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Contents

Energy as an inseparable factor of productive forces and production

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ORIGINAL ARTICLE

Abstract. Energy is an inseparable attribute of productive components. The article considers the need to identify energy production as a fundamental and independent factor. The law of conservation of energy formed an effective demand for the development of the process of searching and using alternative energy sources. However, there is an issue of limited resources of energy. Recent years there is an increasing interest in the study of energy as an economic category. There are many scientific problems of green energy, renewable energy resources, sources, human intellectual energy, etc. The research highlights the role and importance of energy in the industrial development of the Republic of Tajikistan, the correlative relationships between GDP production and electricity consumption per capita, the process of development and placement of productive by regions of the country. The research justifies a number of proposals on the efficient use of energy and formation of energy clusters in the country.

Keywords: factors of social production; energy as an economic category; energy carriers; energy system; industrial and technological revolution

JEL codes: Q43, Q42, O14, R11, O33

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Introduction

The transition of the Republic of Tajikistan to an industrial-agrarian type of economy and accelerated industrialisation of the country ensures the importance and role of energy industries. It provides the spatial development of productive forces and form industrial spaces in all regions of the country. Energy has a stimulating effect on the development of productive forces. Therefore, the development of socio-economic systems, branches and sectors of the economy, and social spheres of society, are closely related to the use of energy.

Energy is the basis of all industrial revolutions, since when describing it with characteristics of new generations of machines, information about energy sources that are crucial in a particular technological order is necessarily given. The global socio-technological revolution faces the modern problems of humanity – the search for new energy sources. Energy is a component of the productive forces. It activates and animates every instrument of labour for industrial and infrastructural purposes. However, energy as an economic category and an independent factor of social production does not have a prominent place in researches.

Energy has a fundamental position in the system of economic relations. Its role and importance in the development of social production, investments, trajectories, technological trends, solving social and environmental problems, the formation and development of international relations, state regulation of the economy, and so on is increasing. In the economic literature, there is a study of the scientific problems of energy within the framework of the theory of factors of production and industrial revolutions. For example, Klaus Schwab [15], exploring the influence of artificial intelligence, robotics, and the Internet of Things on socio-economic relations. He also notes the function of energy, its impact on society, economy, and public administration. V.F. Baynev believes that energy is a key production resource, ensuring the progress of technology and the Earth's civilization as a whole. Natural energy, attracted by the power of human intelligence into production processes, through the mediation of machines replaces complex human functions [3. p. 26]. Beschinsky A.A. and Kogan Yu.M. [5] back in the 80s of the XX century raised the economic problems of electrification, the role of energy in the system of factors of production. They justified the development of electrification and its role in shaping the fuel, energy, and the national economic balance. Bezgodov A.V. and Smirnov V.T. consider the energy as demanded natural resource [4]. Golovanov L.A. studies the issues of energy as an independent factor of production. The author considered the relationship between labour and energy, contributing to intensive economic growth, from the perspective of energy efficiency [6, p. 151]. According to B.V. Naumenko, energy ensures the satisfaction of basic human needs and it is one of the fundamental factors of production used in almost all sectors of the economy, as well as the parallel increase in its consumption with the level of socio-economic development of the country [11]. According to Pankratieva S.G., Rezak E.V., Chervyakova M.V. [12], the one of the most promising areas of energy in the world is renewable energy as an alternative to traditional types of energy. The advantages of this type of energy are inexhaustibility of energy resources, ecological purity, and the absence of a fuel component in the cost of energy produced [12, p. 2-8]. Therefore, energy is the main factor of production and economic categories, reflecting the totality of relations related to the search and development of energy conversion tools. It is increasingly relevant problem of economic theory.

The purpose of this research is to theoretically substantiate energy as an independent factor of production and the attributive properties of the components of productive forces, generating rental income, and identify the main aspects of its role in the rational allocation and development of productive forces, specialisation of production.

Methods

Substantiation of energy as an independent factor of social production and as an economic category required the use of a number of methodological approaches. They are as follows: dialectical, considering economic phenomena and factors of production in constant motion under the influence of kinetic and potential forces, deductive-inductive, determining the logic of reasoning and the stages of accumulation of knowledge, and a systemic-structural approach, to identify the role of energy in social production, in the branches of the national economy, in the development and placement of productive forces.

Results

According to the classical economics, the following classification is known: a set of factors of production: capital, labour, land, and entrepreneurial abilities [10, p. 37]. Energy is not allocated to a separate position, category, or factor. According to philosophical literature, energy is a property of matter, which consists in the movement and interaction of its constituent parts [2]. The Law of Conservation of Energy states that energy does not disappear or reappear, it is only transferred from one energy to another through various physical and chemical processes (or otherwise various forms of energy transfer) [2]. Therefore, energy passes from one type to another, from one energy to another. The principles of this law provide the development of the process of searching and using alternative energy sources. This interpretation shows the fundamental importance of energy in all spheres of society.

The energy component and the attributive properties of matter and production resources have specific physical properties that differ from the tangible matter. Therefore, it involves into all of the above factors of production. For instance, the physical capital functions through energy and determines its usefulness and significance. The land acts as an economic category precisely in the process of using its aboveground and underground energy, minerals (coal, oil, gas, etc.). Energy is acquired by irradiating the sun (solar energy is captured or radiated). Employment and entrepreneurial activity are also associated with the expenditure of human energy (mental, intellectual, and physical one). Therefore, energy is crucial in all factors as it is integrated with production resources. However, it is understudied and an urgent issue of economic theory. There are a few researches on the issue of energy as an economic category. Nevertheless, the scientific interest to this particular issue is increasing in terms of modern conditions of 'green energy', renewable energy, human intellectual energy, etc. In connection with the fundamental or substantial positions of energy in factors of production system, it is necessary to consider it as an important independent factor of production. Indeed, it is very important in the context of the technical and technological evolution of social production and the development of the productive forces of society.

In the historical process of the development of social production, the main role was played by the evolution of machinery and production technologies. As a result, there was an easing of labour, the phenomenon of the law of economy of social labour, an increase in labour productivity, and patterns of the placement and development of productive forces. The steam engines were the reason for the first industrial revolution and the development of the technical and technological base of production. The transformed nature energy contributed to the mechanisation of production, i.e., it caused the substitution of human physical energy into the energy of steam engines. As a result, the managerial and creative functions of man, the functions of controlling machines, have become more active. Energy electricity, or industrial electricity, became the cause or basis of the second industrial revolution. The computing processor and electronic computing machines became the basis of the third industrial revolution. Due to the use of electric drives, it is possible to automate production.

Industry 4.0 determines the profound changes in the industry associated with the introduction of digital and information technologies. It determines the transition from traditional production methods to information and innovative production methods. Moreover, the fourth industrial revolution implements digital technologies, automation, and the transition to more sustainable energy sources and provides energy conservation and the search for alternative energy sources. Nowadays, information technologies with electrical devices are being massively applied. Indeed, electricity is used as power base and also as an information carrier. Therefore, the development of information electricity is intensified. The fourth industrial revolution and the intellectual economy form an intelligent electricity circulating inside microprocessors to intellectualise the technosphere, production activities, and artificial intelligence systems. The fourth Industrial Revolution defines the trajectory of modern industrial and innovative development of economic sectors. The modern stage of development of social production is determined by the emergence and use of a new generation of machines to perform intellectual and creative human functions. These means of labour are machines aimed at converting specific types of natural energy. They replace the muscular and intellectual abilities of humans in the social production process.

