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Research article

Development of production cooperation in Russia: Quantitative measurement

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Abstract: We analyze the dynamics of the production cooperation development in Russia in 2011–2020 on the basis of Input-Output tables. For this purpose, we use indicators that characterize the degree of fragmentation of production and help assess enterprises' interaction in input demand and output supply chains.

Keywords: production cooperation; value chains; fragmentation of production; input downstreamness; output upstreamness; input-output tables

JEL Codes: O11, D24, E23

1. Introduction

Production acts as the basis of the economy, providing society with goods and services, generating revenues of institutional units and thereby forming the final demand. Due to the complexity of modern technological and design solutions, a final product cannot be manufactured at one enterprise. This causes an increase in the division of labor and specialization of production processes with their subsequent cooperation. The development degree of production cooperation characterizes the length of value chains in the country's economy and largely determines its economic dynamics. The analysis of these processes is especially significant in the conditions of external restrictions.

The authors conduct a quantitative assessment of trends in the development of production cooperation in Russia in 2011–2020 based on the analysis of production fragmentation in the economy and the degree of interaction of enterprises in input demand and output supply chains. The study of the processes of production cooperation is seen as an urgent task for the elaboration of a purposeful economic policy to form and develop intra-country links in value-added chains of final products.

2. Theoretical and methodological aspects of the study

In this study, production cooperation is understood in a broad sense as the interaction between enterprises within the framework of one or different (but related) production processes. It can be defined as an economic relationship or activity focused on interrelation between industrial enterprises and other organizations, as well as authorities that arise in the manufacture of a certain product (material goods) (Makarov and Trapeznikov, 2011).

Production cooperation problems are widely discussed in the scientific literature. Various aspects of its impact on economic development (Belousova, 2012), spatial organization of territories (Okten et al., 1998) and processes of regional integration (De, 2014) are studied. Interrelation between enterprises and their growth (Han and Wang, 2015), as well as possibilities for upgrading production by embedding the value added into existing chains (Joudeh, 2018), are assessed, strategies for strengthening production cooperation are worked out (Kim et al., 2013) and organizational and economic mechanisms for the development of integration processes in the manufacture and processing of products are formed (Voronkova et al., 2019). Development of appropriate methodological tools is caused by the growing need for an adequate assessment of production cooperation. It requires the use of a wide range of model tools, such as agent-based (Yazan et al., 2018), optimization (Ben Yahia et al., 2017), intersectoral models (Zaclicever, 2017) and game theory techniques (Matsui, 2006).

Furthermore, there is a lack of generalizing quantitative estimates of the development of production cooperation. Most often, for these purposes, researchers use a list of specific examples of interaction (Ustyuzhanina et al., 2010), survey data or partial palliative indicators, such as volume of sales of integrated enterprises (Kurganov, 2016), number of joint R&D and technological modernization projects (Gavrilyuk, 2016), volume of mutual-artificial investments, etc.

To analyze production cooperation development, we propose to use two indicators that characterize the degree of fragmentation of production and allow a comprehensive assessment of the interaction level of enterprises in input demand and output supply chains.

The first index — input downstreamness (D) — reflects the weighted average of the number of stages consistently involved in the manufacture of a particular product or service (weighting is conducted according to the value of final consumption of products). The higher the value D, the greater the share of intermediate products in the resources consumed, the more complex the intermediate links in the supply of resources with technologically related industries. The minimum value D is observed when production does not require any intermediate goods, which may indicate a low development level of production cooperation in the input demand chain.

The second index — output upstreamness (U) — shows the weighted average of the number of stages that the manufactured products go through before reaching the final consumer (weighting is conducted according to the amount of gross value added created by a particular industry). The higher

the value *U*, the greater the share of intermediate products in gross output, the more complex the intermediate links with technologically related industries in the sale of products. The coefficient *U* equals to 1 when all manufactured products are sent to final consumption. This situation characterizes a low development level of production cooperation in the output supply chain.

Taking the output supply chain perspective, Antràs et al. (2012) proposed the following measure of industry *i*'s upstreamness:

$$u_i = 1 \times \frac{f_i}{x_i} + 2 \times \frac{\sum_j a_{ij} f_j}{x_i} + 3 \times \frac{\sum_{j,k} a_{ik} a_{kj} f_j}{x_i} + 4 \times \frac{\sum_{j,k,l} a_{il} a_{lk} a_{kj} f_j}{x_i} + \ldots \quad (1)$$

where x_i is gross output of industry i ($i = 1, \ldots, n$); x_i is equal to its final use f_i plus its intermediate output sales to all industries $\sum_j z_{ij}$; industry; $a_{ij} = z_{ij}/x_j$ is an input coefficient.

Sector *i* is positioned upstream with respect to households, government(s) and investors (HGIs) as final users, u_i in Equation 1 quantifies *i*'s average upstream position from HGIs. For this reason, Antràs et al. (2012) refer to u_i as industry *i*'s "average distance from final use" or "average production line position". It should be noted that in defining such average distance, in Equation 1 an explicit assumption of imposing "an ad hoc cardinality in the sense that the distance between any two stages of production is set to one" (Antràs et al., 2012) is made. If u_i is large, then *i* is interpreted to be an upstream industry in the sense that its output goes through many production stages before reaching final use. On the other hand, low values of u_i (close to unity which is its lower bound by construction if $f_i > 0$ for all *i*) indicate that *i* is a "downstream" industry with a large share of its output going directly to the end-user.

Miller and Temurshoev (2017) additionally consider the input demand perspective in quantifying industries' relative positions with respect to HGIs as their providers of primary inputs. The average distance of industry *j* from its providers of primary inputs is defined as follows:

$$d_j = 1 \times \frac{v_j}{x_j} + 2 \times \frac{\sum_i v_i b_{ji}}{x_j} + 3 \times \frac{\sum_{i,k} v_i b_{ik} b_{kj}}{x_j} + 4 \times \frac{\sum_{i,k,l} v_i b_{ik} b_{kl} b_{lj}}{x_j} + \ldots \quad (2)$$

where x_j is total input of industry j ($j = 1, \ldots, n$); x_j is equal to the value of its primary inputs (value added) v_j plus its intermediate input purchases from all industries $\sum_i z_{ij}$; $b_{ji} = z_{ij}/x_i$, x_j is an output coefficient.

