THE IMPORT INTENSITY OF RUSSIAN INDUSTRIES UNDER SANCTIONS: AN ANALYSIS USING INPUT–OUTPUT TABLES

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Abstract. Since 2014, the Russian government has been implementing an economic policy of import substitution. On this path, the need for economic research using mathematical models of economic management at different levels (enterprise, industry, and the entire economy) becomes crucial. Among such modeling approaches, note input–output tables, yielding quantitative estimates with direct and indirect links throughout the entire production chain. This paper focuses on the import intensity of Russian industries in 2014–2022. The objective is to obtain dynamic industry-level estimates of import intensity for each year of the period under consideration. The analytical tool is the author's input–output model for the Russian economy, which incorporates a dedicated import block. Explicit formulas are introduced in this model to calculate the import intensity of intermediate output by industries within the input–output framework. The model is based on the statistical data on intermediate consumption flows from the Inter-Country Input–Output (ICIO) tables, published by the Organisation for Economic Co-operation and Development (OECD) in 2025. The model is tested on the Russian mining sector. The import intensity dynamics across all industries of this sector are estimated for the period under consideration. According to the findings, in contrast to the previous years, 2022 witnessed a sharp substitution of intermediate machinery imports by domestic supplies in the mining sector, i.e., by 10% on average, depending on the industry. Some promising improvements of the model are identified.

Keywords: input–output tables, OECD ICIO, industries management, mining, import substitution, import intensity, sanctions.

INTRODUCTION

In recent years, input–output models have become a widespread tool for economic analysis. This is due to theoretical results in several areas (in particular, *global value chains*, *trade in value added*, and world input–output tables [1, 2]) and the expanded practical capabilities for implementing high-dimensional models on personal computers (operations with large datasets).

For the practical use of input–output models in economic modeling, the regular release of Inter-Country Input–Output (ICIO) tables is essential. These tables are compiled by the *Organisation for Economic Co-operation and Development* (OECD) under the auspices of the United Nations (UN) [3]. The database maintained by the OECD is one of the most reliable databases in the world.

First, this organization uses reliable information consistent with the *System of National Accounts* (SNA) [4] and statistical sources containing official data from government agencies around the world and major international organizations: the UN, the UN Trade and Development (UNCTAD), the World Trade Organization (WTO), and others.

Second, the OECD regularly updates and publishes ICIO tables. Compiling such tables is always a complex, costly, and labor-intensive process typically taking several years, considering the need for thorough statistical processing of the available data. The separation of the import component for each item of intermediate consumption and end product (the GDP income approach) further extends the required timeframe. Therefore, input–output tables are compiled for a long time and become available to researchers with a time

lag. The OECD provides these tables to users with a lag of 3–4 years.

Third, the input–output tables of this organization cover all years starting from 1995 and are updated whenever the developers change the methodology, classification, or composition of industries. This was the case in the latest version as well, published in 2025: the mining sector was further disaggregated into five industries, in contrast to three ones in the previous version. To facilitate retrospective comparisons and the generation of long time series (e.g., for forecasting), the OECD recalculated the old input–output tables for previous years using the new classification and also included them in the database.

Fourth, input–output tables are compiled for Russia as one of the world's leading powers occupying a prominent position in the global economy and the international division of labor, even despite that Russia is not an OECD member.

Thus, ICIO tables can be used in various economic tasks, including the management of import substitution across Russian industries. The challenge of import substitution and the corresponding modeling process are crucial amid sanctions pressure on the Russian economy and its manufacturing sector (especially, the mining sector).

The **problem** addressed here is to modify the author's previous model [5] in order to calculate the import intensity of the national economy based on the latest ICIO tables. The **objective** of the study is to estimate the import intensity of industries in the Russian mining sector using the input–output model for the period 2013–2022.

This study has the following limitations.

- A scientifically grounded choice or a methodology for determining optimal and/or maximum permissible import levels for individual industries, types of production, goods, or the economy as a whole goes beyond the scope of the study. This is a large, complex, and independent problem. It should be formulated within the country's public administration system (specifically by federal executive bodies) and assigned to Russian research institutes, centers, and universities for analysis, modeling, elaboration of appropriate proposals, and decision-making.
- The start of the period under consideration (2013) is chosen as the last year of Russia's free foreign trade before economic sanctions. And Russia's input–output tables for 2022 are the most recent ones currently available in the ICIO database. At the same time, we use economic data for other years when necessary for the study.