Therefore, the energy drives the system of factors of production and the machines, increases the labour productivity, etc. According to an ontological or substantive approach, in the process of social production, machines transform specific type of natural energy. Energy in the factor system is the leading factor of production. On the one hand, energy combined with a variety of natural resources and ways to use them generates one type of natural rent – energy rent. An increase in the volume of demand for energy resources generates energy rent flows. For instance, Tajikistan's huge hydropower resources (about 527 bn kW per year) is three times higher in the CIS countries. It provides opportunities to assess rents from energy production, the use of advantageous mountain river locations, and the supply of clean drinking water on the global market. In addition, the flows of solar energy and light, the power of the water, the magnetic field of the mountainous territories (93%) of the republic are sources of energy rent. Energy and hydropower resources in Tajikistan are the exclusive state monopoly property. Therefore, energy rent is an economic form of energy resources ownership. In these conditions, the monopoly rents are occurred. They are a source of replenishment of the country's budget and, accordingly, resources for the protection of nature and energy resources, the maintenance of ecosystems, and ecological balances. The source of income from energy is different. It depends on the type of extracted energy or the method of its production and marketing. Indeed, it is possible to allocate the following types of income: from the production and supply of electricity, from thermal energy, from the processing of waste into energy, and income from solar and wind energy use. As a result, energy owner acquires a profit as a factor income.

Therefore, energy as a factor of production for the separation of energy as an independent sector of the economy. The energy system was formed as a result of historical development, technological breakthroughs, and the need for centralising management of energy production, transmission, and distribution. This process is determined by the demand for energy in the economy. An energy system is a set of integrated facilities and elements that promotes a continuous mode of operation regarding the production, conversion, transmission, distribution, and consumption of electrical and thermal energy within a specific integrated management system. The energy system is a key element of the productive forces. It ensures the production, transmission, and distribution of energy, necessary conditions for the development of productive forces through the effective functioning and development of production processes.

Moreover, the energy system is a catalyst for technological change. It is a result of electrification, technological processes, automation, and development of production through the implementation of the information function of energy. It increases the level of social labour productivity and reduces the cost of material resources. Therefore, in the National Development Strategy of the Republic of Tajikistan for the period up to 2030, the one of the fundamental priorities for development in the real sector of the economy is ensuring the transition of the country's hydropower industry to the budget-forming industry of the country. Its decisive role is in reducing poverty, contributing into development, ensuring Tajikistan's transition from regional and global the leader in potential reserves of hydropower, effective developing and using the country's energy potential, and promoting the interests of national energy in foreign markets both through appropriate energy diplomacy and through the use of market mechanisms[1].

The country's energy system has a fundamental impact on the formation of regional specialisation. It is a form of manifestation of the regularity of the location and development of productive forces. The concentration of production is in the regions of the country. It depends on their natural, socio-economic, and institutional conditions and potentials, demographic and other characteristics. In this aspect, the energy sector determines the trajectories of structural shifts in the economy of territories, the location of economic enterprises and the technological capabilities of the region's economy. The main mechanisms that influence the allocation of productive forces and the regional specialization of production are shown in Figure 1.

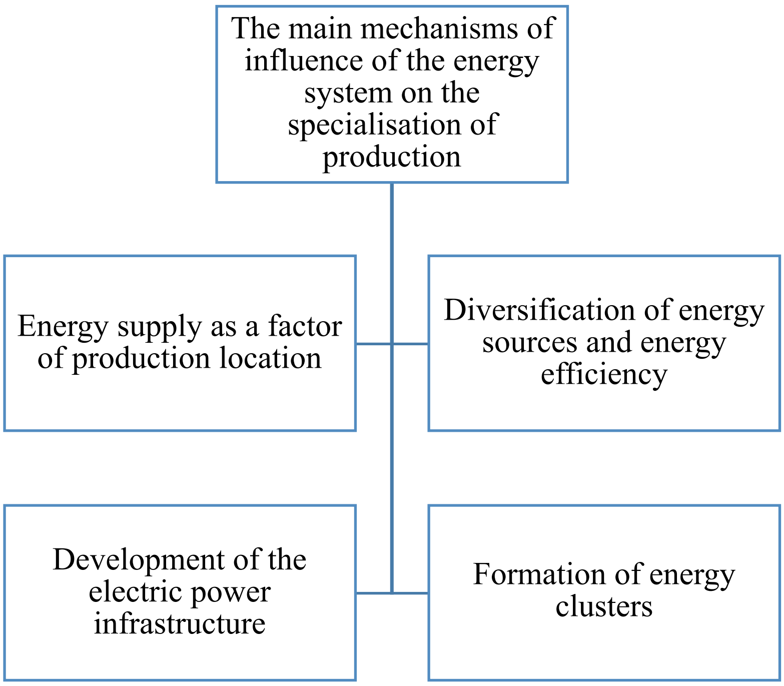

Figure 1. The main mechanisms of the energy system's influence on the allocation of productive forces and regional specialisation [8; 9]

The energy system influences the formation of structural proportions of social reproduction, the participation of economic sectors in the formation of gross domestic product, etc. As the level of energy supply increases, the participation of individual sectors of the economy, especially sectors of the real economy, in the production of gross domestic and regional product is changing. In 2018-2024, the share of mining enterprises related to electricity consumption in the formation of GDP increased from 3.5% to 4.6%. During the period under study, it increased by 1.2 percentage points.

Conclusion

[1] *Republic of Tajikistan. (2016). National Development Strategy of the Republic of Tajikistan for the period up to 2030. Source: https://egov.tj/site/farhang-tjk/documents/details/1008?lang=en&ysclid=mrdkjues11587214634 (accessed on 04.03.2026)*

Therefore, energy as a factor of production has a significant impact on the pace of social reproduction and is a source of rent. However, it depends on the conditions of its use, production technologies, and energy market conditions. Currently, the many theories of economic growth, with the exception of certain models of supply-side economics and resource economics exist. In the context of the growing global energy crisis, the importance of renewable energy resources is increasing. In Tajikistan, hydroelectric power is the largest source of renewable energy. The hydroelectric power plants produce more than 96% of the country's electricity. They almost have no greenhouse gas emissions, have flexibility in management, etc. It allows the energy system to quickly respond to changes in electricity consumption to ensure stability in the network and correspond stability in production processes.

In terms of the development of innovative and digital economy parameters in the economy of the republic and its regions, the electric power industry is a strategic resource and a determining factor. The process of rational allocation and development of productive forces depends on the nature of the placement of electric power sets. In the republic, special attention is paid to ensuring energy efficiency and energy sustainability. The energy sustainability of the country and its regions involves the diversification of energy sources, increases energy efficiency and the use of renewable technologies, contributes to the efficient placement and development of productive forces, guarantees the long-term competitiveness of the country's economy, regions, and economic sectors. Ensuring energy efficiency and energy savings is a major factor in reducing transformation and transaction costs to increasing product competitiveness. Moreover, it is necessary to form energy clusters as a stimulating factor for the efficient placement of production, and energy sustainability of the country's regions. This institution or mechanism for the development of productive forces and the effective placement of production across the country's territories contributes to the integrated development of the country's regions, accelerates the transition from the sectoral principle to the program-target principle, ensuring integrated development, etc. In this aspect, the development of energy-saving technologies as an element of energy sustainability forms the incentive systems for the emergence of new growth points based on the innovative clusters, digitalisation of energy infrastructure. As a result of technological modernisation of industries and sectors of the economy, it causes a qualitative structural shift in the economy of the regions. The development of the electric power system and the parameters of energy sustainability ensures spatial development of the industrial space of the country's regions.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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Structural asymmetry and bilateral complementarity in Russia-ASEAN trade in Agri-products: evidence from entropy, comparative advantage, and trade intensity measures

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ORIGINAL ARTICLE

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Abstract. This article examines the structural configuration of agricultural trade between the Russian Federation and the ten member states of the Association of Southeast Asian Nations (ASEAN) over the period 2015-2024. Drawing on disaggregated bilateral trade data across HS chapters 01-24 sourced from ASEANstats and ITC Trade Map, the study applies four complementary analytical measures: Shannon export entropy to quantify product diversification, the Bilateral Revealed Comparative Advantage (BRCA) index to assess bilateral specialisation, the Balassa Revealed Comparative Advantage (RCA) index to evaluate global competitiveness, and the Trade Intensity Index (TII) to gauge the depth of mutual trade engagement. The analysis reveals a persistent structural asymmetry: ASEAN maintains a broadly diversified agricultural export portfolio toward Russia (average entropy 1.94), while Russia's exports to ASEAN are concentrated in cereals, fish, and vegetable oils (average entropy 1.42). BRCA results confirm complementary rather than competitive specialisation across the majority of HS categories. The TII remained above unity throughout the entire decade and accelerated from 1.17 in 2020 to 1.32 in 2024, indicating that bilateral trade intensity is deepening beyond globally predicted benchmarks. The post-2022 acceleration coincides with Russia's geopolitical reorientation away from Western markets. The article argues that the relationship rests on durable agro-climatic complementarities and intensifying structural interdependence, while identifying SPS regulatory divergence, logistical distance, and export policy unpredictability as the three principal constraints on further expansion.