The shares in Equation 2 sum up to one. Sector *j* is positioned downstream with respect to HGIs as its providers of primary inputs, d_j can be alternatively viewed as a measure of industry *j*'s downstreamness. A large value of d_j indicates that sector *j* is positioned rather downstream from its providers of primary inputs along the input demand chain with the majority of its inputs coming directly and indirectly from other production sectors. Since these sectors also use primary inputs from their HGIs, one can alternatively state that primary inputs of all HGIs go through many production stages before reaching, in the form of intermediate inputs, an input-downstream sector *j* with large d_j. On the other hand, a sector with a low value of d_j (close to unity which is its lower bound by definition assuming that $v_j > 0$ for all *j*) is an "upstream" industry along the input demand chain with a large share of its input coming directly from HGIs. In order not to confuse the up/down-streamness in connection with the output supply and the input demand chains, we refer to u_i in Equation 1 and d_j in Equation 2, respectively, as "output upstreamness" (*U*) and "input downstreamness" (*D*) measures of industry.

A graphic illustration of these processes is shown in Figure 1.

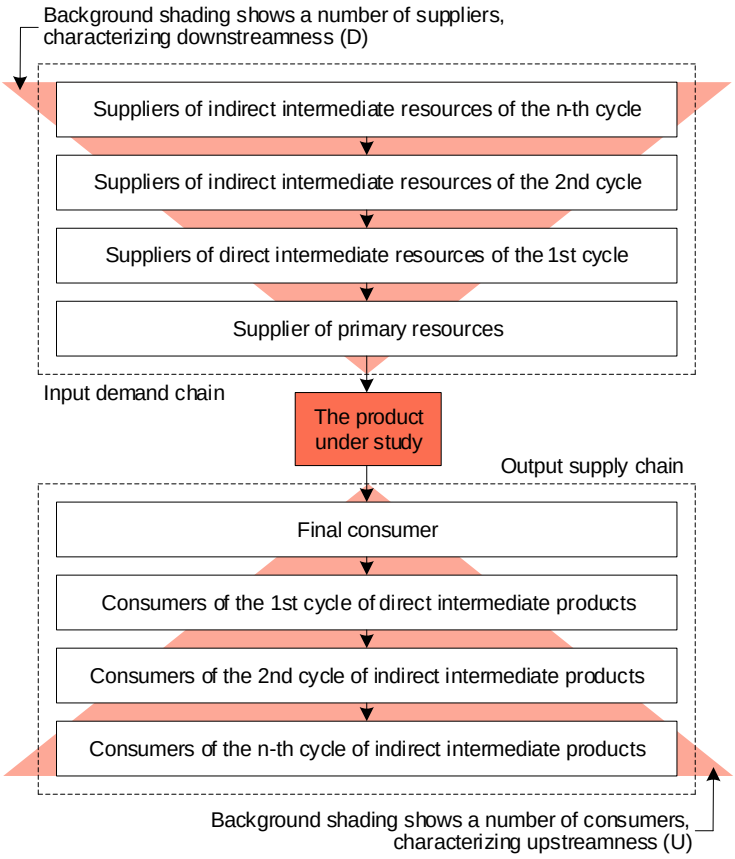

Figure 1. Illustration of input demand and output supply chains.

According to Miller and Temurshoev (2017), industries "average distance from final output users" and "average distance from primary inputs suppliers" become exactly equivalent to, respectively, total forward linkages and total backward linkages indicators because the distance between any two stages of production is assumed to be one in equations 1 and 2. Deriving the *U*s and *D*s on the Input-Output table sheds light on the position of industries along the output supply and input demand chains. Using one summary measure of the *U* and one summary measure of the *D* could be useful to see the development of the average industry relative position over time with respect to HGIs. One might use for this purpose a simple arithmetic average of the *U*s and *D*s. However, this will not take into account the differing sizes of industries in a considered input-output system. Therefore, it seems reasonable to use a weighted average of the *U*/*D* measures as a summary indicator of interest for a particular point in time.

Value chains were studied with the help of similar methods in the economies of the USA (Antràs et al., 2012), China (Chen, 2017), Russia (Lukin, 2019; Kuznetsov and Sedalishchev, 2018), as well as in the global context (Miller and Temurshoev, 2017). Dynamic characteristics for Russia are studied for the first time.

The empirical base is Input-Output tables of the Russian Federation for 2011 and 2016, as well as tables of resources and use of goods and services of the Russian Federation for 2012–2015 and 2017–2020, developed by the Federal State Statistics Service of the Russian Federation (Rosstat). The time interval determined in the study (2011–2020) is due to the availability of the source data.

3. Research results

3.1. Characterizing input demand and output supply chains in the Russian economy

According to state statistics, as of the end of 2022, there were more than 2.5 million enterprises and organizations in Russia. Most of them (over 1.8 million) were engaged in the production of services (including almost 816 thousand — in trade). The remaining 725 thousand enterprises were engaged in material production, in particular 64 thousand enterprises — in agriculture and forestry, 286 thousand — in industry and 375 thousand — in construction. These data characterize the scale of economic activity in the country and the complexity of its assessment.

Obviously, input demand and output supply chains of different products have different characteristics. Goods and services are distinguished by the number of completed conversions, the structure of material, labor and investment resources used for their production and the share of imports in it. They have different consumers and distribution channels. Accordingly, the fragmentation of a particular chain and the need for cooperation differ significantly.

In 2011–2020, the weighted average of the input downstreamness in the Russian economy was 1.94, i.e., before the manufacture of the product, resources on average passed through one production stage. This value is due to the predominance of activities that are either at the initial stages of input demand chains (mining, agriculture and forestry) or have low material intensity and, therefore, poorly interact with other sectors of the economy (commercial and social services). They create more than 70% of GDP annually.

