA				China's import from the EU / EU export to China				Import the rest of the world from the EU / EU export to the rest of the world			
	2																				
	...																				
	11																				
USA	1	Russia's import from the USA / U.S. export to Russia				EU import from the USA / U.S. export to the EU				CIS inside the USA				China's import from the USA / U.S. export to China				Import of the rest of the world from the USA / U.S. export to the rest of the world			
	2																				
	...																				
	11																				
China	1	Russia's import from China / China's export to Russia				EU import from China / China's export to the EU				U.S. import from China / China's export to the USA				CIS inside China				Import of the rest of the world from China / China's export to the rest of the world			
	2																				
	...																				
	11																				
Rest of the world	1	Russia's import from the rest of the world / export of the rest of the world to Russia				EU import from the rest of the world / export of the rest of the world to the EU				U.S. import from the rest of the world / export of the rest of the world to the USA				China's import from the rest of the world / export of the rest of the world to China				CIS inside the rest of the world			
	2																				
	...																				
	11																				

Source: own compilation.

5.4. Calculating the share of partner countries in the import of country  $c_n$  by industry:

$$d\_imp_k^{c_n-c_m} = \frac{imp_k^{c_n-c_m}}{imp_k^{c_n}}, \quad (14)$$

where  $d\_imp_k^{c_n-c_m}$  – share of country  $c_m$  in the import of aggregate industry  $k$  in country  $c_n$ ;  $imp_k^{c_n-c_m}$  – import of goods of aggregate industry  $k$  in country  $c_n$  from country  $c_m$ ;  $imp_k^{c_n}$  – total import of goods of aggregate industry  $k$  in country  $c_n$ .

5.5. Calculating import volumes of cross-industry supplies by customer sector, commodity group and supplier country:

$$imp_{kl}^{c_n-c_m} = imp_{kl}^{c_n} * d\_imp_l^{c_n-c_m}, \quad (15)$$

where  $imp_{kl}^{c_n-c_m}$  – import of the goods of aggregate buyer industry  $k$  from country  $c_n$  at supplier industry  $l$  from country  $c_m$ ;  $imp_{kl}^{c_n}$  – total

import of the goods of integrated buyer industry  $k$  from country  $c_n$  at supplier industry  $l$ ;  $d\_imp_l^{c_n-c_m}$  – share of country  $c_m$  in the import of aggregate industry  $l$  in country  $c_n$ .

The calculated volumes of import cross-industry supplies (CIS) by customer sector, commodity group and supplier country are entered in the general cross-country table of industry supplies (Tab. 2). The cells in the cross-country table of industry supplies are grouped into quadrants – square matrices for 11 industries, so each quadrant consists of 121 cells. The quadrants on the main diagonal correspond to the first quadrants of domestic intermediate supplies of input-output balances of the respective countries, reduced to the sectoral structure of the model. The quadrants in one row, except for the main diagonal, reflect the export of intermediate and final goods from the country in the corresponding row to other countries.

The quadrants in one column, except for main diagonal, reflect imports of intermediate and final goods to the country from other countries.

A table similar in structure is built for domestic and international supplies of investment products.

6. Reducing trade flows between countries in the table of international input-output balance to the units of base prices. For the reduction, we use a base price of one US dollar, the exchange rates of national currencies to the US dollar and the coefficient of additional trade margin, which we assume to be equal to 1.2 for developed countries (USA and EU) and 1 for developing countries (Russia, China, and the rest of the world). The reduction formula is as follows:

$$\begin{aligned} & \text{UnifyingCoefficient}_{c_b}^{c_s} = \\ & = \text{CurrencyRate}^{c_b-USD} / \text{PriceCoefficient}^{c_s}, \end{aligned} \quad (16)$$

where  $\text{UnifyingCoefficient}_{c_b}^{c_s}$  – coefficient of reduction to standard values in the quadrant of buyer country  $c_b$  and supplier country  $c_s$ ;  $\text{CurrencyRate}^{c_b-USD}$  – exchange rate of country  $c_b$  to USD;  $\text{PriceCoefficient}^{c_s}$  – coefficient of additional trade margin of supplier country  $c_s$ .

Step 1 of the algorithm (comparing industry classifiers of countries with the industry structure of the model) is performed for all countries simultaneously at the beginning of data processing. Further, for each country, in accordance with the algorithm, the input-output balance for 2019 (2017 for China) is reduced to 2021 based on data on the country's GDP, imports and exports for 2021 according to formula (1) (step 2). Then the updated balance sheet is brought to the industry structure of the model according to formulas (2)–(4) (step 3), and a table of investment supplies is compiled according to formula (6) (step 4).

Since information about the import and export of countries is presented with varying degrees of detail, the further procedure for processing according to the described algorithm is important. The most detailed data on international trade are

presented for the EU, so they are converted first. In step 5.1, formulas (6) and (7) are used, commodity groups  $t$  are SITC classifiers. The data obtained are converted to the currency of the partner countries and serve as the initial calculations for them (formulas (8) and (9)). Data on imports and exports with the rest of the world are formed according to formulas (10)–(13), then the shares of partner countries in imports are calculated according to formula (14) and the volume of import cross-industry supplies in the context of supplier countries are calculated according to formula (15).