Keywords: Russia-ASEAN trade; agricultural trade; comparative advantage; Shannon entropy; Trade Intensity Index; export diversification; food security; bilateral complementarity; geopolitical trade reorientation

JEL codes: F14, Q17, Q18, F51

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Introduction

Agricultural trade between the Russian Federation and ASEAN has grown in both volume and strategic significance across the past decade. ASEAN's population exceeds 685 million, with more than half under the age of 35 and a middle class that expanded from approximately 41 million in 2000 to over 200 million by 2020, generating sustained growth in food import demand across the region [10]. Russia, for its part, emerged during this same period as the world's leading wheat exporter accounting for approximately 16 percent of global wheat export volumes by 2023 [7] while simultaneously reorienting its agricultural trade following Western sanctions imposed in 2014 and deepened after February 2022.

Despite this convergence of supply and demand fundamentals, Russia-ASEAN agricultural trade has attracted relatively limited systematic empirical analysis. Existing scholarship has tended to treat the bilateral relationship in either broad political-economy terms [4] or through single-indicator approaches to competitiveness [6]. No prior study has applied the full suite of entropy-based diversification measures alongside bilateral comparative advantage and trade intensity indices to characterise the structural configuration of this relationship across all 24 HS agricultural chapters and a decade-long time horizon.

This article addresses that gap through three specific contributions. First, it applies Shannon entropy analysis to both trade directions ASEAN exports to Russia and Russia exports to ASEAN documenting asymmetric diversification structures and their evolution from 2015 to 2024. Second, it computes BRCA and RCA indices across HS chapters 01-24 to identify where each partner holds bilateral comparative advantage and where complementarity rather than competition characterises the trade structure. Third, it calculates the TII for both directions and traces its trajectory over the full period, evaluating whether bilateral agricultural trade is intensifying or converging toward expected benchmark levels.

Literature review

Research on Russia's agricultural trade reorientation following the 2014 sanctions has focused predominantly on the domestic import-substitution response and the shift away from European partners [13]. The eastward pivot captured in Russia's foreign trade statistics and in the political-economy literature on the "turn to the East" [9] has been discussed largely at the macro level rather than through disaggregated product analysis. Rogozhin and Rogozhina identified ASEAN as a natural destination for Russian agricultural exports given the region's structural import dependence in cereals and its demographic growth trajectory [9], while Voronova and Novikova examined trade potential in Russia-ASEAN agricultural cooperation under conditions of global economic fragmentation [11]. Kanaev and Korolev observed that economic cooperation, including in agriculture, has historically lagged behind the political ambitions of the Russia-ASEAN dialogue partnership [3].

On the ASEAN side, Mizik applied the Balassa RCA and trade intensity measures to ASEAN agri-food trade, finding pronounced specialisation in tropical commodities and processed goods across several member states [6]. The recent network analysis by Fakour and Gholamnia of ASEAN-EAEU agricultural trade confirmed that Vietnam and Indonesia dominate the grain-trade corridors flowing toward the Eurasian Economic Union, illustrating how intra-regional production networks feed external markets [2].

Shannon entropy as a measure of export diversification in international trade was formally developed in the competitiveness literature by Teza, Caraglio, and Stella, who demonstrated that entropy measures reliably unveil country specialisation patterns across global trade networks[1]. Applied to agricultural trade, entropy distinguishes commodity-dependent export structures from diversified agri-industrial profiles and enables temporal tracking of structural adjustment.

The geopolitical dimensions of agricultural trade have attracted growing scholarly attention following the 2022 conflict in Ukraine. Wieck et al. documented the geostrategic dimensions of food policy decisions, showing that Russia's conduct around the Black Sea Grain Initiative illustrated the direct interface between foreign policy and food security policy [14]. Wang et al. demonstrated that global agricultural trade networks exhibit measurable sensitivity to geopolitical shocks and that established bilateral trade relations tend to exhibit greater resilience than newly formed ones [12]. Zhang, Li, and Zhou analysed the impact of the Russia-Ukraine conflict on international staple agri-food trade networks, confirming structural shifts in global grain flows with direct implications for Southeast Asian cereal importers [15]. The present study builds on this literature by providing the first systematic multi-indicator empirical characterisation of Russia-ASEAN bilateral agricultural trade structure across a full decade.

Methodology

The empirical analysis draws on two primary sources. Bilateral trade flow data between all ASEAN member states and Russia were obtained from the ASEANstats Data Portal (Trade in Goods, IMTS, Annually, HS 2-digit, in USD), covering HS chapters 01-24 from 2015 to 2024. Global trade data used for RCA and TII computation were drawn from ITC Trade Map. Agricultural production data for contextual background were sourced from FAOSTAT. Trade values are in current USD millions. Four analytical measures are applied.

Shannon Export Entropy. Export entropy captures the degree of concentration or diversification in a bilateral export portfolio across n product categories. It is computed as:

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[1] Teza, G., Caraglio, M., & Stella, A. L. (2021). Entropic measure unveils country competitiveness and product specialization in the World trade web. Scientific Reports, 11(1), Article 10189. https://doi.org/10.1038/s41598-021-89519-3

$$E = -\sum_{i=1}^{n} p_i \ln(p_i) \quad (1)$$

where p_i denotes the share of HS chapter i in total exports in a given year. For n = 24 product groups, the theoretical maximum entropy is ln(24) = 3.18. Values below 1.5 indicate high concentration; values between 1.5 and 2.2 indicate moderate diversification; values above 2.2 indicate broad diversification[2].

Bilateral Revealed Comparative Advantage (BRCA).

The BRCA measures whether one partner holds a comparative advantage in exporting a given product to the bilateral partner, relative to that partner's global export structure. For ASEAN exports to Russia:

BRCA(ASEAN) = (Export_ASEAN→Russia / Total_ASEAN→World) / (Export_Russia→World / Total_Russia→World) (2)

A BRCA value greater than 1.0 indicates bilateral comparative advantage. The index is computed for each HS chapter in each year with trade values aggregated across all ten ASEAN member states.

Balassa Revealed Comparative Advantage (RCA).

The standard Balassa RCA [1] measures each partner's global export competitiveness in a given product category:

RCA = (Export_partner→World / Total_partner→World) / (Import_World / Total_World_Imports) (3)

Values above 1.0 indicate global comparative advantage. RCA is computed separately for ASEAN and Russia across all 24 HS chapters.

Trade Intensity Index (TII).

The TII evaluates whether bilateral trade is more or less intense than expected given each partner's share in global trade[3]:

TII = (Export_A→B / Total_A→World) / (Import_B / Total_World_Imports) (4)

A TII above 1.0 indicates bilateral trade intensity exceeds the globally predicted benchmark. Separate TII series are computed for ASEAN exports to Russia and for Russia exports to ASEAN for each year in the study period.

Results

Bilateral Trade Balance and Aggregate Trade Flows

ASEAN maintained a positive agricultural trade surplus with Russia in nine of the ten years reviewed, the sole exception being 2018, when a surge in Russian cereal exports temporarily reversed the balance. Russia's agricultural imports from ASEAN rose from USD 1.27 billion in 2015 to USD 2.24 billion in 2024 a 76.3 percent increase. Russia's agricultural exports to ASEAN rose from USD 0.19 billion in 2015 to USD 1.02 billion in 2024, reflecting more than a fivefold expansion concentrated primarily in cereals following Russia's record harvests from 2017 onward. Table 1 presents the full annual trade balance series.