Manufacturing industries are the most fragmented (D = 2.61). The structure of their industrial consumption is dominated by intermediate industrial products (raw materials, electricity, semi-finished products), which require further processing operations. Transportation equipment (D = 2.96), plastics and rubber products (D = 2.87) and fabricated metal product manufacturing (D = 2.71) take the lead (Figure 2). Food (D = 2.66), machinery (D = 2.57), nonmetallic mineral product (D = 2.57), primary metal (D = 2.60) and paper manufacturing (D = 2.55) are characterized by a high degree of fragmentation. Textile, apparel and leather manufacturing (D = 2.46), printing and related support activities (D = 2.45), petroleum and coal products manufacturing (D = 2.41) are outsiders in this group.

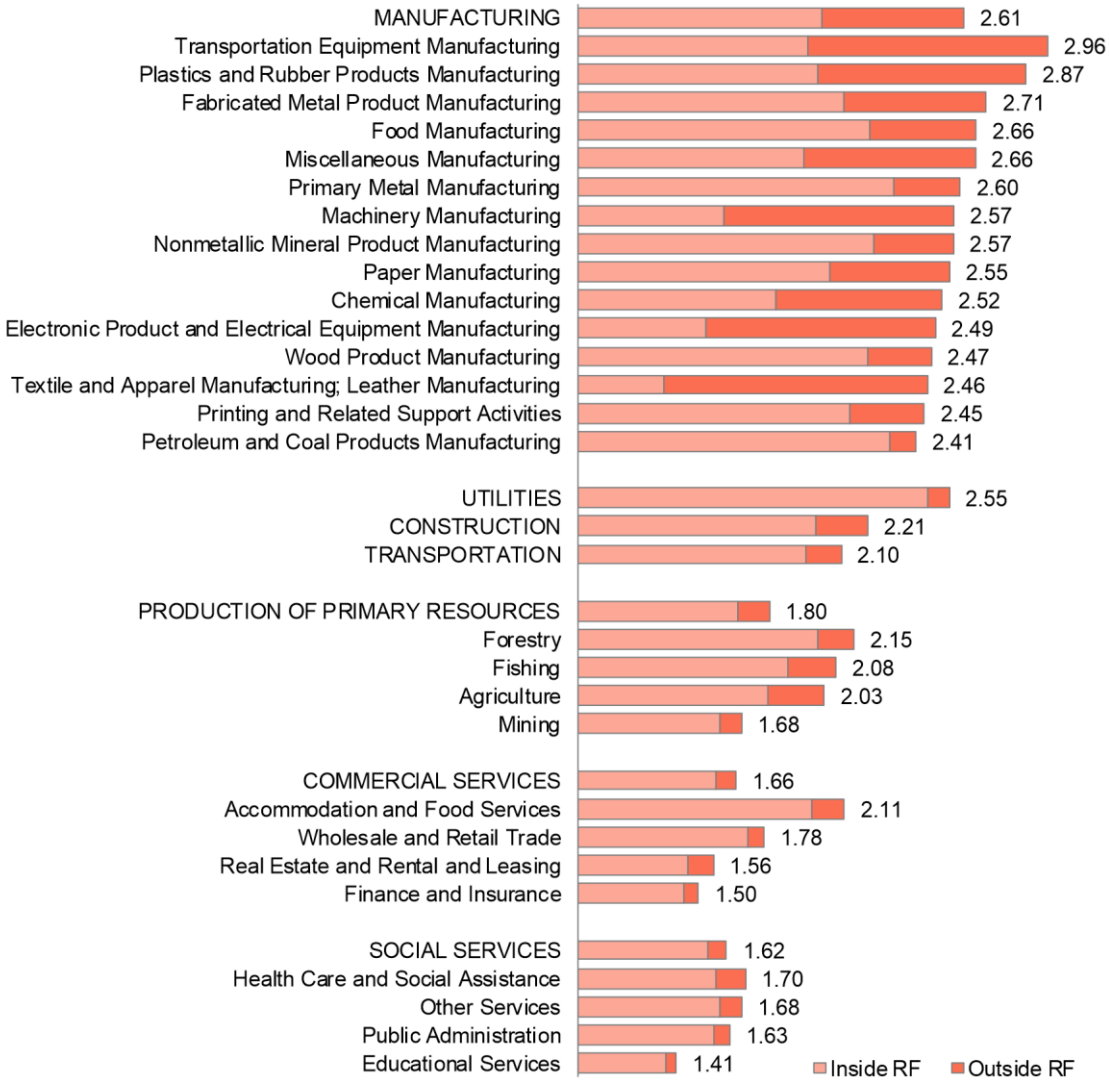

Figure 2. Average downstreamness in sectors of the Russian economy, 2011–2020.

Outside the manufacturing industry, high downstreamness values are typical for construction (D = 2.21), agriculture (D = 2.03) and forestry (D = 2.15), accommodation and food services (D = 2.11), as well as transportation (D = 2.10). Mining (D = 1.68), as well as commercial (D = 1.66) and social (D = 1.62) services, are the least fragmented. Low downstreamness values are largely caused by weak interaction with technologically related industries in terms of the rates of consumed resources and the intensive use of direct labor costs (this is especially typical for social services, such as public administration, education and human health).

The study of the structure of production costs of economic sectors characterizing the ratio of consumption of primary and intermediate resources makes it possible to determine downstreamness (Figure 3). Thus, high labor intensity determines low downstreamness values in education, human health and public administration, significant capital intensity — in mining and real estate, rental and leasing. Manufacturing industries are characterized by higher downstreamness values, since they are

material-intensive and purchase the bulk of the resources they need from other sectors of the economy. The results of the correlation analysis make it possible to assert that the higher the material intensity (the correlation coefficient between the value D and the material intensity of the industry is 0.98) and the lower the labor and capital intensity of production (the correlation coefficients are −0.56 and −0.17, respectively), the higher downstreamness values (the longer the input demand chain) of a particular industry, the more fragmented this chain.