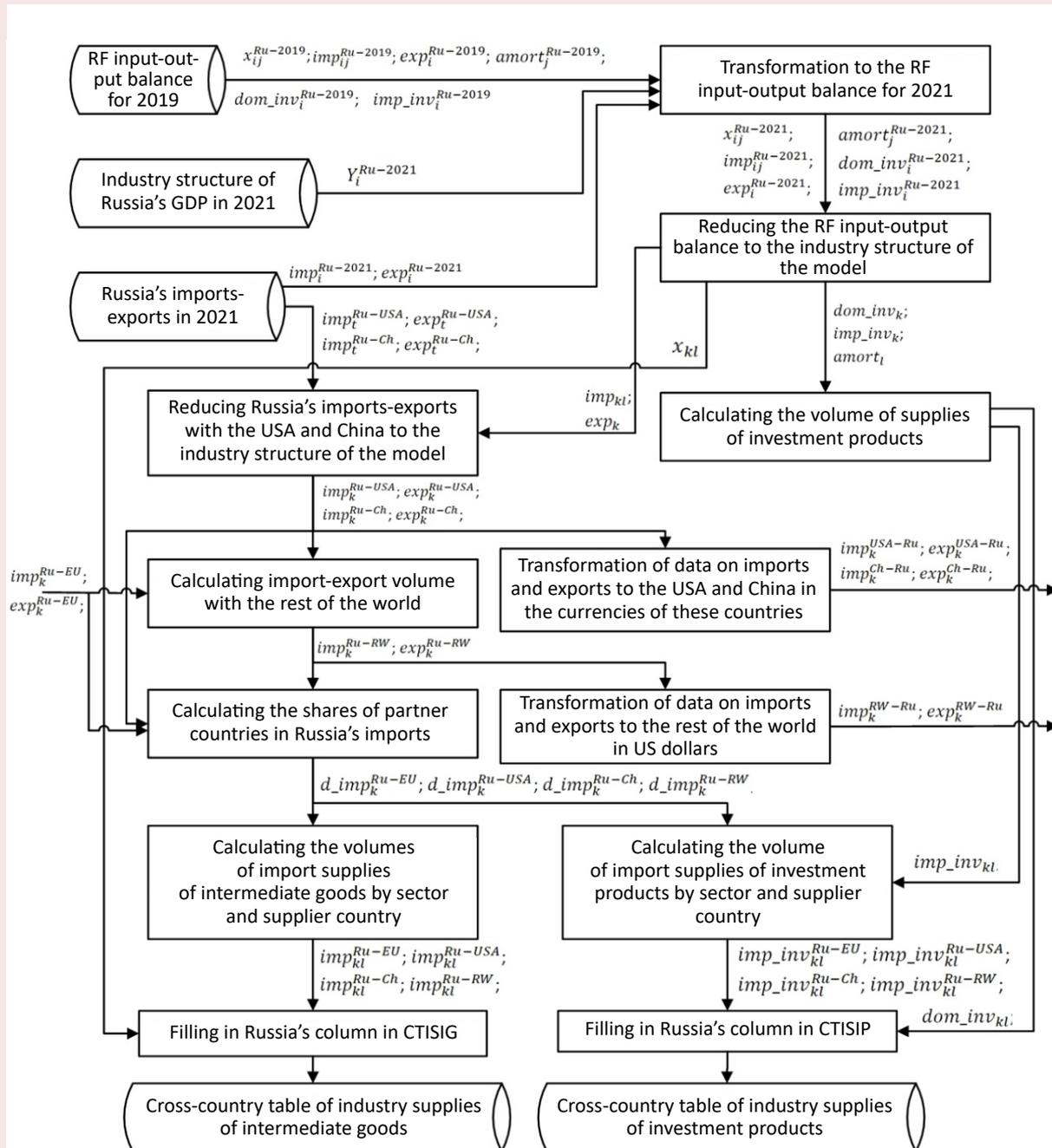
The transformation of data for Russia is a general case of the algorithm, since one part of the import and export data is obtained from previous calculations for the EU, and the other (for trade turnover with the USA and China) is based on the original Russian data converted according to formulas (6) and (7); commodity groups  $t$  are TN VED classifiers. The sequence of data processing for Russia is shown in the Figure.

For the USA, the data on trade turnover with the EU and Russia are received as pre-calculated, and the data on trade with China are converted from the initial ones according to formula (3), since the information on imports and exports is presented in an industry structure similar to the input-output balance.

In the calculations for China, all information about the sectoral structure of trade turnover with partner countries is transmitted from the calculations carried out for the EU, Russia and the USA, the output is only data on imports and exports with the rest of the world (formulas (10)–(13)).

GDP of the rest of the world is calculated based on World Bank data as the difference between global GDP (94 trillion USD in 2021) and GDP of the countries considered in the model (55.4 trillion USD). We consider the sectoral structure of the economy of the rest of the world and the coefficients of inter-industry supplies to be similar to these parameters for the Chinese economy, which is

Sequence of processing the data on production and trade in Russia



Source: own compilation.

the largest among developing countries. Based on these data, the input-output balance of the united rest of the world is built in the industry structure of the model, and data on imports and exports with the countries represented in the model come from previous calculations.

Upon completion of calculations for individual countries and the rest of the world as a whole, the obtained data on intermediate and investment supplies are entered into the corresponding columns of the cross-country table of industry supplies of intermediate goods (CTISIG) and the cross-country table of industry supplies of investment products (CTISIP), which are then reduced to base prices in US dollars according to formula (16).

### Results and discussion

As the first result, let us consider the analysis of the industry structure of international commodity exchange in 2021, carried out in steps 5.1–5.4 of the presented algorithm. *Table 3* shows data on the sectoral structure of EU imports and exports to Russia, the USA, China, and the rest of the world. The initial information for calculations is

presented on the Eurostat website in the SITC commodity nomenclature. When comparing the SITC nomenclature with the industry structure of the model, a number of nuances should be taken into account. First, groups 6 and 8 are presented in the Eurostat tables as a pair, and the shares of countries in imports and exports are considered the same for the corresponding aggregate industries (for example, Russia's share in EU exports of materials (sector 6) and light industry products (sector 8) is 3.9%. However, the application of this approach in the subsequent comparison of Eurostat data with data from other countries may reveal contradictions, for example, the estimated volume of exports to one country may exceed the total volume of exports for a certain industry, which requires additional mutual adjustments of the shares of countries. Thus, as a result of adjustments to EU import data, Russia's share in sector 6 was 8.6%, and in sector 8 – 0.7%. No discrepancies were found for the USA and China, and the share of these countries in the import of sectors 6 and 8 are equal (7.3% for China and 31.1% for the USA).

Table 3. Sectoral structure of EU imports and exports with partner countries and the rest of the world in 2021

#	Aggregate industry in the model	EU exports					EU imports				
		Total, billion euro	Share of countries in exports, %				Total, billion euro	Share of countries in imports, %			
			Russia	USA	China	Rest of the world		Russia	USA	China	Rest of the world
1	Agriculture, food production	175.5	3.3	12.3	8.6	75.8	117.1	1.8	5.6	4.1	88.5
2	Mining	70.8	3.7	9.6	15.6	71.1	106	59.3	11.0	3.5	26.2
3	Fuel production	104.2	0.8	12.6	1.4	85.2	385.8	12.2	8.6	0.3	78.9
4	Public sector	0.5	15	20.7	7.3	57.0	3.4	0.6	13.6	3.7	82.1
5	Chemical production	456.2	4.4	25.3	7.2	63.1	270.7	2.5	21.3	12.7	63.5
6	Production of materials	288	3.9	17.5	8.8	69.8	220.5	8.6	7.3	31.1	53.0
7	Manufacture of equipment and transport	831.5	4.7	17.6	14.0	63.7	671.8	0.3	12.0	39.3	48.4
8	Light industry	208.6	3.9	17.5	8.8	69.8	304.5	0.7	7.3	31.1	60.9
9	Services	35.2	3.2	27.0	7.3	68.8	9.3	66.3	27.2	3.7	2.8
10	Trade	10.2	0.7	0	7.3	71.3	28.2	48.5	5.7	3.7	42.1
11	Construction	0.5	29.9	0	7.3	42.1	1.3	48.6	0	3.7	47.7
Total, billion euro		2181.1	89.3	399.7	223.6	1468.5	2118.4	162.5	232.6	472.8	1250.5

Source: own compilation.