Table 1 – ASEAN-Russia bilateral agricultural trade balance, 2015-2024 (USD billion)

Indicator	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Russia's imports from ASEAN	1.27	1.25	1.38	1.39	1.33	1.41	1.89	1.98	1.55	2.24
Russia's exports to ASEAN	0.19	0.22	0.79	1.43	0.71	0.93	0.63	0.61	0.87	1.02
ASEAN trade surplus	1.08	1.03	0.59	−0.04	0.62	0.48	1.26	1.37	0.68	1.22

Source: ASEANstats[4]

[2] *Ibidem.*
[3] *orld Integrated Trade Solution (WITS). (2025). Trade indicators. Source: https://wits.worldbank.org (accessed on 20.11.2025)*
[4] *ASEANStats. Source: https://data.aseanstats.org/trade-annually (accessed on 18.03.2025)*

ASEAN's surplus is concentrated in vegetable oils and fats (HS 15, average annual surplus of USD 710.7 million), coffee, tea, and spices (HS 09, USD 258.9 million), and cocoa preparations (HS 18, USD 115.9 million). Russia's export surpluses with ASEAN are anchored in cereals (HS 10, average annual ASEAN deficit of USD 409.4 million), meat and offal (HS 02, USD 66.6 million), and fish and crustaceans (HS 03), where the balance shifted from a USD 49 million ASEAN surplus in 2015 to a deficit exceeding USD 134 million by 2022. Cereals, meat, and fish together account for approximately 85 percent of ASEAN's cumulative agricultural import expenditure from Russia over the decade, reflecting the concentration of Russian exports in a limited set of primary commodity groups.

Export Diversification: Shannon Entropy

Table 2 reports annual Shannon entropy values for both bilateral export directions. Two structurally distinct patterns are visible.

Table 2 – Shannon entropy of bilateral agricultural exports across HS chapters 01-24, 2015-2024

Export series	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Avg.
ASEAN → Russia	1.88	1.91	1.93	1.97	2.04	2.02	1.84	1.73	2.01	2.04	1.94
Russia → ASEAN	1.73	1.82	0.95	0.63	1.20	1.41	1.83	1.74	1.51	1.34	1.42

Source: ASEANstats[5]

ASEAN's export entropy fluctuated within a narrow band of 1.73-2.04, averaging 1.94 comfortably within the moderate-to-broad diversification range. The gradual upward trajectory from 1.88 in 2015 to 2.04 in 2024 indicates that ASEAN progressively widened the range of agricultural categories supplied to Russia, consistent with the production heterogeneity of its ten member states and with the expansion of regional agro-processing industries. Stability through the COVID-19 period (2020-2021) suggests that the diversified structure provided resilience against external disruption.

Russia's export entropy averaged only 1.42, exhibiting substantially greater volatility. The sharp decline to 0.95 in 2017 and 0.63 in 2018 reflects the surge in wheat exports following Russia's record harvests and the concurrent concentration of cereal deliveries to ASEAN markets. Partial recovery to 1.83 in 2021 gave way to renewed decline to 1.34 by 2024. The persistent gap between ASEAN's average entropy (1.94) and Russia's (1.42) documents a structural asymmetry in product composition: while ASEAN's exports to Russia are distributed across a broad range of categories, Russia's exports to ASEAN are anchored in a small number of primary commodity groups principally cereals, fish, and vegetable oils. This asymmetry describes differentiated modes of specialisation rather than a commercial imbalance: Russia holds a strong, concentrated comparative advantage in temperate-zone primary commodities, while ASEAN's exports span a wider spectrum from tropical raw materials to processed agri-industrial goods.

Bilateral Comparative Advantage: BRCA Analysis

Table 3 presents BRCA values for ASEAN exports to Russia across selected HS chapters, averaged over two sub-periods. ASEAN sustained bilateral comparative advantage (BRCA > 1.0) in approximately two-thirds of HS chapters throughout the period. The highest and most persistent values are observed in tropical and processed categories: HS 15 (vegetable oils), HS 09 (coffee, tea, spices), HS 18 (cocoa), HS 20 (prepared fruit and vegetables), and HS 08 (fresh and dried fruit). These categories align directly with ASEAN's agro-climatic production strengths.

Table 3 – BRCA values for ASEAN exports to Russia, selected HS chapters (five-year sub-period averages)

HS	Product description	Avg. BRCA 2015-2019	Avg. BRCA 2020-2024	Direction
15	Vegetable fats and oils	3.42	3.81	↑
09	Coffee, tea, spices	2.87	3.14	↑

[5] *ASEANStats. Source: https://data.aseanstats.org/trade-annually (accessed on 18.03.2025)*

HS	Product description	Avg. BRCA 2015-2019	Avg. BRCA 2020-2024	Direction
18	Cocoa and cocoa preparations	2.53	2.71	↑
20	Prepared vegetables/fruit	2.14	2.44	↑
08	Edible fruit and nuts	1.89	2.12	↑
03	Fish and crustaceans	1.62	0.91	↓
10	Cereals	0.38	0.24	↓
02	Meat and edible offal	0.22	0.19	→
04	Dairy products and eggs	0.41	0.38	→

Source: ASEANstats[6]
Note: BRCA > 1.0 = bilateral comparative advantage

Russia's BRCA profile is the structural inverse of ASEAN's. Russia sustained clear bilateral comparative advantage in cereals (HS 10, BRCA values exceeding 4.0 in peak years), meat (HS 02), and fish (HS 03). Russian BRCA values in tropical categories (HS 09, HS 15, HS 18) remain well below unity throughout the period. This inverse structure confirms that the two partners are not competing for the same bilateral markets in the same product categories. Rather, each side supplies the other with commodities it cannot efficiently produce domestically the empirical hallmark of complementary rather than competitive trade.

Global Competitiveness: RCA Analysis

RCA analysis contextualises bilateral patterns within global competitive positions. ASEAN's collective RCA exceeds unity across the majority of its bilateral export categories to Russia, confirming that the products ASEAN supplies to Russia are those in which ASEAN holds strong global positions. Vegetable oils (HS 15) present the clearest case: Indonesia and Malaysia together account for approximately 84 percent of global palm oil output, and ASEAN's RCA in this category exceeds 8.0 across most years. Coffee and spices (HS 09) and cocoa (HS 18) similarly exhibit RCA values well above unity.

Russia's RCA profile reflects its well-documented role as a global primary commodity exporter. Cereals (HS 10) show RCA values consistently above 3.0 from 2017 onward, coinciding with Russia's position as the world's largest wheat exporter. Fish and seafood (HS 03) carry RCA above 1.5 throughout the period. The alignment between Russia's global RCA and its bilateral BRCA profile toward ASEAN confirms that Russia's exports to ASEAN reflect genuine productive specialisation rather than trade diversion. Taken together, the BRCA and RCA evidence indicates that bilateral trade is the intersection of two globally competitive export profiles in products where each partner faces structural domestic scarcity.

Trade Intensity Index

Table 4 presents the annual TII series for ASEAN agricultural exports to Russia. The TII remained above unity in every year of the study period, confirming that ASEAN's agricultural exports to Russia are consistently more intense than global trade shares alone would predict.

Table 4 – Trade Intensity Index: ASEAN agricultural exports to Russia, 2015-2024

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
TII (ASEAN → Russia)	1.21	1.19	1.15	1.09	1.14	1.17	1.24	1.29	1.31	1.32

Source: ASEANstats[7]
Note: TII > 1.0 = bilateral trade intensity exceeds the globally predicted benchmark

Three temporal phases are distinguishable. In the first phase (2015-2018), the TII declined modestly from 1.21 to 1.09, reflecting the surge in Russian cereal exports that temporarily shifted the bilateral balance

[6] *ASEANStats. Source: https://data.aseanstats.org/trade-annually (accessed on 18.03.2025)*
[7] *ASEANStats. Source: https://data.aseanstats.org/trade-annually (accessed on 18.03.2025)*

and compressed ASEAN's relative export intensity. In the second phase (2019-2021), the TII stabilised and began recovering as ASEAN tropical commodity exports to Russia resumed growth and the post-sanctions market reorientation consolidated. In the third phase (2022-2024), the TII accelerated markedly, reaching 1.32 the highest value recorded over the decade. This acceleration coincides with Russia's deepened geopolitical pivot toward Asian markets following the full-scale intensification of Western sanctions in 2022, which further concentrated Russian external trade toward non-Western partners and reinforced ASEAN's relative importance as an agricultural supplier.