1. METHODOLOGICAL ISSUES

1.1. Applications of Models

The research of economic systems based on input–output models is a key area of economic-mathematical modeling. In Russia, such scientific schools exist at different structural divisions of the Russian Academy of Sciences (RAS): the Central Economics and Mathematics Institute (CEMI RAS), the Institute of Economic Forecasting (IEF RAS), the Institute of Economics and Industrial Engineering (IEIE SB RAS), and others. The macroeconomic models of such authoritative international organizations as the UN, the World Bank, the International Monetary Fund (IMF), and the OECD were reviewed, e.g., in [6].

Large-scale socioeconomic systems are analyzed, among other methods, using input–output models. One of the leading schools in the management of large-scale system development has been established at the Trapeznikov Institute of Control Sciences (ICS RAS). In recent years, the Institute's notable works in this field include [7–10].

With the imposition of sanctions on Russian enterprises, it is vital to analyze import substitution opportunities at the goods and industry levels. The first issue is addressed at the enterprise level, while the second required broader, generalized studies. Here, modeling is the primary research tool as well [11, 12].

Models based on input–output tables are important for the analysis of import substitution challenges: this tool yields estimates considering direct and indirect costs throughout the entire production chain. On this topic, note the studies [13, 14]. The problem of assessing economic effects was considered in [15, 16].

Russian academic literature includes publications on the use of ICIO tables in economic research; for example, see [17]. There are far more such publications abroad [18–21]. ICIO tables are employed to monitor economic development, estimate macro- and microeconomic effects, and study intra- and inter-industry proportions, structural shifts, etc. Over 20 different economic-mathematical models based on statistics from the ICIO database were presented at the world's largest conference of *the International Input–Output Association* (IIOA), held in 2023; for details, see [22]. In the same context, one should consider the application of input–output models for the development of the global economy and interregional integrations (associations) of several countries [23–25].

For example, the global economic model [25] describes the dynamics of the global trade structure by country. In particular, it provides quantitative estimates of structural shifts, showing that the dynamics of

China and developing countries accelerated during 2000–2014 compared to those of developed countries. Also, specific estimates considering inter-country and inter-industry links are given.

While general issues of modeling import substitution using input–output tables have been thoroughly covered in the scientific literature, there are a few studies of this kind with application to the mining sector [26]. Indeed, some authors noted insufficient attention to the issues of modeling import substitution and assessing the impact of external shocks amid intensifying sanctions [11]. To a certain extent, this paper addresses the existing gaps in the empirical analysis of import substitution through the lens of the import intensity indicator using input–output tables.

1.2. OECD Methodology

The first inter-country input–output tables were developed at the OECD as early as the mid-1990s. The rapid advancement of globalization over the following 10–15 years intensified this line of research and activity, and the global financial and economic crisis of 2008–2009 demonstrated in practice the unprecedented level of interdependence and vulnerability among all countries that had grown over the past three decades. When the leaders (drivers) of the global economy faced economic problems, the negative effects spread very quickly to other countries due to their high level of economic integration and their inclusion in production and supply chains.

The global crisis of 2008–2009 also revealed an urgent need for modern tools to assess the economic state of all countries, based on mathematical models of global reproduction processes, including world input–output tables. The COVID-19 pandemic (2020) confirmed the relevance of the OECD's work in this area. In 2023, the database of input–output tables was updated, allowing one to assess the development of the global economy during the pre-pandemic period. In 2025, its latest version was released, including tables for 2020, 2021, and, most importantly, for 2022, a pivotal year for the Russian economy (a sharp escalation of international sanctions against Russia, followed by production and foreign trade challenges).

Thus, the current database of long time series of input–output tables for 1995–2022 provides valuable economic information on the production and financial indicators of the global economy and national production systems, foreign trade activity, and the flows of goods and services used as intermediate goods in production and for final goods, both for individual countries and for the global economy as a whole.