Second, the industry classification in the model is more detailed in relation to the public sector and the service sector. Four branches of the model (public sector, trade, services, industry) are not reflected in the SITC nomenclature, and their share in imports (exports) is defined as the difference between total imports (exports) and the amount of imports (exports) in real sector industries. The shares of countries in imports and exports for these four industries are also considered the same, except for adjustments caused by contradictions in the processing of the data from other countries. So, for the European Union, it was necessary to adjust Russia's shares and reset the U.S. share in the export of trade and construction services, since for the USA, imports of these industries are indicated in statistics as zero.

There was also a discrepancy between the SITC classifiers and the industry structure of Russia's exports in terms of minerals and fuels. Oil and gas in the Russian classifiers fall into aggregate industry 2, and industry 3 contains only refined products; in the SITC classifier, oil and gas fall into group 3 (mineral fuel), which corresponds

to aggregate industry 3. Therefore, the flow of oil and gas exports from Russia was divided between sectors 2 and 3 in such a ratio that allowed avoiding contradictions in the volume of trade exchange between the countries and Russia's total exports.

As a result of these adjustments, Russia's share in EU imports of minerals in 2021 amounted to about 60%, most of which accounted for oil and gas. Also, fuel (12.2%) and materials (8.6%) occupied significant shares in EU imports from Russia, while in other industries, including agriculture, the shares did not exceed 2.5%. Thus, the EU dependence on Russia was limited to the sphere of oil and gas resources, but in this area it was extremely profound. In technological industries, China (more than 30% in the production of materials and light industry, almost 40% in equipment and transport) and the USA (21% in chemical production, 12% in equipment and transport) are more significant suppliers to the EU.

Data on the sectoral structure of Russia's imports and exports to the European Union, the USA, China, and the rest of the world are presented in *Table 4*. The adjusted Eurostat data were used as

Table 4. Industry structure of Russia's imports and exports with partner countries and the rest of the world in 2021

#	Aggregate industry in the model	RF exports					RF imports				
		Total, billion rubles	Share of countries in exports, %				Total, billion rubles	Share of countries in imports, %			
			EU	USA	China	Rest of the world		EU	USA	China	Rest of the world
1	Agriculture, food production	2224.1	8.3	0.4	9.3	82.0	2610.3	19.3	1.3	4.2	75.2
2	Mining	10245.3	53.4	3.2	18.1	25.3	444.5	51.2	1	1.7	46.1
3	Fuel production	5476.6	75.0	3.3	17.3	4.4	342.1	20.2	1.2	1.6	77.0
4	Public sector	21.3	8.4	3.6	0	88.0	42.2	14.3	4.1	25.7	55.9
5	Chemical production	3347	17.6	4.1	6.6	71.7	3940.9	44.3	6.6	14.9	34.2
6	Production of materials	6470.3	25.5	5.4	8.9	60.2	1912.9	51.6	2.8	23.6	22,0
7	Manufacture of equipment and transport	2388.2	7.1	2.3	9.0	81.6	9592.5	35.4	5.1	33	26,5
8	Light industry	268.6	68.2	1.7	0.6	29.5	2280.8	31.3	0.8	45.4	22,5
9	Services	3886.7	13.7	3.9	16.8	65.6	3672.5	2.3	4.1	25.7	67,9
10	Trade	2880.8	41.3	0	16.8	41.9	14.6	41.3	10.0	25.7	23,0
11	Construction	422.1	12.6	0	16.8	70.6	507.2	2.4	1.0	25.7	70,9
Total, billion rubles		37631	14132	1211	5232	17056	25360	7754	1019	6458	10129

Source: own compilation.

initial data on the industry structure of trade with the European Union, and data from the Federal Customs Service of Russia were used for trade with the United States and China. Additional adjustments at this step were required by data on trade exchange with the United States in industries 4,6,8, 9,10,11.

In the structure of Russia's imports in 2021, there is a strong dependence on the EU in terms of supplies of materials (51.6%), chemical products (44.3%), equipment and transport (35.4%) and light industry (31.3%), as well as services in the field of exploration and mining (51.2%), i.e. practically in all high-tech areas. The second place in imports was occupied by China with shares in the listed industries from 15% to 33%, while the share of the United States was from 1% to 6%.

The European Union also played a leading role in Russia's exports; the volume of product supplies to European countries was almost three times higher than supplies to China (14 trillion rubles compared to 5 trillion rubles), and almost equaled the total supplies to the rest of the world (17 trillion rubles).

Table 5 shows data on the sectoral structure of U.S. imports and exports to the European Union, Russia, China, and the rest of the world. The data processed above by Eurostat and the Federal Customs Service of Russia were used as the initial data on the sectoral structure of trade with the European Union and Russia, data from the U.S. Bureau of Economic Analysis were used to analyze the sectoral structure of trade with China. No additional adjustments were required at this step, since data on U.S. imports and exports with individual countries are published in an industry structure compatible with the aggregate model industries without loss of accuracy.

Of the countries considered in the model, the most significant trading partners for the United States are China and the EU countries, but their total share in exports is about 20%, and in imports – about 30%, which indicates a high degree of diversification of U.S. trade relations.

The sectoral structure of China's imports and exports to the European Union, Russia, the USA, and the rest of the world is calculated on the basis of

Table 5. Industry structure of U.S. imports and exports with partner countries and the rest of the world in 2021

#	Aggregate industry in the model	U.S. exports					U.S. imports				
		Total, billion USD	Share of countries in exports, %				Total, billion USD	Share of countries in imports, %			
			EU	RF	China	Rest of the world		EU	RF	China	Rest of the world
1	Agriculture, food production	179.5	4.3	0.3	11.0	84.4	188.3	13.5	0.1	2.0	84.4
2	Mining	131.1	10.6	0	6.5	82.9	153.2	5.3	2.9	3.0	88.8
3	Fuel production	132.8	29.5	0	7.0	63.5	71.7	21.7	3.4	.06	68.9
4	Public sector	6.4	8.5	0.4	0	91.1	7.5	1.5	0.1	0	98.4
5	Chemical production	278.2	24.5	1.3	7.0	67.2	420.8	32.5	0.4	10.0	57.1
6	Production of materials	130.8	14.6	0.6	6.8	78.0	267.6	22.3	1.8	10.0	65.9
7	Manufacture of equipment and transport	526.4	18.1	1.3	7.2	73.4	1137.7	15.2	0.1	17.0	67.7
8	Light industry	63.8	41.3	0.4	4.0	54.3	343.2	12.6	0	24.0	63.4
9	Services	609.3	0.5	0.3	4.8	94.4	265.0	3.3	0.8	5.8	90.1
10	Trade	2.5	76.8	0.8	0	22.4	0	0	0	0	0
11	Construction	0.1	0	68.3	0	31.7	0	0	0	0	0
Total, billion USD		2060.9	275.3	13.9	135.7	1636	2854.9	470.5	16.5	372.6	1995.3

Source: own compilation.