The post-2022 TII trajectory is analytically significant because it occurred precisely when global trade fragmentation was disrupting many established bilateral relationships. The fact that Russia-ASEAN agricultural trade intensity increased during this period provides quantitative confirmation that the bilateral relationship was reinforced rather than weakened by the geopolitical shock.

Discussion

The four empirical measures converge on a coherent structural picture. Russia-ASEAN agricultural trade is characterised by complementary rather than competitive specialisation, is deepening in intensity beyond what global trade benchmarks predict, and rests on production profiles that are well-grounded in each partner's global export strengths. The structural asymmetry in diversification ASEAN's broader export basket versus Russia's concentrated commodity profile reflects not a commercial weakness but a difference in comparative advantage modes that creates the conditions for mutually beneficial and durable trade.

This complementarity is rooted in agro-climatic endowments that cannot be altered by policy decisions in the near term. Russia's temperate continental climate enables large-scale cereal, oilseed, and livestock production but excludes tropical commodities entirely. ASEAN's equatorial and subtropical climates produce palm oil, coconut, coffee, cocoa, and tropical fruits in quantities far exceeding regional consumption and for which Russia represents a major import market. This structural basis distinguishes the Russia-ASEAN agricultural relationship from trade partnerships that are primarily policy-driven and therefore vulnerable to policy reversal [3].

The post-2022 acceleration of the TII is consistent with the broader literature on geopolitical trade reorientation. As Western sanctions constrained Russia's access to traditional partners [8], ASEAN emerged as a more prominent agricultural destination. This is consistent with aggregate evidence showing that the share of "friendly" states in Russian agri-food exports rose to approximately 90 percent by 2023[8]. The quantitative TII evidence adds bilateral precision to this aggregate picture: the shift toward ASEAN was not merely a political declaration but a measurable intensification of actual trade flows relative to global benchmarks.

Three structural constraints qualify an otherwise favourable reading of these trends. First, Russia's export policy architecture creates an inherent tension with ASEAN's food security interests. Russia's 2020 Food Security Doctrine authorises export restrictions whenever domestic supply thresholds are at risk[9], meaning ASEAN's dependence on Russian cereals is structurally unguaranteed. ASEAN wheat importers face sensitivity in the sense of Keohane and Nye's interdependence framework without the institutional mechanisms that would convert this sensitivity into structured vulnerability capable of generating cooperative obligations.

Second, SPS regulatory divergence constitutes a persistent non-tariff barrier. Heterogeneous SPS measures increase transaction costs substantially, particularly for exporters from developing countries [5], and no bilateral or multilateral SPS harmonisation framework currently governs Russia-ASEAN agricultural trade. The ASEAN-Russia Work Programme for Cooperation on Agriculture and Food Security 2021-2025 identifies food safety standards and veterinary controls as priority domains[10], but this identification has not

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[8] *OSW Centre for Eastern Studies. (2024). An increase in Russia's agri-food exports. Source: https://www.osw.waw.pl/en/publikacje/analyses/2024-03-01/increase-russias-agri-food-exports (accessed on 26.03.2026)*

[9] *USDA, Foreign Agricultural Service. (2020). New food security doctrine adopted (GAIN Report No. RS2020-0003). Source: https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=New+Food+Security+Doctrine+Adopted_Moscow_Russian+Federation_02-03-2020 (accessed on 26.03.2026)*

[10] *ASEAN Secretariat. (2020). Work programme for the ASEAN-Russia cooperation on agriculture and food security 2021-2025.*

yet translated into binding regulatory alignment.

Third, geographical distance imposes transport cost disadvantages relative to Australia, the United States, and Canada as wheat suppliers to Southeast Asia. These disadvantages are partially offset by Russia's competitive export pricing, but their structural persistence means that competitiveness is sensitive to global freight and energy market conditions[11].

These constraints indicate that the deepening interdependence documented by the TII and BRCA analyses remains fragile unless accompanied by institutional developments that provide greater predictability, lower transaction costs, and formal linkages between bilateral trade flows and each partner's food security frameworks.

Conclusion

This article has provided the first systematic multi-indicator characterisation of Russia-ASEAN agricultural trade structure across the 2015-2024 period, applying Shannon entropy, BRCA, RCA, and TII measures to disaggregated HS chapter data. Four principal findings emerge.

ASEAN's agricultural export portfolio to Russia is moderately to broadly diversified (average entropy 1.94), while Russia's exports to ASEAN are substantially more concentrated (average entropy 1.42), reflecting differentiated specialisation rooted in agro-climatic endowments. BRCA analysis confirms that the two partners are overwhelmingly complementary: ASEAN holds bilateral comparative advantage in tropical and processed categories where Russia has negligible production, while Russia holds advantage in cereals, meat, and fish where ASEAN faces structural import dependence. RCA analysis confirms that bilateral comparative advantage profiles mirror global competitiveness positions, indicating that bilateral trade is structurally embedded within each partner's broader international trade network. The TII remained above unity throughout the full decade and accelerated to 1.32 in 2024, with the post-2022 intensification providing quantitative evidence of deepening bilateral engagement under conditions of global trade fragmentation.

These findings carry clear practical implications. For Russia, diversifying agricultural export destinations toward ASEAN aligns with the strategic logic of its eastward reorientation but requires investment in logistics and SPS harmonisation to convert structural complementarity into durable commercial relationships. For ASEAN food importers, Russia represents a strategically meaningful supplementary cereal supplier whose export reliability is subject to domestic policy constraints not yet addressed through formal bilateral arrangements. For both parties, the gap between the institutional ambitions of the 2021-2025 Work Programme on Agriculture and Food Security and the actual depth of institutional integration represents the principal development priority for the relationship.

Future research should address several limitations of the present analysis. The HS 2-digit aggregation level conceals product heterogeneity that determines actual price competitiveness and market access conditions. Data gaps for Russia-to-ASEAN TII after 2021 reflecting Russia's cessation of detailed customs data publication limit post-conflict bilateral analysis to the ASEAN-to-Russia direction. Extension to HS 4-digit and 6-digit classifications, integration of unit-value data, and analysis of intra-ASEAN heterogeneity in bilateral trade relations with Russia would substantially deepen the empirical picture.

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Source: https://asean.org/wp-content/uploads/22.-WP-2021-2025-29-as-of-21-August-Supported-by-Russia-20201002.pdf (accessed on 26.03.2026)

[11] *Hossen, M.D. (2023). Tariff and non-tariff barriers affect U.S. agricultural exports to the ASEAN market. Southern Ag Today. Source: https://southernagtoday.org/2023/12/01/tariff-and-non-tariff-barriers-affect-u-s-agricultural-exports-to-the-asean-market/ (accessed on 26.03.2026)*

CONFLICT OF INTEREST
The author declares no conflict of interest.

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The technological leadership of the Russian Federation as the basis of the country's international competitiveness

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ORIGINAL ARTICLE

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Abstract. Nowadays, the Russian Federation has a lot of geopolitical and economic challenges, including the West's large-scale hybrid war, the urgency of enhancing its international competitiveness in all areas, particularly in technology. Therefore, achieving of the technological leadership is the one of the seven national goals for the period up to 2030 and for the long term up to 2036. The objective of this research is to consider the challenges of increasing the Russian Federation international competitiveness and identify ways to achieve technological leadership. The scientific novelty of the research involves identifying key challenges in enhancing the international competitiveness of the Russian Federation and ways to achieve technological leadership for the country. Moreover, it concerns with the development of technologies of the 3rd, 4th, 5th, 6th, and 7th technological paradigms in a multi-structured economy. The results have their potential use in developing comprehensive strategic plans to enhance the international competitiveness of the Russian Federation, including achieving technological leadership.