The OECD's work on compiling these tables is carried out under the UN auspices and support. It involves data from each country's SNA and the UN Comtrade database on international trade, developed and maintained by the UN [27]. The SNA consists of key macroeconomic statistical indicators presented in an analytically linked format: intermediate consumption (total and by industry), final output (total, by industry, and by component), gross output, value added, exports (imports), taxes, etc.

If OECD experts encounter information problems when compiling input–output tables, they obtain the missing data from additional sources of national statistics or estimate the values of indicators using special methodologies. The remaining gaps are filled with estimates using special procedures, particularly expert assessments. All numerical information is open and available to users in the form of a set of accounts and tables.

Due to the delay in the publication of national data, the timeframe for compiling ICIO tables for each current year is approximately 3–4 years, with four stages as follows [28].

1. Collection of statistical data. For each country, information received from national statistical agencies, customs services, and regional and international statistical agencies is collected, verified, and processed. This primarily consists of:

– aggregated SNA data;
– production volume (gross output);
– value added;
– GDP by use, in total and by components;
– balance of payments;
– tourism statistics;
– customs statistics;

2. Assessment of the balance of trade flows. This stage includes preliminary balancing and corrections to ensure that exports and imports by product and industry correspond to output data. Balancing is performed for:

– the total volume of exports and imports by country and at the global level;
– exports and imports by industry and goods groups;
– bilateral trade flows.

3. Harmonization of national input–output tables. Based on the information obtained, input–output tables are compiled for the current year for all countries; if necessary, the existing national tables from previous years are corrected. In cases where certain industry data are unavailable for a country, the average production and technological indicators of other countries are

used as initial values to start the balancing procedure. Extrapolation, interpolation, and expert assessments are also applied to obtain the missing information.

4. Compilation of inter-country input–output tables. Goods flows between countries are estimated using customs statistics and the shares of trading partners calculated at previous stages.

When compiling inter-country input–output tables, one of the most significant challenges is converting economic indicators from different countries to a common price scale. In the ICIO tables, in accordance with the SNA, domestic production data are expressed in USD at *basic prices*. Exports and imports are valued at *Free On Board* (FOB) prices. Taxes, net of subsidies on intermediate and final goods, including import duties, are shown by a separate line in quadrant III. Expenditures on the delivery of goods are allocated to the transportation industry; for details, see [28].

The OECD methodology uses official statistics and includes additional information, particularly data on direct purchases by residents abroad (imports) and on direct purchases by non-residents in the domestic market (exports) during personal and business trips, as well as data on re-exports and re-imports. This distinguishes it from other similar databases, which are limited only to official government statistics.

2. MODEL

2.1. Model Development

In this paper, the basic model is the conventional input–output model presented in [5]; this model is modified by separating, in quadrant I, domestic intermediate inputs and intermediate imports. The modification is carried out by aggregating the global ICIO table to Russia.

The 2025 version of the ICIO tables has two levels of aggregation, namely, global and national (a specific country). At the global level, the world economy is represented by a single table comprising 80 countries and, for balancing purposes, another group of countries (The rest of the world). Each country is broken down into 50 industries in accordance with the 2008 *International Standard Industrial Classification of All Economic Activities* (ISIC) [29]. Thus, the matrix for quadrant I (intra- and inter-country flows of intermediate goods) has dimensions of 4050 × 4050. The OECD has compiled such global tables for all years in the period 1995–2022. By summing the corresponding rows and columns of the global matrix, for any country, it is possible to obtain both total and bilateral (with other countries) flows of exports/imports of goods and services. This transformation, called aggregation (or convolution), provides opportunities for various analytical work on Russia's foreign trade flows, both with the rest of the world and with individual countries.

In addition to the global level, ICIO provides national tables, i.e., a series of 50 × 50 tables for each of the 80 countries, including Russia. The main ones are the *total table*, the *domestic output table*, and the *imports table*. All three tables are harmonized across industries and are derived by the full aggregation of the global economic table for a specific country.

The author's independent aggregation of the global matrices for 2013–2022 for Russia showed complete consistency with the Russian national matrices presented in the ICIO tables.