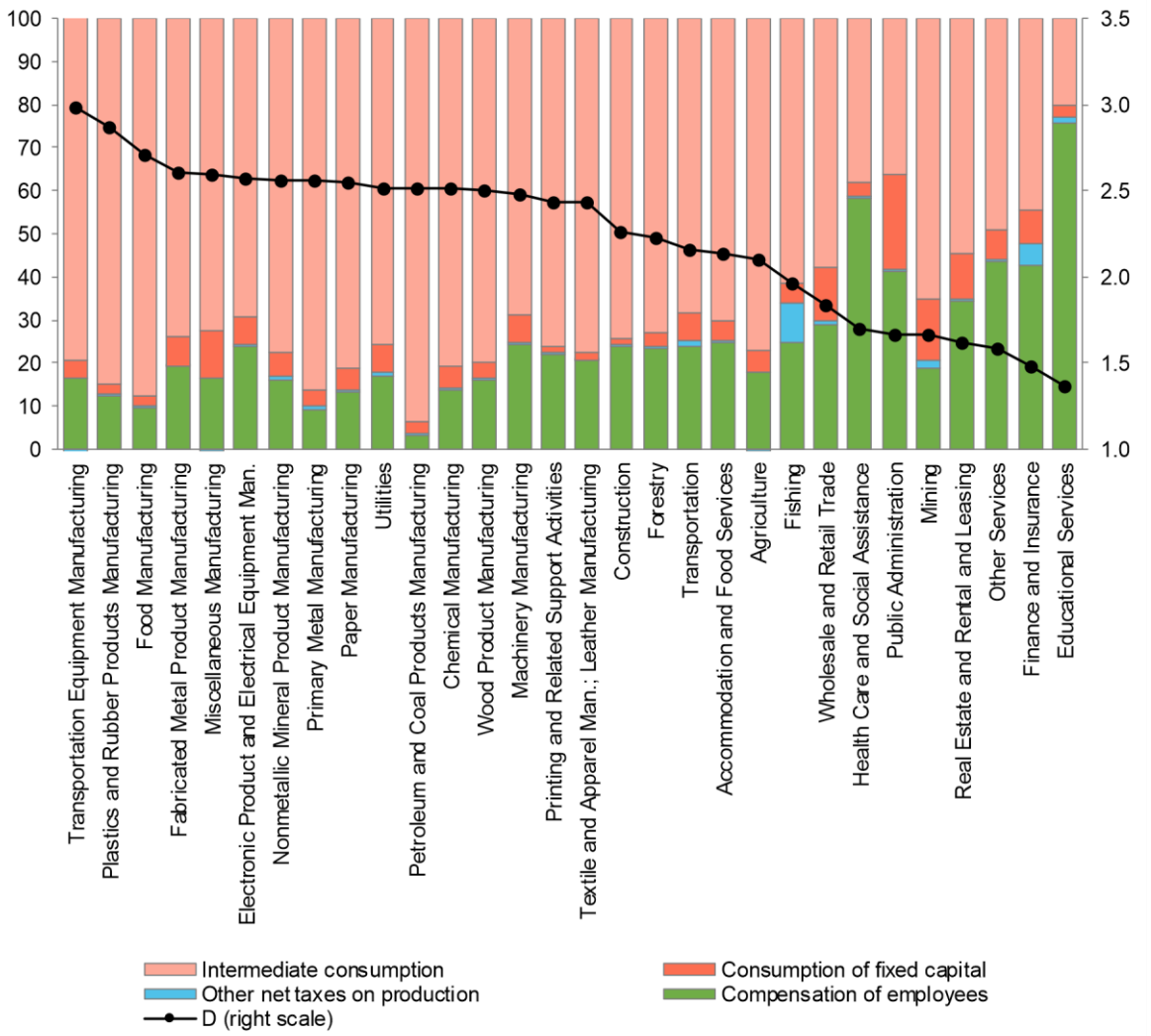

Figure 3. Structure of production costs of sectors of the Russian economy in 2019, % of the total.

In 2011–2020, the weighted average of upstreamness in the Russian economy amounted to 2.32, i.e., from the moment of production to the moment of the use by the final consumer, products on average passed through a little more than one production stage. Higher upstreamness values are typical for production of primary resources ($U \approx 4$; Figure 4). Primary metal, petroleum and coal products manufacturing, utilities, transportation, forestry, wood product, chemical and paper manufacturing are slightly closer to the final consumption ($U \approx 3$). They are used as resources and

intermediate goods in technologically related sectors of the economy. Trade, real estate, rental and leasing, printing and related support activities, machinery manufacturing, agriculture and fishing are located at one stage from final consumers ($U \approx 2$). Other types of economic activity, including food, textile, apparel and leather manufacturing, construction, accommodation and food services, education, human health, public administration, direct almost all products to households and authorities ($U \approx 1$), providing them with food, clothing, goods and services in the field of nutrition, accommodation, healthcare and education.