Keywords: technological leadership; the Russian Federation; international competitiveness; technological paradigms

JEL codes: O14, O32, M15

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Introduction

The natural change of technological structures taking place in the 2020s (currently the fifth technological structure of the sixth) [4] is traditionally accompanied by processes of deglobalisation and disintegration[1].

Due to the various types of wars taking place in the world during this period (ranging from trade wars to fairly large-scale armed confrontations), this period for the Russian Federation included sanctions and restrictions.

It resulted in import substitution policy, technological sovereignty. However, achieving the goal of technological leadership is a national goal[2] (Fig.1) and the basis for the growth of the country's international competitiveness.

[1] *Economic deglobalisation: A challenge, risks, and an impetus for growth. Source: https://www.if24.ru/deglobalizatsiya-ekonomiki/ (accessed on 11.01.2026)*

[2] *Russian Federation. President. (2024, May 7). Decree No. 309: On the national development goals of the Russian Federation for the period up to 2030 and for the future up to 2036. Source: http://www.kremlin.ru/acts/bank/50542 (accessed on 11.01.2026)*

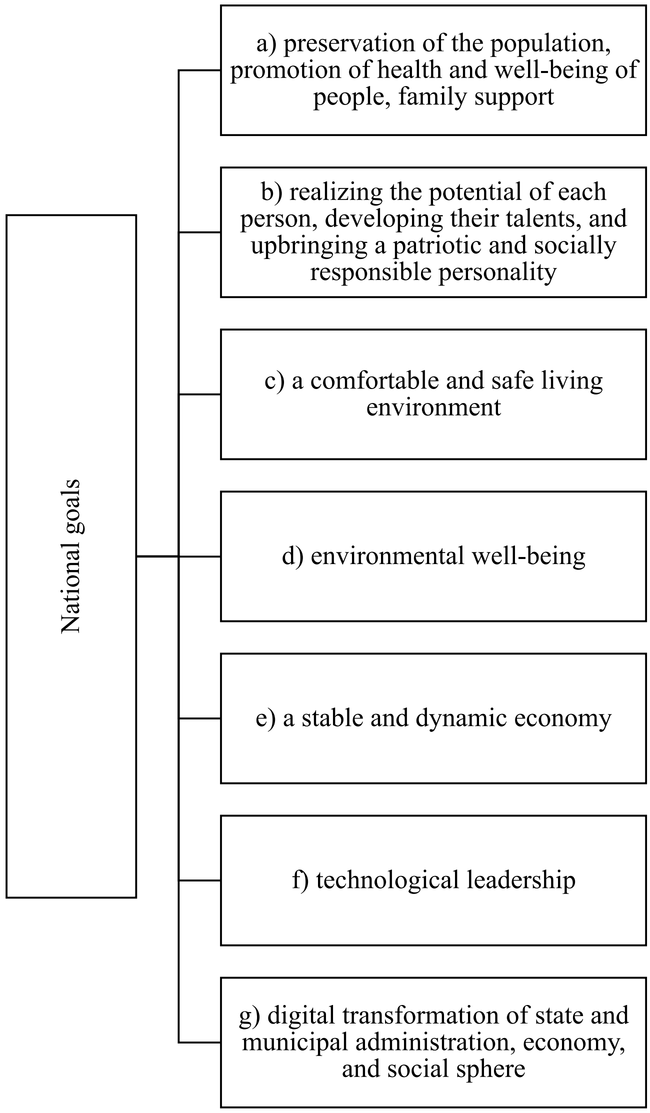

Figure 1. The national development goals of the Russian Federation for the period up to 2030 and for the future up to 2036

Source: Decree of the President of the Russian Federation on May 7, 2024 No. 309[3]

The purpose of the research is to consider the challenges of increasing the Russian Federation international competitiveness and identify ways to achieve technological leadership.

Methods

The methodological basis of the research consisted of scientific works devoted to the problem of increasing international competitiveness and ensuring the technological sovereignty of the Russian Federation by the following authors: Afanasyev A.A. [1], Zimovets A.V. [5], Kanunnikova A.M. [6], Kopteva L.A. [7], Lenchuk E.B. [8], Petrov M.N. [11], Rodina I.B. [12], Savenkova I.V. [13], Esterle T.A. [16], Yurevich M.A. [17], Tebekin A.V. [15], etc.

Results

According to the previous studies, failure to solve the problem of import substitution[4] (largely due to inflated expectations when relying on parallel imports)[5], in the domestic economy relied on ensuring the

[3] *Russian Federation. President. (2024, May 7). Decree No. 309: On the national development goals of the Russian Federation for the period up to 2030 and for the future up to 2036. Source: http://www.kremlin.ru/acts/bank/50542 (accessed on 11.01.2026)*

[4] *Klishas announced the failure of the import substitution program in Russia. (2022, May 19). RBC. Source: https://www.rbc.ru/politics/19/05/2022/6285f0c79a7947c127bab983 (accessed on 11.01.2026)*

[5] *Ministry of Industry and Trade of the Russian Federation. (2023, July 21). Order No. 2701 on approval of the list of goods (groups of*

technological sovereignty of the country.

Moreover, in terms of the process of solving the problem of technological sovereignty, the technological independence of a country does not guarantee the leadership on the domestic market. However, in this situation many domestic companies continued to purchase foreign technical solutions.

As a result, the technological sovereignty of the country began to be considered together with the goal of technological leadership. Later it became a national goal (Fig.1).

Therefore, in the process of iteratively setting and solving the tasks of increasing the country's international competitiveness (Fig.2) Russia has to achieve the technological leadership.

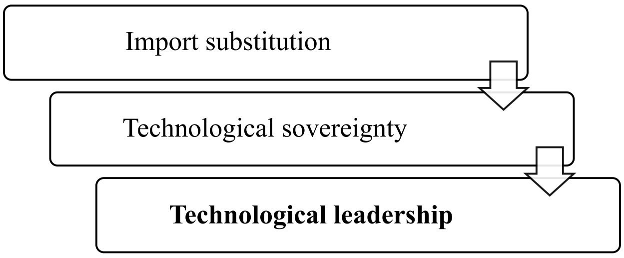

Figure 2. Iterative solution of the tasks of increasing county international competitiveness

Source: Authors

According to the 'Strategy for Economic Security of the Russian Federation for the period up to 2030'[6], during the period of technological change that has occurred in the current decade [14], structural imbalances in the global economy are increasing. Therefore, the achievement of the technological leadership in the Russian Federation starts the prospects for the country.

Moreover, countries that are the first to master new technologies (technologies of the sixth technological order) during the period of technological change gain a significant production and technological advantage over other countries, increasing their international competitiveness.

In the initial formulation of the problem, the country's technological leadership was supposed to be achieved through the development of technologies of the sixth technological order (i.e. digitalisation).

However, the problem of increasing the country's international competitiveness, including achieving technological leadership within the framework of the sixth technological order, is significantly complicated by the disrupted continuity with the technologies of previous orders in the national economy (Fig.3) [10].

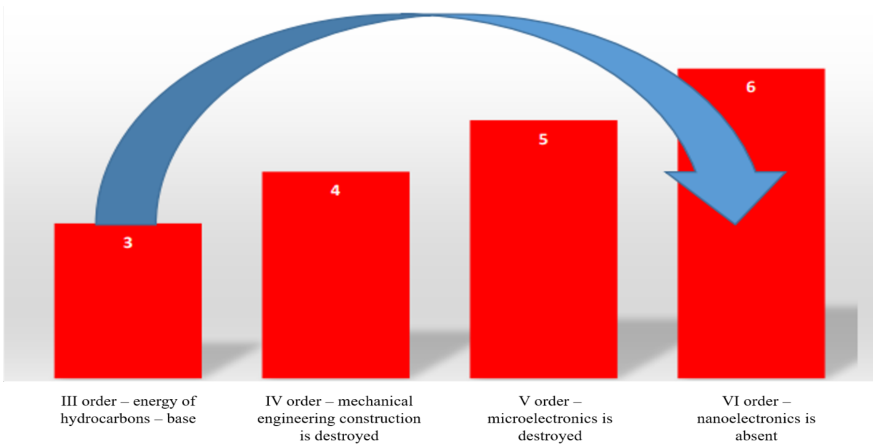

Figure 3. A model of the destroyed technological structure of the Russian economy [10]

Moreover, there is the continuing high level of dependence of the Russian Federation on imported supplies of machinery and equipment (Fig.4)[7].