Table 6. Sectoral structure of China's imports and exports with partner countries and the rest of the world in 2021

#	Aggregate industry in the model	China's exports					China's imports				
		Total, billion yuan	Share of countries in exports, %				Total, billion yuan	Share of countries in imports, %			
			EU	RF	USA	Rest of the world		EU	RF	USA	Rest of the world
1	Agriculture, food production	633.9	5.7	1.5	3.8	89.0	1381.6	8.3	1.3	9.1	81.3
2	Mining	64.6	43.9	1.0	45.4	9.7	2710.3	3.1	6.0	2.0	88.9
3	Fuel production	887.7	0.9	0.1	3.1	95.9	1102.1	1.0	7.5	5.4	86.1
4	Public sector	304.4	0.3	0.3	0	99.4	-	-	-	-	-
5	Chemical production	1270.0	20.5	4.0	21.2	54.3	1219.6	20.4	1.6	10.2	67.8
6	Production of materials	1345.9	38.6	2.9	12.7	45.8	1031.4	18.5	4.9	5.5	71.1
7	Manufacture of equipment and transport	9377.6	21.3	2.9	13.2	62.6	6362.5	13.8	0.3	3.8	82.1
8	Light industry	4099.3	17.5	2.2	12.8	67.5	905.6	15.3	0	1.8	82.9
9	Services	773.0	0.3	10.6	12.6	76.5	1868.1	1.0	3.0	10.0	86.0
10	Trade	2864.3	0.3	0	0	25.2	721.0	5.6	42.1	0	0
11	Construction	109.4	0.3	10.4	0	62.0	67.9	0.3	6.2	0	0
Total, billion yuan		21730.0	3576.2	561.5	2380.8	15211.5	17370	1691.1	454.9	866.9	14357.1

Source: own compilation.

the data processed above by Eurostat, the Federal Customs Service of Russia and the U.S. Bureau of Economic Analysis; the calculation results are presented in *Table 6*. China's trade relations, like those of the USA, are quite diversified: countries not considered in the model account for 60–90% of exports and 70–80% of imports of most industries.

The second result of the work carried out is the formation of cross-country tables of industry supplies of intermediate and final goods (based on information from the first quadrants, columns of exports and final goods of input-output balances of individual countries) and investment products (based on columns of exports and investments from the second quadrants).

The initial data of the countries' input-output balances were processed in accordance with steps 1–4 of the algorithm proposed in the article and brought to the form of cross-country tables of industry supplies using the data presented above on the shares of countries in the import and export of industries (step 5.5). To load the data into the model, the tables are reduced to the base prices

in US dollars (step 6). The dimension of each of the tables is 3,025 cells (square matrix 55\*55). A fragment of the table obtained as a result of the calculations, reflecting the supply of intermediate and final goods between Russia and the EU, as well as supplies within these countries, is presented in *Table 7*.

The first quadrant represents cross-industry supplies of domestic goods in the Russian economy, the second – Russia's exports to the EU (EU imports from Russia), the third – Russia's imports from the EU (EU exports to Russia), the fourth – cross-industry supplies of domestic products in the EU economy (in accordance with the proposed structure of the cross-country table of industry supplies presented in Table 3).

To forecast the dynamics of international trade, it is necessary to assess the scale of the sanctions imposed on goods of various industries by the EU and the United States. To solve this problem, data on the volume of imports and exports with Russia published by Eurostat and quarterly data from the U.S. Bureau of Economic Analysis were used.

Table 7. Fragment of the cross-country table of industry supplies for 2021 (trade turnover of intermediate and final goods and services between Russia and the EU, in base prices)

ind.#	RF											EU										
	1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10	11
1	75417	59	0.5	3020.3	230.5	3452.2	14.1	284.4	4721.3	109419	195.4	794.3	0.2	1.3	18.5	30.4	11.4	2.3	14.2	204.6	1000.5	3.3
2	90.7	15217	66726	54.2	2279.7	13251	48.1	337.9	13090	4003.3	2233.4	587.5	764.8	32657	468.6	4656.8	4390.1	757.3	202.1	13749	3982.9	1360.8
3	4257.7	5130.8	22020	1420.5	8111.2	4875.6	563.9	64.4	17741	22131	3533.6	1378.2	1037.5	4295.1	1110.6	3717.2	849.4	607.9	173.6	17677	15130	1379.8
4	292.8	347	181.2	227338	199	379.2	311.1	37.4	2226.6	24311	251.8	0.1	0	0	5.7	0.1	0	0.1	0	6.6	6.8	0.7
5	6655.4	968.6	1756.9	3634.6	19309	4212	4167.9	1041.5	4811.7	11964	17720	352.7	13.8	68.9	849.8	1972	287.6	520.5	154.3	932.5	1028	400.6
6	4213.2	1845.6	100.3	1304.9	4361	44890	17320	2063.3	11958	5519.8	16740	371.1	41.6	61.2	260.5	730.7	7071.5	4351.1	627.1	1438.8	1295.8	1664.1
7	3190.2	4018.3	200.5	1632.7	1366.4	4676.1	24873	132.2	16095	18320	4472.5	7.7	2.3	2.9	39.7	14.2	26.1	566	11.1	199.9	314.9	61.3
8	173.4	129.6	22	859.8	388.8	160.1	351.6	1720	873.6	10861	116.6	10.1	0.4	0.8	42.4	29.1	22.8	55.1	245.8	186.1	1165.6	21
9	19801	33014	21831	58925	22584	33465	15727	2757.8	233050	299800	18864	89.9	6.5	17.1	339.5	281.8	92.9	339.8	42.6	2823.8	1064.1	105.8
10	11181	2685.9	4178.9	5944.5	8305.6	13889.0	11188	1682.2	23679	163931	9942.7	897.1	13.6	64.1	272.8	628.2	415.5	1884.1	390	3211.5	4971.2	621.1
11	620.3	3911	752	9971.6	677.8	1201.7	541.6	49	12107	928.5	4728	2.5	0.4	0.4	36.3	2.6	11.4	7.2	0.4	85.1	15	262.5
1	1341.1	0.2	0	88.4	43.4	1.9	0.3	10.6	163.7	3132.8	0.2	369761	170.2	667.6	11443	11762	15869	1779.6	3609	139147	509233	2089.1
2	3.6	120.4	36.8	0.2	134.2	924.8	0.6	44.3	78.7	0.9	70	1658.7	5305.9	29162	1130.7	10308	5076	822.9	269.4	18303	5845.2	8876
3	53.9	2.4	86	4.1	26	60.6	0.5	0	425.6	0.6	1.7	8316	24698	32036	4106.1	13284	4577.5	2572.4	616	55635	80810	8734.3
4	0.7	1.3	0.3	28.8	0.6	1.2	1.5	0.1	14.7	7.9	0.8	3825.4	326.2	1238.4	2168726	5158.1	3812.9	9078.3	1181.6	165443	426279	7522
5	895.9	223.7	371.6	1888.3	3754	923.4	1098.1	314.2	757.8	4657.9	1366.5	39537	2084.9	9908.1	45105	181342	32616	69575	17083	92597	113019	105576
6	342.1	212.3	9.9	82.5	321.9	3107.7	1161.6	207.5	846.3	767.7	1502.9	21311	1459.8	2553.6	19947	25602	226969	182559	23022	103647	70344	89454
7	316.2	437.4	102.6	310.3	131.8	586.8	6761.3	21.6	2716.1	6254.3	908.3	15968	4215.5	4914.2	22510	15980	28436	403976	6839.6	145778	252307	46884
8	24.6	7.9	0.8	247.9	49.2	14.3	53.1	410.5	146.1	5415.7	17	1349.5	79.3	137.6	5870.1	3415.7	2802.5	7030.5	39924	26844	125786	4436
9	34.4	38.5	14	40	29.1	36.5	31.3	3.2	346	157.6	42.3	178826	15050	41405	625288	180562	169515	271555	53106	3120984	3686036	231732
10	0	0.1	0	15.2	3.5	3.5	1.6	0.1	1	28.4	0	114029	3913.9	11655	65812	66577	63243	167906	32583	281821	1060052	88473
11	0.2	1.8	0.3	18.9	0.3	0.5	0.2	0	6.9	4.3	2.2	6946.3	1279.5	1689.8	33091	6162.5	7015.5	12271	1828.8	197284	56041	307363