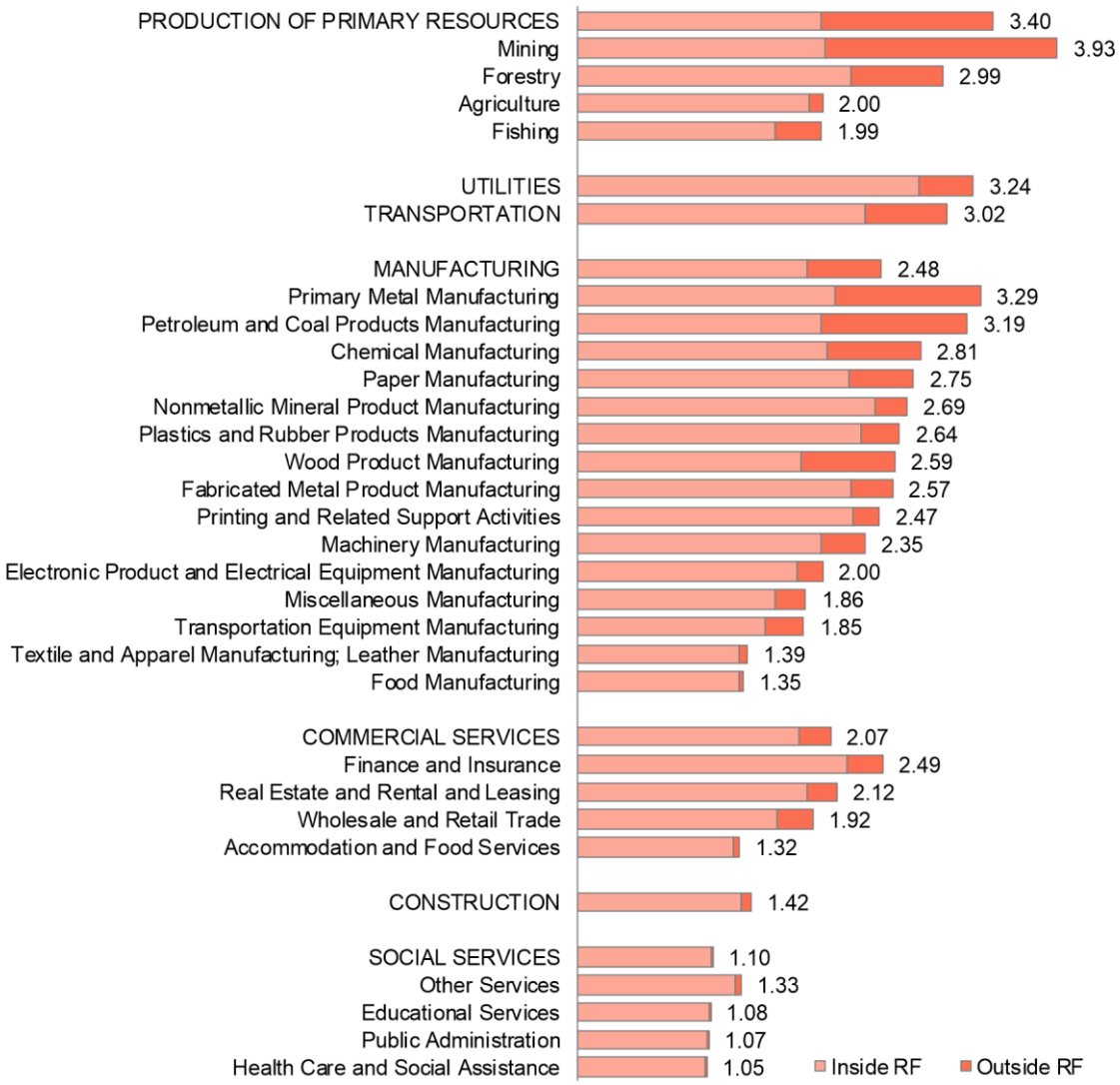

Figure 4. Average upstreamness in sectors of the Russian economy, 2011–2020.

Upstreamness of a particular product depends on its consumer and its purpose (Figure 5). Thus, a high share of final consumption by authorities determines low upstreamness values in education, public administration and human health, while a high proportion of final consumption by households determines low upstreamness values in trade, food manufacturing and textile, apparel and leather

manufacturing, as well as accommodation and food services. The use of products for gross capital formation of economic sectors predetermine higher upstreamness values in construction and machinery manufacturing. Export of intermediate products in many ways determine high upstreamness values in fishing, mining, petroleum and coal products manufacturing, wood product manufacturing and fabricated metal product manufacturing. For the economy as a whole, output upstreamness is determined by the ratio of proportions of its intermediate and final use. In particular, the correlation coefficient U with the share of intermediate use amounts to 0.89, final consumption expenditure by households — −0.59, Final consumption expenditure by government — −0.46, profit accumulation — −0.19, exports — 0.42.