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goods) for which certain provisions of the Civil Code of the Russian Federation do not apply under parallel import conditions. Source: https://www.garant.ru/products/ipo/prime/doc/407384679/ (accessed on 11.01.2026)

[6] *Russian Federation. President. (2017, May 13). Decree No. 208: On the Strategy of Economic Security of the Russian Federation for the period up to 2030. Source: https://www.garant.ru/products/ipo/prime/doc/71572608/ (accessed on 11.01.2026)*

[7] *Russian exports and imports in 2024: Raw materials dominate, Asia maintains stability. (2025). Source: https://spcard24.ru/*

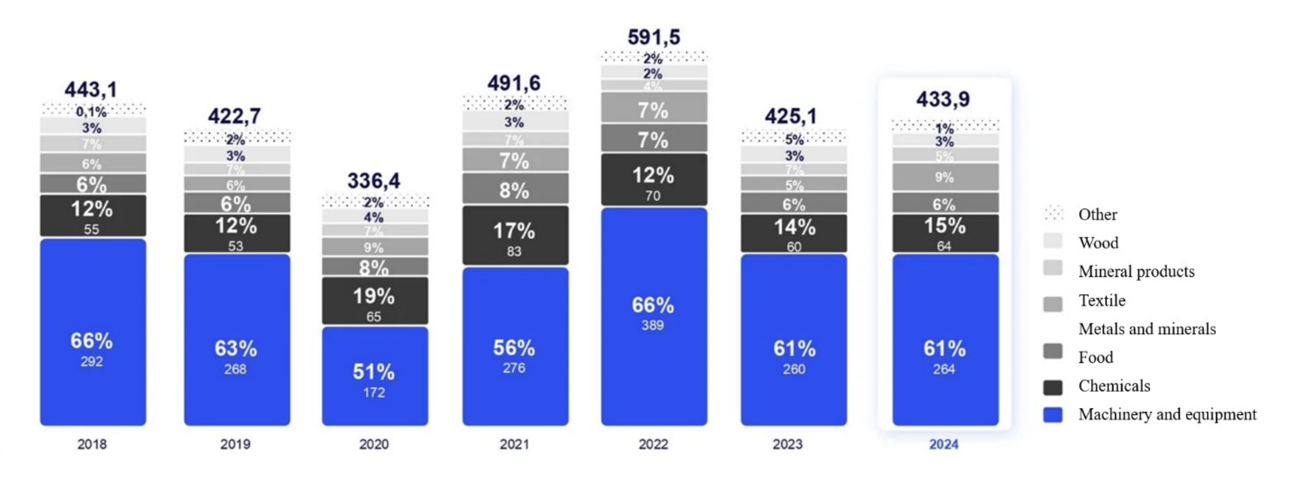

Figure 4. The structure of the Russian Federation exports and imports, 2018-2024
Source: Russian exports and imports in 2024: Raw materials dominate, Asia maintains stability, 2025[8]

The model of the destroyed technological structure of the Russian economy, shown in Fig.4, clearly demonstrates that the attempt is being made to move from technologies of the third stage, which are still the basis of the national economy[9], to technologies of the sixth stage (in the absence of sufficient technological reserve). However, significantly destroyed structures of production based on technologies of the IVth and Vth modes of technological modes seems to be unpromising [10].

In scientific literature, the development of domestic engineering is considered as the primary basis for increasing the international competitiveness of the Russian Federation. It includes achieving the country's technological leadership (Fig.5). Indeed, the production of high-tech means of production ensures the quality and competitiveness of goods and services provided.

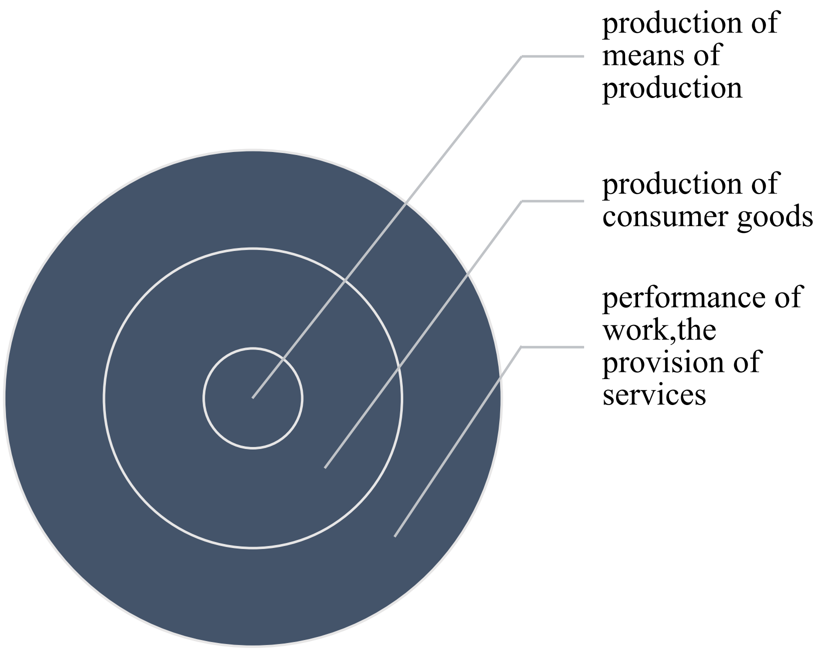

Figure 5. The production of means of production is the most relevant for the material production of consumer goods, the performance of work, and the provision of services
Source: Authors

novosti/tpost/hky7jhlty1-rossiiskii-eksport-i-import-v-2024-godu (accessed on 11.01.2026)
[8] *Russian exports and imports in 2024: Raw materials dominate, Asia maintains stability. (2025). Source: https://spcard24.ru/novosti/tpost/hky7jhlty1-rossiiskii-eksport-i-import-v-2024-godu (accessed on 11.01.2026)*
[9] *Fact-checking: Is the Russian budget dependent on oil revenues? (2024). Higher School of Economics. Source: https://www.hse.ru/expertise/news/967286528.html (accessed on 11.01.2026)*

Therefore, the destruction of the branches of domestic engineering, weakening of the military-industrial complex, and erosion of fixed capital [9] of domestic industry were the main goals of the Western curators of Gaidar's reforms. These destructive actions resulted in determination of the technological structure of domestic production (Fig.4). Nowadays, it has to be restored to ensure technological sovereignty and achieve technological leadership of the Russian Federation.

In this regard, the simultaneous development of technologies of the III, IV, V, and VI technological structures should be considered as priorities for increasing the international competitiveness of the Russian Federation. It includes the achievement of the technological leadership, while simultaneously forming scientific and technological reserves for technologies of the VII technological structure (Fig. 6).