Source: own calculation.

Table 8. Dynamics of commodity exchange between the EU and Russia in 2022 relative to the values of 2021

SITC	EU imports from Russia, million euro			EU exports to Russia, million euro		
	2021	2022	dynamics, %	2021	2022	dynamics, %
Food, beverages and tobacco	2123.1	2402.9	13.2	5781.6	5770	-0.2
Crude materials	7273.7	-	-	2617.3	-	-
Mineral fuels	104005.9	148151.3	42.4	789.7	485.4	-38.5
Chemicals	6796.7	7114.8	4.7	20012.9	18235.5	-8.9
Other materials and goods	21046.8	18496.2	-12.1	19538.7	11876.1	-39.2
Machinery and transport equipment	1953.4	1277.8	-34.6	39437.5	16117.8	-59.1
Other groups	20447.0	-	-	1015.0	-	-
Total imports/exports	163646.6	203578.7	24.4	89192.7	55161.8	-38.2

Source: own compilation.

Since Eurostat publishes data on international trade in the context of commodity groups, it is possible to estimate the dynamics of EU imports and exports with Russia for each of them (*Tab. 8*). The exception is the SITC 2+4 commodity group, representing minerals, for which the details of turnover with Russia are no longer published on the Eurostat website (the data for 2021 presented in Table 8 were uploaded in November 2022; this information was unavailable when accessed in March 2023). The lack of data for group 2+4 also makes it impossible to estimate the volume of trade for other groups of goods, which is defined as the difference between the total volume of imports (exports) and the amount of imports (exports) for the selected groups.

According to the data in Table 8, Russia's imports from EU countries fell by 38%, the most significant drop in industry 7 (equipment and transport) – 59%. There are noticeable changes in the import of materials and light industry products (39%), while the import of agricultural and food products remained virtually unchanged. Changes in Russia's exports to the EU in 2022 are of even greater interest. Despite the unprecedented number of sanctions imposed, exports to the EU increased by 24%, while fuel exports (industry 3) increased by 42%. This indicates that with the reduction of energy supplies in physical terms, buyers from the EU paid much more for them in value terms. If we estimate a 50% decrease in physical energy

supplies relative to 2021, then Eurostat data indicate an actual price increase of 3 times (more accurate figures will be available after the publication of expanded data on Russia's international trade for 2022). At the same time, exports of high-tech products to the EU decreased by 34% in equipment and transport, and by 12% in materials and light industry products.

Due to the fact that at the time of writing this article, the Federal State Statistics Service and the Federal Customs Service have not yet published data on Russia's trade with the United States in 2022, it is necessary to rely on data from the U.S. Bureau of Economic Analysis to assess its dynamics (*Tab. 9*). The data are published quarterly, which allows for a more detailed assessment of the pace of changes compared to annual reports; however, data on U.S. trade with Russia are not detailed by industry, so only the dynamics of total imports and exports will be evaluated.

Changes in trade relations between Russia and the United States are more predictable than with the European Union, but here, too, the decline in U.S. exports to Russia is more significant (70%) than the decline in imports from Russia (51%). We can also note that exports to Russia decreased almost instantly in the second quarter of 2022, while imports gradually decreased by 51% in the second quarter, by 84% in the third quarter, and then partially recovered in the fourth quarter of 2022.

Table 9. The dynamics of commodity exchange between the United States and Russia in 2022 relative to the values of 2021

Indicator	Year	Period				
		I quarter	II quarter	III quarter	IV quarter	Total for the year
U.S. imports from Russia, million USD	2021	6219	7918	8390	7111	29638
	2022	7285	3872	1340	1966	14463
Import dynamics in 2022 relative to 2021, %		17.1	-51.1	-84.0	-72.4	-51.2
U.S. exports to Russia, million USD	2021	1477	1780	1588	1621	6466
	2022	1035	293	287	303	1918
Export dynamics in 2022 relative to 2021, %		-29.9	-83.5	-81.9	-81.3	-70.3

Source: own compilation.

In general, we can conclude that as a result of the sanctions imposed, the EU countries were the most affected; they not only faced a shortage of energy carriers in 2022, but also paid a higher price for fewer of them than for the full volume of supplies in the previous year. Thus, Russia's revenues from energy exports to Europe turned out to be high in the end, and the greatest difficulties were the substitution of imports of materials, machinery and equipment previously supplied from the EU in a significant volume. For the United States, on the contrary, the costs of severing trade ties with Russia turned out to be relatively small, since the volume of imports and exports with Russia is less than 1% for them.

### Conclusion

In this paper, the goal was to analyze the available data on trade relations between Russia, China, the EU, the USA, and the rest of the world and bring them to a unified form for uploading to an agent-based model of trade wars. In order to achieve this goal, the following objectives were addressed:

1. The structures of industry and commodity nomenclatures in various countries were analyzed and a scheme for their unification in 11 aggregate branches of the model was proposed.

2. An algorithm was proposed that determines the sequence of processing the initial statistical data to the form necessary for their loading into the model.

3. The data of the input-output tables for various countries were updated to the values of 2021 based on information on GDP, imports and exports, and reduced to the industry structure of the model.

4. Data on imports and exports of countries were reduced to the industry structure of the model and detailed in the context of partner countries using the proposed algorithm. In the process of solving this problem, an analysis of the sectoral structure of international commodity exchange in 2021 was also carried out, which showed a high level of interconnection between the economies of the European Union and Russia before the introduction of large-scale sanctions, and relatively low indicators of commodity exchange between Russia and the United States.