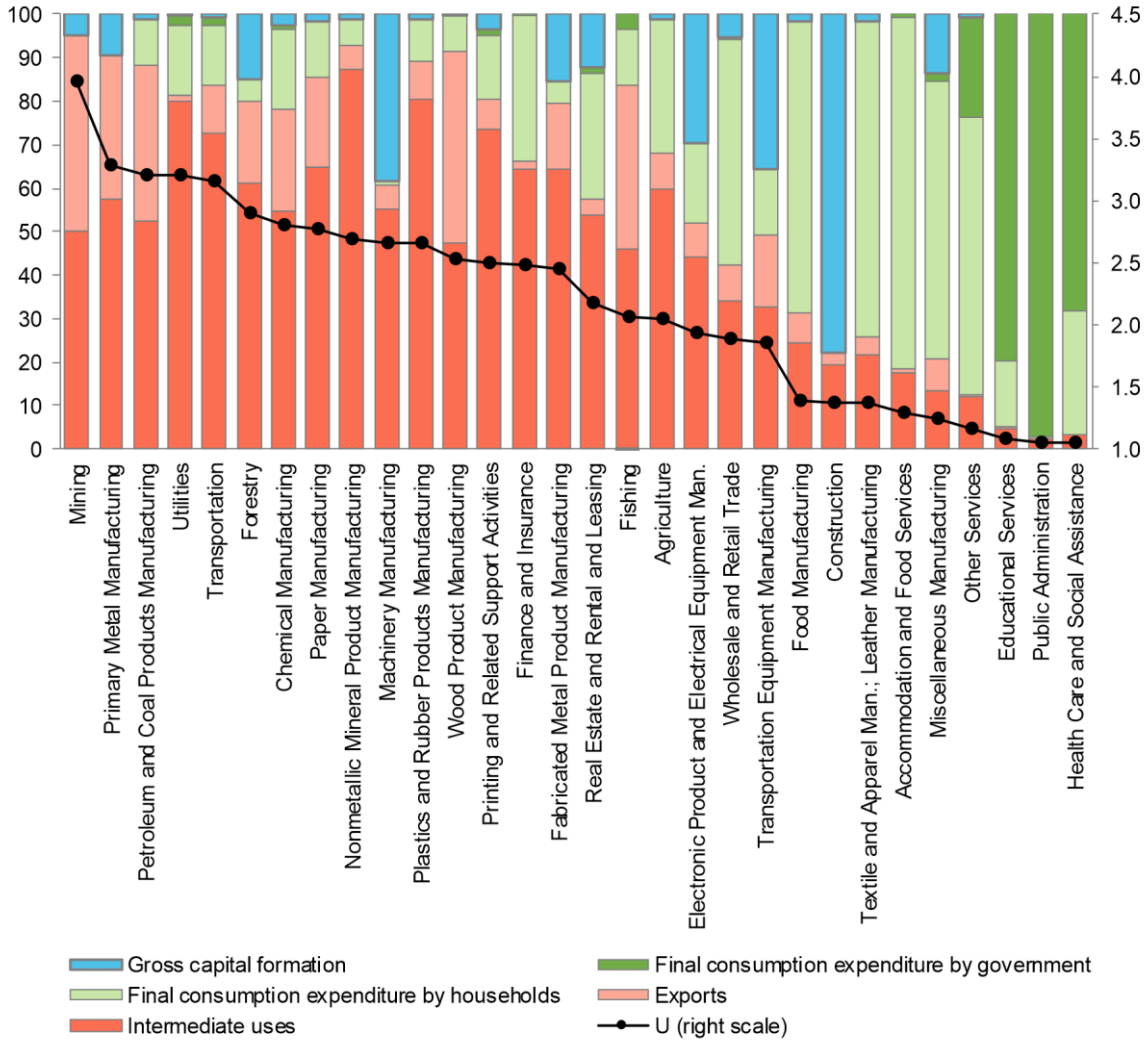

Figure 5. Structure of the use of products of Russia's economic sectors in 2019, % of the total.

The presented data characterize fragmentation of the Russian economy. Its level varies from industry to industry and depends on technical characteristics of the goods produced, as well as problems that arise when production is differentiated at different stages and regions. Material-intensive production is characterized by a greater number of production stages than labor- and capital-intensive one.

Furthermore, the share of the gross value added decreases as the input demand chain lengthens, i.e., the more fragmented production, the less value added is created at each stage (Lukin, 2019). In other words, production cooperation contributes to reducing profit concentration, thereby ensuring the smoothing of excessive spatial inequality in the country. Lengthening value chains and stimulating business cooperation can drive the economy and, in our opinion, should be an important direction of state economic policy.

The problem is how to boost development of the most profitable stages of value chains within the country. Currently, the weighted average of input downstreamness in Russia (D = 1.94) is significantly lower than output upstreamness (U = 2.22), due to the disparity in export-import operations (in a closed economy, values of downstreamness and upstreamness are equal). The tools used in the study make it possible, based on the information about total costs of imported products and the structure of the use of manufactured goods and services, to identify the part of input demand and output supply chains that is external for the country. Figures 2 and 4 show that Russia is an active participant in the international division of labor. Many sectors of Russian economy are included in global value chains. However, the current format of the country's participation in these processes is far from optimal. There is a high dependence on imported production resources in most types of manufacturing industries (except, perhaps, only petroleum and coal products manufacturing). The Russian textile, apparel and leather manufacturing depends on the supply of imported textile products; chemical manufacturing — organic and inorganic chemicals, basic pharmaceutical products; machinery manufacturing — automotive vehicles, computers, electronic and optical products, machines and equipment, etc. Exported products are used by other countries as raw materials and semi-finished products in their further technological processes. To the greatest extent, this concerns mining, metallurgical and chemical manufacturing, petroleum and coal products manufacturing, forestry and wood product manufacturing. Obviously, such specialization does not promote the creation of a high value added within the country. The resources exported by Russian companies return to the economy already in the form of ready-made foreign goods with an appropriate margin, aggravated by tariff and non-tariff trade restrictions (Meshkova and Moiseichev, 2016).

Creating production stages that are absent in the country, stimulating domestic demand (both final and intermediate) along value chains and supporting the development of production cooperation will trigger changes in the situation.

3.2. Trends in the development of production cooperation in Russia

The conducted analysis reveals that recent macroeconomic and geopolitical events have had a certain impact on the processes of production fragmentation and production cooperation in the country (Figure 6).

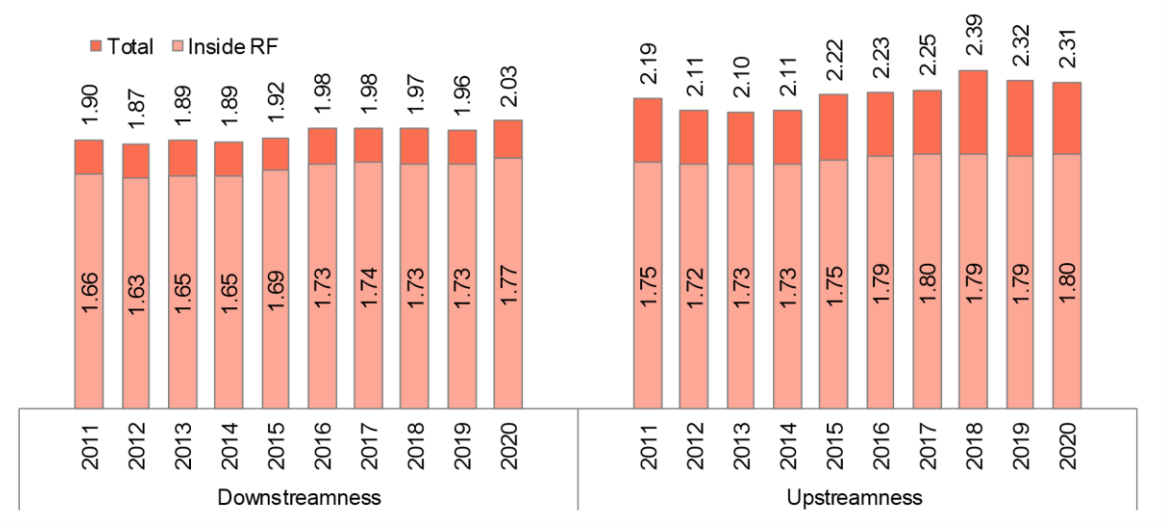

Figure 6. Dynamics of average down/upstreamness in the Russian economy in 2011–2020.