Let n = 1995, …, 2022 denote the year for which the national input–output table comprising 50 industries was compiled from the global ICIO table. Then the well-known Leontief formula can be written as

$$X^n = \left(E - A^n\right)^{-1} * Y^n, \tag{1}$$

where $X^n = \left\{x_i^n\right\}_{i=1}^{50}$ is the vector of gross output in year n; $A^n = \left\{a_{i,j}^n\right\}_{i,j=1}^{50}$ is the matrix of direct input (technological) coefficients in year n; $Y^n = \left\{y_i^n\right\}_{i=1}^{50}$ is the vector of GDP by use in year n; finally, E is an identity matrix of appropriate dimensions.

The technological coefficients $a_{i,j}^n$ of the matrix A^n are calculated using the formula

$$a_{i,j}^n = \frac{b_{i,j}^n}{x_j^n}, \tag{2}$$

where $B^n = \left\{b_{i,j}^n\right\}_{i,j=1}^{50}$ is the matrix of intermediate output flows from industry i to industry j in year n.

The matrix B^n can be decomposed into the sum of two goods flow matrices—domestically produced (Dom^n) and imported for intermediate consumption (Im^n):

$$B^n = Dom^n + Im^n, \tag{3}$$

where $Dom^n = \left\{dom_{i,j}^n\right\}_{i,j=1}^{50}$, with $dom_{i,j}^n$ representing domestic intermediate supplies from industry i to industry j in year n; $Im^n = \left\{im_{i,j}^n\right\}_{i,j=1}^{50}$, with $im_{i,j}^n$ representing imports of industry i to industry j in year n.

Next, using formulas (1)–(3) of the model, we calculate the overall and product-specific import dependence of mining industries.

Let us introduce two concepts as follows.

Definition 1. Overall import dependence is the import intensity of intermediate consumption as a whole[1] and is calculated as the share (φ) of imports (*Im*) of a given industry *i* in its intermediate consumption (*B*) in year *n*:

$$\varphi\left(Im,B\right)_i^n = \frac{\sum_{j=1}^{50}\left(im_{j,i}^n\right)}{\sum_{j=1}^{50}\left(b_{j,i}^n\right)}. \quad (4)$$

Definition 2. The product-specific import dependence is the import intensity of intermediate consumption of a particular product *j* and is calculated as the share (φ) of imports of this product in the total volume of its intermediate consumption by industry *i*, including domestic (*Dom*) and imported (*Im*) components.

In this paper, we calculate the product-specific import dependence of mining on machinery (*Mach*).

The calculations are performed using the formula

$$\varphi\left(ImMach, DomMach\right)_j^n = \frac{im_{Mach,j}^n}{im_{Mach,j}^n + dom_{Mach,j}^n}. \quad (5)$$

where $im_{Mach,j}^n$ is the imports of machinery by industry *j* in year *n*; $dom_{Mach,j}^n$ is domestically produced machinery for intermediate consumption by industry *j* in year *n*.

2.2. Equations for the Russian Mining Sector

The mining sector in the model includes five industries (listed by their codes in an input–output table):

4. Mining of coal and lignite;
5. Extraction of crude petroleum and natural gas;
6. Mining of metal ores;
7. Other mining and quarrying;
8. Mining support service activities.

In the model, the gross output of the Russian mining sector is calculated as

$$x_d^{\mathrm{RF}} = \sum_{s=4}^{8}\left(\sum_{j=1}^{50} b_{sj}^{\mathrm{RF}} + \sum_{k=1}^{9} y_{sk}^{\mathrm{RF}}\right),$$

where x_d^{RF} is the gross output of all industries of the mining sector; b_{sj}^{RF} (s = 4, …, 8; j = 1, 2, …, 50) is the flow of intermediate goods from mining industry *s* to industry *j* of the Russian economy, including imports; y_{sk}^{RF} (s = 4, …, 8; k = 1, …, 9) is the final output of component *k* of mining industry *s*, including imports. In total, the model identifies nine components of GDP by use: final consumption expenditure of households; final consumption expenditure of non-profit institutions serving households; final consumption expenditure of general government; gross fixed capital formation; changes in inventories; direct purchases abroad by residents (imports); direct purchases by non-residents (exports); exports (cross border); and imports (cross border).