5. The structure of cross-country tables of industry supplies was proposed; based on the data obtained, tables were formed reflecting the flows of intermediate and investment products both within and between the participating countries of the model.

6. The analysis of the dynamics of trade exchange between Russia and the countries that imposed sanctions restrictions was carried out, which showed that Russia's imports from the EU countries fell by 38%, and exports increased by 24%, in particular fuel exports – by 42%. These data are presented in value terms and under the conditions of the imposed sanctions indicate a significant increase

in prices (about 200%) with a halving of supplies in kind. With regard to the trade exchange between Russia and the United States after the imposition of sanctions, we can note that the decrease in imports to Russia amounted to 70%, and exports – about 50%.

The obtained data sets were used to carry out calculations with the help of an agent-based model of trade wars, in which the dynamics of trade relations in a three-year period under various scenarios of state investment policy were studied. The results of the experiments are presented in the paper (Mashkova, 2023) and show that the degree of impact of investments on the economy is

directly proportional to the severity of the sanctions imposed, and while maintaining the imposed trade restrictions, the implementation of large-scale investment programs can accelerate economic recovery by an average of 0.5% of GDP per year. The further experimental research plan includes an assessment of the sensitivity of the economic systems of various countries to the restructuring of world trade relations, in particular, the speed of recovery of the economies of the countries involved in the conflict, taking into account their ability to replace the resources and goods that have fallen under the restrictions.

## References

- Afontsev S.A. (2022). Political paradoxes of economic sanctions. *Zhurnal Novoi ekonomicheskoi assotsiatsii=Journal of the New Economic Association*, 3(55), 193–198. DOI: 10.31737/2221
- Aguiar A., Narayanan B., McDougall R. (2016). An overview of the GTAP 9 data base. *Journal of Global Economic Analysis*, 1, 181–208. DOI: <https://doi.org/10.21642/JGEA.010103AF>
- Altiner A., Bozkurt E., Topcuoglu O. (2022). The impact of R&D expenditures on high-tech product exports. *Ekonomicheskie i sotsial'nye peremeny: fakty, tendentsii, prognoz=Economic and Social Changes: Facts, Trends, Forecast*, 15(5), 153–169. DOI: 10.15838/esc.2022.5.83.8 (in Russian).
- Andreyev M.Yu., Polbin A.V. (2023). Macroeconomic effects of the expected future decline in oil revenues for the Russian economy under capital control. *Voprosy ekonomiki*, 4, 5–28. Available at: <https://doi.org/10.32609/0042-8736-2023-4-5-28> (in Russian).
- Bashmakov I.A. (2022). CBAM and Russian export. *Voprosy ekonomiki*, 1, 90–109. DOI: <https://doi.org/10.32609/0042-8736-2022-1-90-109> (in Russian).
- Belozеров S.A., Sokolovskaya E.V. (2022). The game-theoretic approach to modeling the conflict of interests: The economic sanctions. *Terra Economicus*, 20(1), 65–80. DOI: 10.18522/2073-6606-2022-20-1-65-80 (in Russian).
- Bollen J., Rojas-Romagosa H. (2018). *Trade Wars: Economic Impacts of US Tariff Increases and Retaliation: An International Perspective. CPB Background Document*. CPB Netherlands Bureau for Economic Policy Analysis. Available <https://www.cpb.nl/sites/default/files/omnidownload/CPB-Background-Document-November2018-Trade-Wars-update.pdf>
- Borisov V.N., Pochukaeva O.V. (2021). Analysis and forecast of competitiveness of Russian investment equipment in the foreign markets. *Ekonomicheskie i sotsial'nye peremeny: fakty, tendentsii, prognoz=Economic and Social Changes: Facts, Trends, Forecast*, 14(2), 43–58. DOI: 10.15838/esc.2021.2.74.3 (in Russian).
- Bouët A., Laborde D. (2017). *US Trade Wars with Emerging Countries in the 21st Century. Make America and Its Partners Lose Again. IFPRI Discussion Paper*. Available at: <http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/131368>.
- Cherniavsky A.V., Chepel A.A. National and regional type I and II input-output multipliers: Analysis of calculation methods. *Voprosy ekonomiki*, 4, 32–57. Available at: <https://doi.org/10.32609/0042-8736-2021-4-32-57> (in Russian).
- Chupina D.A. (2022). Impact of the Green Deal on copper imports from Russia to the EU. *Voprosy ekonomiki*, 1, 110–125. Available at: <https://doi.org/10.32609/0042-8736-2022-1-110-125> (in Russian).
- Corong E., Hertel T., McDougall R. et al. (2017). The standard GTAP model, version 7. *Journal of Global Economic Analysis* 2, 1–119. DOI: <https://doi.org/10.21642/JGEA.030101AF>