In 2011–2014, input downstreamness values went down by 0.5% and output upstreamness values — by 3.7% (including outside the Russian Federation — by 13.6%; mainly due to some improvement in the exports structure due to the decline in supply of raw materials).

Further trends in the development of production cooperation were predetermined by the significant weakening of the ruble in 2014–2015 against the background of an almost threefold drop in world oil prices during this period and the economic sanctions against Russia because of Crimea's accession to Russia. On the one hand, this fostered domestic production due to the relative rise in the cost of imports in the domestic market and the growth of price competitiveness of Russian exporters in foreign markets. On the other hand, lending was not much available, since external lending was restricted due to the sanctions imposed and internal lending — due to the key interest rate increased by the Central Bank of the Russian Federation.

In 2015, average downstreamness values increased by 1.6%, while inside the Russian Federation — by 2.4%, and outside, on the contrary, decreased by 8.3% (mainly due to increased difficulties with financing and increased transaction costs). Output supply chains on average grew by 5.2%, including within the Russian Federation — by 1.2% and outside — by 21.1%.

Positive effects of the ruble devaluation were also observed in 2016. The revival of the economy contributed to the strengthening of cooperative ties in both input demand and output supply chains.

However, Russian enterprises could not fully respond to the challenges. The increase in the gross value added (i.e., output minus intermediate consumption) for 2015–2017 amounted to 0%, and economic indicators of the vast majority of industries grew slower than import figures fell. The acceleration of economic development by stimulating domestic demand was hampered by the lack of a mechanism for transferring momentum from aggregate demand to aggregate supply, and most importantly, a mechanism for replacing imported means of production. Thus, in 2017, imports increased by 17.3% against the background of the adaptation of enterprises to new economic conditions.

In 2018–2019, despite some recovery in economic dynamics (GDP growth in this period amounted to 2.8 and 2.2%, respectively), the fragmentation of production remained the same (the value

D fell by 0.7% over these two years, *U* increased by 2.9%). Moreover, the length of the external part of Russian output supply chains increased sharply (by more than 15% in total), due to the shift of the value added in export supplies towards initial stages of production (Antràs et al., 2012) influenced by a number of factors: changes in price proportions between various intermediate goods, weakening of the national currency (the average weighted rate (rubles/US dollar) went up by 7.5% in 2018 and by 3.2% in 2019), transformation of logistics and input demand chains caused by the strengthening of the Russian sanctions since 2018.

The decline in domestic final demand (consumer demand by 3.9%, investment demand by 4.3%), multidirectional industry dynamics and an outstripping reduction in imports (by 11.9%) compared to exports (decreased by 4.2%) in 2020, caused by Covid-19 pandemic-related restrictions, also had an impact on the fragmentation of Russian production. According to our estimates, in 2020, the length of input demand chains increased by 3.5% (including their external part — by 9.6%), while the length of output supply chains decreased by 0.6% (including their external part — by 5.5%).

The change in the degree of fragmentation of production largely depends on the industry dynamics. The occurred events affected functioning of various types of economic activity in different ways. Therefore, seven enlarged sectors of the economy are identified to analyze development trends of production cooperation. Figures 7 and 8 show that these sectors differ in fragmentation, the scale and direction of its change, as well as the chain length inside and outside the Russian Federation.

In 2011–2020, an increase in input downstreamness was recorded in the commercial services (+11), construction (+9%), transportation (+6%) and utilities (+4%), a decrease in input downstreamness — in social services (−5%). In manufacturing (+1%) and production of primary resources (+2%), the value *D* remained practically the same.

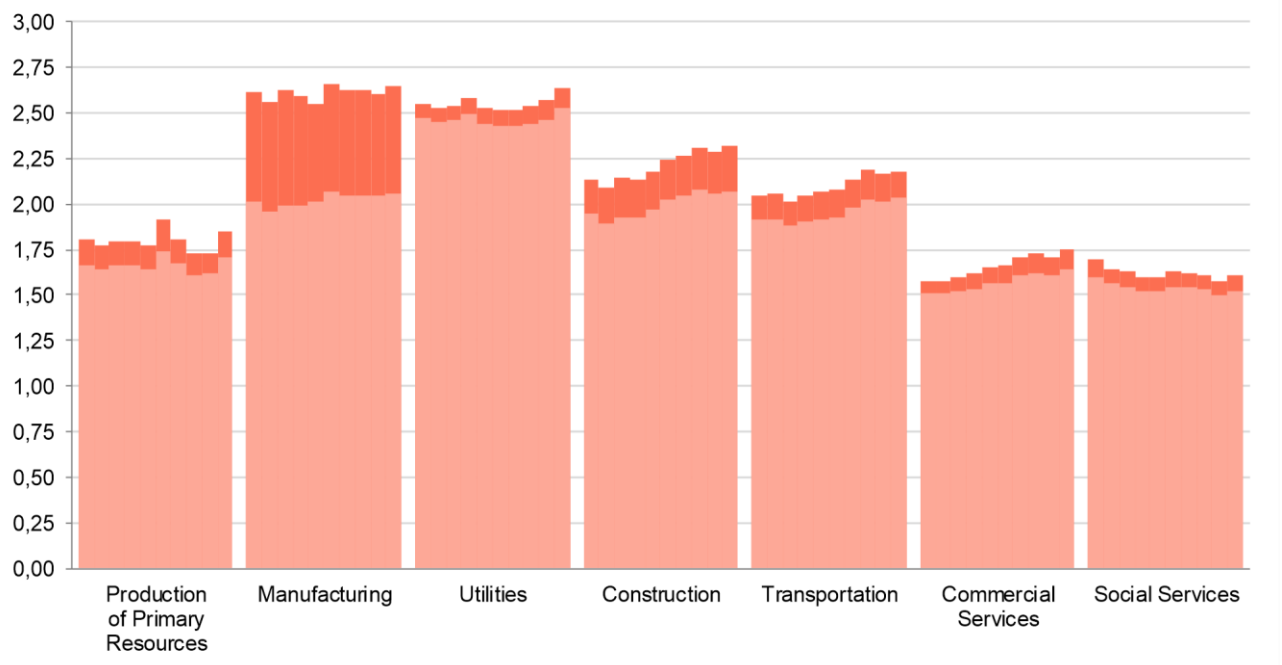

Figure 7. Dynamics of average downstreamness in sectors of the Russian economy in 2011–2020.