3. MODEL CALCULATIONS AND ECONOMIC ANALYSIS

Model (1)–(5) was tested using the example of industries of the Russian mining sector. This choice can be explained by several factors. First, mineral extraction plays a prominent role in the economy; according to the model calculations, it accounts for approximately 8% of the country's GDP, being important for foreign trade. Russia's future is largely determined by the successful operation of this sector.

Second, in recent years, mining companies have been subject to the most stringent sanctions, both on the exports of their end products and the imports of products for their intermediate consumption. The results of import substitution are particularly evident in the industries of this sector.

Overall, the Russian mining sector grew at a slow pace during the period under consideration. As shown by calculations, from 2013 to 2022, the sector's output increased by only 5.4% in terms of gross output and by 6.8% in terms of value added (Table 1).

In some years, there was even an absolute decline in value indicators, due to a sharp drop in global market prices for energy resources and mineral raw materials (2015–2016) and the COVID-19 pandemic (2020). The same trends were characteristic of intermediate consumption and imports across all industries of the mining sector, which stood at nearly 7 billion USD at the beginning of the period and remained at that level through 2022. The observed fluctuations around the average values can be explained by changes in global market conditions.

Based on the calculations of the overall import intensity of the industries, we specify the above results (Table 2).

[1] Some researchers use the level of import dependence, a term of similar meaning and content: the share of imported equipment in the total amount of equipment at an enterprise [26].

Table 1

Dynamics of economic indicators for the Russian mining sector (2013–2022), in billion USD

Indicator	Year									
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Gross output	322.1	284.8	207.4	191.5	250.3	283.6	284.8	222.6	275.4	339.6
Value added	185.5	162.3	119.6	110.3	140.5	153.7	155.8	129.3	160.7	198.1
Intermediate consumption, in total	136.6	122.5	87.8	81.1	109.8	129.9	129.0	93.4	114.7	141.5
including imports	7.2	7.3	5.5	5.5	6.8	7.9	6.8	5.9	7.8	7.3

Table 2

Dynamics of the overall import intensity of mining industries (2013–2022), in %

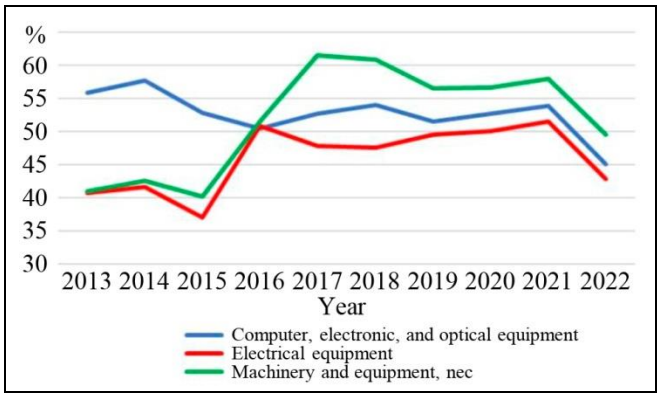
Year	Mining of coal and lignite	Extraction of crude petroleum and natural gas	Mining of metal ores	Other mining and quarrying	Mining support service activities
2013	9.4	4.4	7.4	11.0	5.2
2014	7.9	5.5	8.6	10.9	6.2
2015	6.8	5.8	9.2	11.1	6.8
2016	7.3	5.3	8.0	11.0	6.2
2017	7.3	5.3	8.0	11.0	6.2
2018	8.1	5.2	7.5	13.6	6.0
2019	7.4	4.6	6.9	12.2	5.2
2020	9.0	5.3	8.7	13.9	6.3
2021	9.6	5.7	9.3	14.7	6.8
2022	6.6	4.3	6.9	10.7	5.1

In certain industries of the mining sector, the trends are largely similar. Note that at the time of the calculations, the most recent official Russia's input–output tables were available only for 2016 and 2021 [30]. Based on ICIO tables [3], we analyzed the dynamics of the overall import intensity of the industries in 2013–2022 and draw the following conclusions:

- All mining industries are characterized by a relatively low share of imports in intermediate consumption—less than 10–15%, depending on the industry. For example, for extraction of crude petroleum and natural gas, this indicator never exceeded 6% in any given year; for mining support service activities, it never exceeded 7%. Such a low import intensity is determined by technological specifics: the largest components in the structure of production costs are domestic transportation, warehousing, and construction costs rather than the purchase of foreign equipment. For example, for extraction of crude petroleum and natural gas in 2022, domestic transportation costs amounted to 2.7 billion USD, construction costs to 1.1 billion USD, while purchases of computer, electronic, and optical equipment, electrical equipment, and machinery and equipment, nec (not elsewhere classified) totaled only 113 million USD.
- The import substitution programs adopted in 2014 for mining industries were implemented weakly until 2021. Among the five industries of the sector, only in mining of coal and lignite the share of imports in intermediate consumption remained virtually unchanged by 2021 (at about 9.5%). In the other industries, it increased significantly compared to 2013, by 20–30% in some years.
- In 2022, due to the tightening of sanctions, there was a sharp decline in import intensity across all mining industries. The sanctions caused an absolute reduction in imports from 7.8 billion USD to 7.3 billion USD.

Calculations based on the product-specific import intensity model are shown in the figure. They identified other patterns and confirmed the excessively high dependence on imports in three critically important product groups (computer, electronic, and optical equipment; electrical equipment; machinery and equipment, nec), as previously emphasized by other authors [26].

In terms of import intensity over the seven years of the sanctions regime (2014–2021), there was almost no import substitution in the mining industries for the specified product groups of the manufacturing sector.



The import intensity of intermediate consumption in the Russian mining sector for major product groups of the manufacturing sector, in %.

Import intensity (within the model, the share of imports of major categories of machinery in the total volume of intermediate (production) consumption of these products by the Russian mining industries) fluctuated from year to year but remained very high, averaging 50%. Following a sharp tightening of the sanctions in 2022, mining companies began actively shifting their purchases from the foreign market to the domestic one by approximately 10% (Table 3).

Table 3

Purchases by the Russian mining sector, in million USD

Product	Domestic market purchases		Imports	
	2021	2022	2021	2022
Computer, electronic, and optical equipment	159.4	186.8	185.7	152.7
Electrical equipment	255.5	313.6	270.6	234.6
Machinery and equipment, nec	950.1	1099.5	1305.4	1077.8

As a result, the economic effect of import substitution (a significant reduction in import dependency) became apparent only in 2022. Compared to 2021, that year's growth in domestic market purchases was as follows: for computer, electronic, and optical equipment, by 17.2%; for electrical equipment, by 122.7%; for machinery and equipment, nec, by 115.7%. Accordingly, imports for the above product groups declined by 82.2%, 86.7%, and 82.6%, respectively.

CONCLUSIONS

The model developed has demonstrated its effectiveness for calculating import intensity under sanctions. A distinctive feature of this model is that the estimates consider both direct and indirect inter-industry links in the Russian economy.

According to the study, the overall import intensity of the Russian mining sector has remained relatively low over the years. On average, 90% of the products for intermediate consumption are purchased by the enterprises of this sector on the domestic market, and only 10% come from abroad.

However, in the three key groups of knowledge-intensive, innovative manufacturing products identified in the study (computer, electronic, and optical equipment; electrical equipment; machinery and equipment, nec), the mining sector's dependence on the external market remained extremely high until 2021—at approximately 50%. In 2022, the real import substitution occurred, averaging 10%. Therefore, the Russian mining sector has certain potential for reducing its import dependence.

The model can be further refined with new input–output tables, expected to be published by the OECD in the coming years. Broad opportunities for expanding this research are associated with the aggregation of global ICIO tables by various criteria to address particular tasks of Russia's economy, as well as with a comprehensive cross-sectoral approach to assessing the effects of import substitution, utilizing both this model and various aggregations of global input–output tables with Russia's economic core, e.g., trade ties with friendly countries (China, India, and others).

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