- Derunova E.A., Vasilchenko M.Ya., Shabanov V.L. (2021). Assessing the impact of innovation and investment activity on the formation of an export-oriented agricultural economy. *Ekonomicheskie i sotsial'nye peremeny: fakty, tendentsii, prognoz*=*Economic and Social Changes: Facts, Trends, Forecast*, 14(5), 100–115. DOI: 10.15838/esc.2021.5.77.6 (in Russian).
- Edinak E.A., Sayapova A.R., Shirov A.A. (2022). Endogenization of household consumption in the expanded input-output model. *Problemy prognozirovaniya*=*Studies on Russian Economic Development*, 1(190), 6–18. DOI: 10.47711/0868-6351-190-6-18 (in Russian).
- Egorova A.I., Chepurenko A.Yu. (2022). Factors of the resilience of small businesses under external shocks in Russia (based on the longitudinal study data). *Rossiiskii zhurnal menedzhmenta*=*Russian Management Journal*, 20(2), 172–197. Available at: <https://doi.org/10.21638/spbu18.2022.202> (in Russian).
- Golikova V.V., Kuznetsov B.V. (2021). Strategies of Russian industrial enterprises' importing behavior under economic sanctions. *Voprosy ekonomiki*, 7, 89–106. Available at: <https://doi.org/10.32609/0042-8736-2021-7-89-106> (in Russian).
- Gordeev R.V., Pyzhev A.I. (2023). The timber industry in Russia under sanctions: Losses and opportunities. *Voprosy ekonomiki*, 4, 45–66. Available at: <https://doi.org/10.32609/0042-8736-2023-4-45-66> (in Russian).
- Kheifets B.A., Chernova V.Yu. (2022). Effects of export control policy on food security: The case of the grain market in Russia. *Problemy prognozirovaniya*=*Studies on Russian Economic Development*, 2(191), 131–141. DOI: 10.47711/0868-6351-191-131-141 (in Russian).
- Kolpakov A.Yu., Saenko V.V. (2023). Analysis of Russia's energy sector dependence on imported equipment on the basis of public data. *Problemy prognozirovaniya*=*Studies on Russian Economic Development*, 1(196), 144–155. DOI: 10.47711/0868-6351-196-144-155 (in Russian).
- Kuvalin D.B. (2022). Russian economy under tough external sanctions: Problems, risks and opportunities. *Ekonomicheskie i sotsial'nye peremeny: fakty, tendentsii, prognoz*=*Economic and Social Changes: Facts, Trends, Forecast*, 15(6), 79–93. DOI: 10.15838/esc.2022.6.84.4 (in Russian).
- Lyubimov I. (2021). Services export in developing economies. *Ekonomicheskaya politika*=*Economic Policy*, 16(5), 76–95. DOI: 10.18288/1994-5124-2021-5-76-95 (in Russian).
- Mashkova A., Bakhtizin A. (2021). 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. *Biznes-informatika*=*Business Informatics*, 17(1), 18–36. DOI: 10.17323/2587-814X.2023.1.18.36 (in Russian).
- Partsvaniya V.R. (2022). The import substitution trap in the realities of the automotive industry. *Problemy prognozirovaniya*=*Studies on Russian Economic Development*, 2(191), 119–130. DOI: 10.47711/0868-6351-191-119-130 (in Russian).
- Shirov A.A. (2023). Development of the Russian economy in the medium term: risks and opportunities. *Problemy prognozirovaniya*=*Studies on Russian Economic Development*, 2(197), 6–17. DOI: 10.47711/0868-6351-197-6-17 (In Russian).
- Strizhkova L.A., Islamova G.R., Kashirskaya. S.I. (2022). Intercountry input-output table of the Eurasian Economic Union as a component of the tools for analysis and forecasting of its economy. *Problemy prognozirovaniya*=*Studies on Russian Economic Development*, 2(191), 17–34 (in Russian).
- Tenyakov I.M., Khubiev K.A., Epshtein D.B., Zazdravnykh A.V. (2022). Stagnation in Russia in geopolitical and economic contexts: New alternatives. *Terra Economicus*, 20(2), 40–58. DOI: 10.18522/2073-6606-2022-20-2-40-58 (in Russian).
- Timofeev I.N. (2022). Policy of sanctions against Russia: Newest stage. *Zhurnal Novoi ekonomicheskoi assotsiatsii*=*Journal of the New Economic Association*, 3(55), 198–206. DOI: 10.31737/2221-2264-2022-55-3-11 (in Russian).
- Vnukov I.A., Moiseev N.A., Sokerin P.O. (2023). Evaluation of the effects from various ways of import substitution “input-output” method: Evidence from the Russian Federation. *Ekonomika i matematicheskie metody*, 59(1), 30–47. Available at: <https://emm.jes.su/s042473880024869-4-1/>; DOI: 10.31857/S042473880024869-4 (in Russian).

Appendix. Comparison of industry and commodity classifiers of different countries

Aggregate industry in the mode/	Industries in Russia	TN VED	Industries in the EU	SITC	Industries in the USA	Industries in China
(1) Agriculture, food production	Crop production, animal husbandry, hunting and provision of services in these areas	Live animals	Agriculture, hunting and related service activities	Food and live animals	Agriculture, forestry, fishing, and hunting	Agriculture, forestry & fishery
	Forestry and logging	Meat and edible meat offal	Forestry, logging and related service activities	Beverages and tobacco	Food manufacturing	Food products and tobacco
	Fishing and fish farming	Fish and crustaceans, mollusks	Fishing, fish farming and related activities	Animal and vegetable oils and fats	Beverage manufacturing	
	Manufacture of food, beverages, tobacco products	Dairy products; poultry eggs; natural honey	Manufacture of food products and beverages		Tobacco product manufacturing	
		Products of animal origin	Manufacture of tobacco products			
		Live trees and other plants				
		Vegetables and edible roots				
		Edible fruits and nuts				
		Coffee, tea, mate, spices				
		Cereals				
		Products of the milling and cereal industry				
		Oilseeds and fruits; other seeds, fruits and grains				
		Shellac; gums, resins, vegetable juices and extracts				
		Plant materials for the manufacture of wicker products				
		Fats and oils of animal or vegetable origin				
		Finished products from meat, fish or crustaceans				
		Sugar and sugar confectionery				
		Cocoa and its products				
		Finished products from cereals, flour, starch or milk				
		Processed products of vegetables, fruits, nuts				
	Miscellaneous food products					
	Alcoholic and non-alcoholic beverages and vinegar					

## Continuation of Appendix

Aggregate industry in the model/	Industries in Russia	TN VED	Industries in the EU	SITC	Industries in the USA	Industries in China
		Residues and waste from the food industry; ready-made animal feed				
		Tobacco and industrial tobacco substitutes				
(2) Mining	Mining	Salt; sulfur; earth and stone; lime and cement	Mining of coal and lignite; extraction of peat	Crude materials, inedible, except fuels	Oil and gas extraction	Mining
		Ores, slag and ash	Extraction of crude petroleum and natural gas;	Mineral fuels, lubricants and related materials	Mining, except oil and gas	
			Mining of uranium and thorium ores		Support activities for mining	
			Mining of metal ores			
			Other mining and quarrying			
(3) Fuel production	Production of coke and petroleum products	Mineral fuel, oil and products of their distillation	Manufacture of coke, refined petroleum products and nuclear fuel	Mineral fuels, lubricants and related materials	Petroleum and coal products	Manufacture of coke, refined petroleum products
(4) Public sector	Public administration and military security, social security	-	Public administration and defence; compulsory social security	Commodities and transactions not classified elsewhere in the SITC	Federal general government (defense)	Public administration and defence; social security
	Education		Education		Federal general government (nondefense)	Education
	Health care activities		85 Health and social work		State and local government educational services	Health and social work
	Residential care activities				State and local government hospitals and health services	
(5) Chemical production	Manufacture of chemicals and chemical products	Products of inorganic chemistry; compounds of rare earth metals	Manufacture of chemicals and chemical products	Chemicals and related products	Chemical products	Manufacture of non-metallic mineral products
	Production of medicines and materials	Organic chemical compounds	Manufacture of rubber and plastic products		Plastics and rubber products	
	Manufacture of rubber and plastic products	Pharmaceutical products	Manufacture of other non-metallic mineral products		Nonmetallic mineral products	
	Production of other non-metallic mineral products	Fertilizers				
		Extracts; dyes, pigments; paints and varnishes				
		Essential oils and rubbers; cosmetics				