As for output upstreamness, in the studied period it increased in transportation (+20%), manufacturing (+11%), commercial services (+5%) and utilities (+4%). A decrease in upstreamness was recorded in construction (−4%) and social services (−7%). In production of primary resources, the value *U* remained practically the same (+1%).

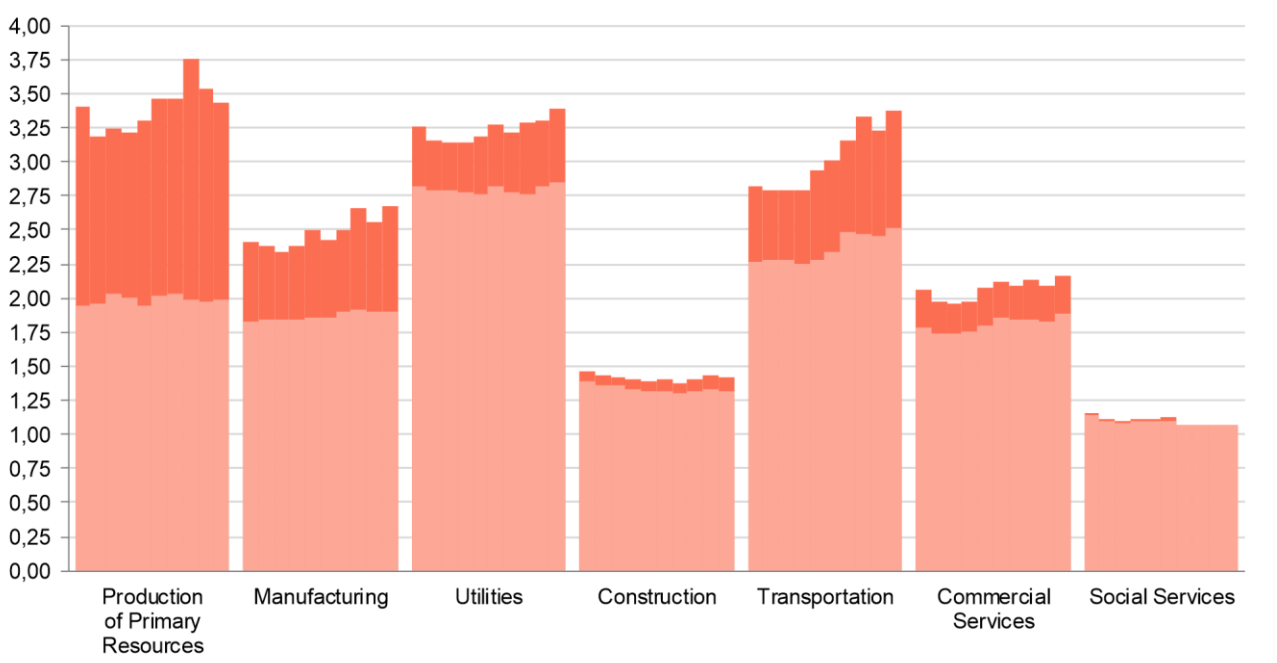

Figure 8. Dynamics of average upstreamness in sectors of the Russian economy in 2011–2020.

In the Russian economy as a whole, in 2011–2020, the fragmentation of production in input demand chains increased by 6.9%, and in output supply chains — by 5.2%. These data may indicate positive development of production cooperation in the country. Furthermore, the outstripping prevalence of downstreamness over upstreamness demonstrates weakening of the disparity in export-import operations and a certain rise in the balance of the economy in the period under review.

4. Conclusions

The conducted research made it possible to quantify trends in the development of production cooperation in Russia based on the analysis of fragmentation of production in the economy and the degree of interaction of enterprises in input demand and output supply chains.

The development degree of production cooperation in these chains is largely determined by their length and the number of alterations that products undergo from the moment of their design, manufacture to sales and post-sale service. Downstreamness of a particular industry is determined by the ratio of consumption of primary and intermediate resources, while upstreamness is determined by the distance to the final consumer. We believe that the presented indicators can be used to assess the quality of regulation of the processes of stimulating production cooperation in the country.

According to our estimates, the input downstreamness value was 1.94 in the Russian economy in 2011–2020, while the output upstreamness value was 2.32. The fragmentation of production in supply chains increased by 6.9% and in sales chains — by 5.2%. It is worth mentioning that the downstreamness value in the USA also does not exceed 2 (Fally, 2012). Moreover, the fragmentation of production in this country has had a steady downward trend for the last 50 years, which largely explains the recent turn towards reindustrialization and the return of enterprises to the United States.

The data obtained substantiate the importance of implementing a state economic policy aimed at increasing the share of input demand chain areas localized in Russia in the manufacturing sector (primarily as part of solving the problem of import substitution and gaining technological sovereignty) and developing output supply chains by reducing their external part in mining and increasing — in manufacturing (especially final).

Business' focus on productive activities is important. Here, we should mention the "Growth Synergy" program, having been implemented by the Government of the Vologda Oblast since 2014. It is based on the unification of large, medium and small businesses. The project is aimed at providing large enterprises with products manufactured by small and medium-sized ones on the basis of long-term contracts. Furthermore, interrelation is built according to one of the following schemes: Either a large enterprise transfers its products to a small one for use in further processing, thus increasing the value added of manufactured goods; or it acts as a consumer of goods and services; or it uses small enterprise's resources to introduce innovations. It is worth mentioning that this project implementation makes it possible to annually increase the extent of cooperative ties in the Vologda Oblast by 20%.

The scientific novelty of the study consists of the identification of modern patterns in the functioning of Russian value chains and the quantitative assessment of the trends in the development of production cooperation in Russia based on the analysis of the fragmentation of production in the economy, and the degree of interaction of enterprises in input demand and output supply chains.

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Use of AI tools declaration

The authors declare that they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

All authors declare no conflicts of interest in this paper.

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