Continuation of Appendix

Aggregate industry in the mode/	Industries in Russia	TN VED	Industries in the EU	SITC	Industries in the USA	Industries in China
		Soap, detergents				
		Explosives				
		Photo and film products				
		Other chemical products				
		Plastics and products made of them				
		Rubber and products made of it				
(6) Production of materials	Metallurgical production	Ferrous metals	Manufacture of basic metals	Manufactured goods classified chiefly by material	Primary metals	Manufacture of basic metals and fabricated metal products
	Production of finished metal products, except machinery and equipment	Ferrous metal products	Manufacture of fabricated metal products, except machinery and equipment		Fabricated metal products	Manufacture of wood and paper products; publishing and printing
	Wood processing and manufacture of wood and cork products	Copper and its products	Manufacture of textiles		Textile mills and textile product mills	
	Production of paper and paper products	Nickel and its products	Manufacture of wood and of products of wood and cork,		Wood products	
	Printing and copying of media	Aluminum and its products	Manufacture of pulp, paper and paper products		Paper products	
		Lead and its products	Publishing, printing and reproduction of recorded media		Printing and related support activities	
		Zinc and its products				
		Tin and its products				
		Other base metals; cermets				
		Raw hides and tanned leather				
		Natural and artificial fur				
		Wood and products made from it				
		Cork and its products				
		Paper and cardboard; products made of them				
		Silk, wool, cotton				
		Chemical fibers and filaments				
	Cotton wool, felt; twine, ropes					
	Lace; tapestries					
	Knitted fabrics					

## Continuation of Appendix

Aggregate industry in the model	Industries in Russia	TN VED	Industries in the EU	SITC	Industries in the USA	Industries in China
(7) Manufacture of equipment and transport	Manufacture of computers, electronic and optical products	Nuclear reactors, boilers, equipment and mechanical devices; parts thereof	Manufacture of machinery and equipment n.e.c.	Machinery and transport equipment	Machinery	Manufacture of machinery and equipment, transport
	Manufacture of electrical equipment	Electrical machines and equipment, their parts, etc.	Manufacture of office machinery and computers		Computer and electronic products	
	Manufacture of machinery and equipment not included in other groupings	Railway locomotives or tram motor cars, rolling stock and parts thereof, etc.	Manufacture of electrical machinery and apparatus n.e.c.		Electrical equipment, appliances, and components	
	Manufacture of motor vehicles, trailers and semi-trailers	Means of land transport, except railway, their parts and accessories	Manufacture of radio, television and communication equipment and apparatus		Medical equipment and supplies manufacturing	
	Manufacture of other vehicles and equipment	Vessels, boats and floating structures	Manufacture of medical, precision and optical instruments, watches and clocks		Motor vehicles, bodies and trailers, and parts	
		Optical, photographic, measuring, medical instruments and apparatus; their parts and accessories	Manufacture of motor vehicles, trailers and semi-trailers		Other transportation equipment	
		Watches of all kinds and their parts	Manufacture of other transport equipment			
(8) Light industry	Manufacture of furniture and other finished products	Leather goods; travel accessories, bags	Manufacture of furniture; manufacturing n.e.c.	Miscellaneous manufactured articles	Furniture and related products	Other manufactured products
	Manufacture of textiles, clothing, leather and related products	Products made of straw, alpha; basket products and wicker products	Recycling		Other miscellaneous manufacturing	Manufacture of textiles, wearing apparel, leather, footwear
		Printed books, newspapers, reproductions and other products of the printing industry	Manufacture of wearing apparel; dressing and dyeing of fur		Apparel and leather and allied products	
		Carpets and other textile floor coverings	Tanning and dressing of leather; manufacture of luggage, handbags			
		Clothing items				
		Other finished textile products				
		Shoes, gaiters				
		Hats				
		Umbrellas, sun umbrellas, walking sticks				

Continuation of Appendix

Aggregate industry in the mode/	Industries in Russia	TN VED	Industries in the EU	SITC	Industries in the USA	Industries in China
		Products made of stone, gypsum, cement, asbestos, mica				
		Ceramic products				
		Glass and its products				
		Pearls, precious stones, coins; jewelry				
		Musical instruments				
		Furniture; bedding; lamps				
		Toys, games and sports equipment				
		Various finished products				
		Works of art				
(9) Services	Provision of electric energy, gas and steam; air conditioning	-	Electricity, gas, steam and hot water supply	Commodities and transactions not classified elsewhere in the SITC	Electric power generation, transmission, and distribution	Electricity, gas and water supply
	Water intake, purification and distribution		Collection, purification and distribution of water		Accommodation	Hotels and restaurants
	Activities of hotels and catering establishments		Hotels and restaurants		Food services and drinking places	
	Land and pipeline transport activities		Land transport; transport via pipelines		Transportation and warehousing	transport, storage and post
	Water transport activities		Water transport		Broadcasting and telecommunications	Information Transmission, software and information technology
	Air and space transport activities		Air transport		Finance and insurance	Finance
	Warehousing and auxiliary transport activities		Supporting transport activities; activities of travel agencies		Real estate and rental and leasing	Real Estate
	Postal communication and courier activities		Post and telecommunications		Data processing, internet publishing, and other information services	Research and technical services
	Financial and insurance activities		Financial intermediation, except insurance and pension funding		Professional and business services	Leasing and business services
	Real estate transactions		Insurance and pension funding, except compulsory social security		Arts, entertainment, recreation, accommodation, and food services	Management of water conservancy, environment

## Continuation of Appendix

Aggregate industry in the mode/	Industries in Russia	TN VED	Industries in the EU	SITC	Industries in the USA	Industries in China
	Rent and leasing		Activities auxiliary to financial intermediation		Information (publishing, motion pictures)	Culture, sports and entertainment
	Telecommunications activities		Real estate activities		Other services, except government	Repair and other services
	Computer software development		Renting of machinery and equipment without operator and of personal goods			
	Activities in the field of architecture and engineering design		Computer and related activities			
	Research and development		Research and development			
	Advertising activities and market research		Other business activities			
	Other professional, scientific and technical activities; veterinary activities		Sewage and refuse disposal, sanitation and similar activities			
	Employment and recruitment activities		Activities of membership organizations n.e.c.			
	Activities of travel agencies		Recreational, cultural and sporting activities			
	Security and maintenance activities for buildings and territories		Other service activities			
	Activities in the field of law and accounting					
	Waste water collection and treatment; waste collection, treatment and disposal					
	Activities of nongovernmental organizations					
	Activities in the field of creativity, art and entertainment organization					
	Activities in the field of sports, recreation and entertainment					
	Publishing activity					
	Production of movies; activities in the field of television and radio broadcasting					

End of Appendix

Aggregate industry in the mode/	Industries in Russia	TN VED	Industries in the EU	SITC	Industries in the USA	Industries in China
	Repair of computers, personal items and household goods					
	Activities for the provision of other personal services					
(10) Trade	Wholesale and retail trade in motor vehicles and motorcycles and their repair		Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel	Commodities and transactions not classified elsewhere in the SITC	Wholesale trade	Wholesale and retail trade
	Wholesale trade, except wholesale trade in motor vehicles and motorcycles		Wholesale trade and commission trade, except of motor vehicles and motorcycles		Retail trade	
	Retail trade, except retail trade in motor vehicles and motorcycles		Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods			
(11) Construction	Construction		Construction	Commodities and transactions not classified elsewhere in the SITC	Construction	Construction
Source: own compilation.						

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