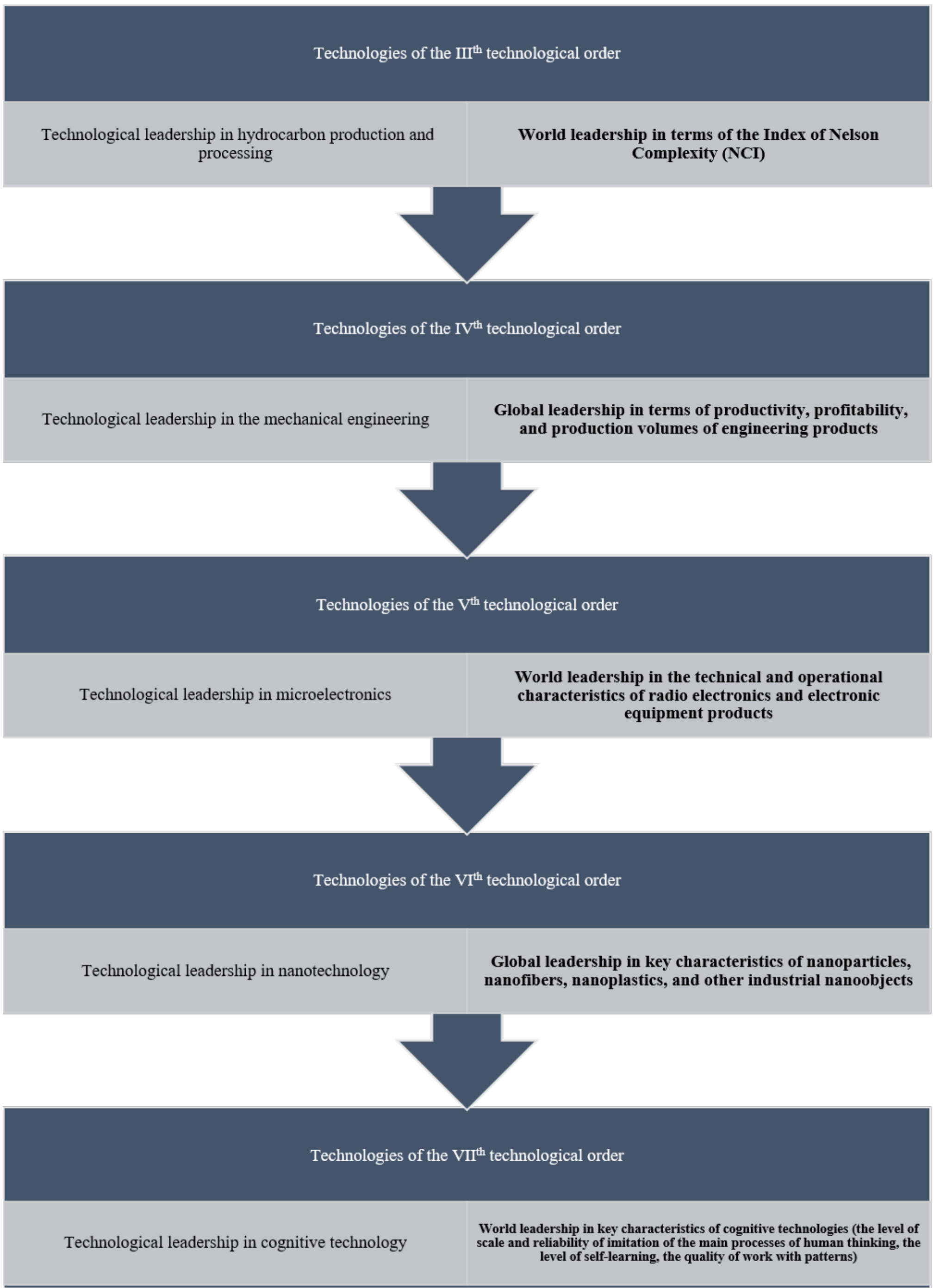

Figure 6. The priorities of increasing the international competitiveness of the Russian Federation through achieving the country's technological leadership

Source: Authors

Conclusions

Therefore, to increase the international competitiveness of the Russian Federation, we should restore the destroyed technological structure of domestic production.

In this regard, the simultaneous development of technologies of the III, IV, V, and VI technological structures should be considered as priorities for increasing the international competitiveness of the Russian Federation. It includes the achievement of the technological leadership, while simultaneously forming scientific and technological reserves for technologies of the VII technological structure

The development of domestic engineering, including achieving the country's technological leadership, is the primary basis for increasing the international competitiveness of the Russian Federation. The production of high-tech means of production determines the quality and competitiveness of goods and services.

The results obtained can be used in the formation of comprehensive strategic plans for improving the international competitiveness of the Russian Federation, including achieving the country's technological leadership.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

Alexey V. Tebekin – writing – original draft.
Artem I. Krivtsov – data curation, formal analysis, validation.

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Sector-specific shock propagation heterogeneity in international production networks: case of EU regions

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ORIGINAL ARTICLE

Abstract. This article examines sector-specific heterogeneity in shock propagation across international production networks. The study investigates whether the impact of sectoral shocks on regional output depends on two structural characteristics of European regions: their geographical and economic proximity to other regions and the degree of industrial diversification. The empirical analysis is based on the EUREGIO interregional input-output database covering 252 NUTS2 regions of the EU-2006 and twelve aggregated economic sectors for 2010. Shock propagation is modelled using the hypothetical extraction method, which simulates the temporary removal of an industry from international intersectoral production linkages. Geographical and economic proximity is measured by the geographically weighted location quotient, while industrial diversification is assessed using the Herfindahl-Hirschman Index. The results reveal substantial sectoral heterogeneity in shock propagation. Strong positive relationships between regional vulnerability to shocks and both explanatory variables are identified for knowledge-intensive service sectors, particularly real estate and business services and financial intermediation. A weaker positive relationship is observed in electrical, optical and transport equipment, whereas mining and energy supply demonstrate an inverse relationship. No systematic relationship is found for labour-intensive sectors such as agriculture, textiles, and food production. The findings suggest that knowledge-intensive services play a systemic role in transmitting shocks across European production networks, while greater industrial diversification enhances regional resilience by mitigating the economic consequences of sector-specific disruptions. These results contribute to the understanding of regional competitiveness, resilience and the structural determinants of shock propagation in international production networks.

Keywords: European production networks; shock propagation; geographic and economic proximity; sector heterogeneity; industrial diversification

JEL codes: C53, D57, F15, F23, O52

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Introduction

The modern world economy is increasingly more exposed to shocks originating from various sources (political, economic, ecological, technological, etc.). Importantly, shocks have a mutually reinforcing cumulative impact on the economy on different levels, including global, national, and regional. Among the main amplifiers of heterogeneous shocks is the network structure of the global production, which implies a close interconnectedness and interdependence of productive units on the inter-country and inter-industry planes. Considering a growing policy demand for resilience strategies of the national economies, the study of the network patterns of shock propagation at the regional level becomes important.

One of the most popular theoretical frameworks to study the dynamics of international production networks is the 'Global Production Networks' (hereinafter – GPN) paradigm. Under this framework international production is viewed as a complex process on the network cooperation between suppliers, producers, and other intermediaries on the matter of value addition to create sophisticated finished goods. Global production networks span through three main dimensions, namely organizational, network (or topological), and geographical. Organizational space stands for the production technologies as sequential chains of value addition to intermediary goods and their respective transfer to other counterparts. Network space depicts topologies of interfirm relations under production of complex goods and reflects, primarily, the number of a node's neighbors, its proximity in a production network, as well as the relational features of production network architecture. Geographic space, in its turn, traces the spatial positioning of firms and other intermediaries, thus highlighting the factor of partners' remoteness and specifics of logistical coordination of international production. Therefore, a simultaneous account of all the three spaces allows the GPN paradigm to act as a powerful tool for studying the role of firms' dynamics for the regional economic activities.

The network nature of international production implies a great degree of interdependence between firms and intermediaries originating from various countries and regions across the globe. Therefore, the behavior of individual firms may non-linearly impact other firms that do not directly collaborate with these actors. In other words, the evidence suggests divergent "network effects" as unintentional adverse effects experienced by network actors, which become visible through non-systematic shifts of the key indicators of firms' performance. At the same time, the 'shocks' propagation is subject to the organizational, network, and geographic properties of GPNs. Hence, shock propagation patterns may be conceived in terms of buyers and sellers of a specific firm's products (here – upstream and downstream flows), as well as its direct and indirect partners and their impact on firms operating in the same region or in other locations.

In Europe, international production networks have become particularly complex, compared to other countries and world regions. An increasing number of firms integrate into electronics, transport manufacturing, chemical production, as well as military. These sectors have very dense value chains, and a large portion of value creation is provided by knowledge-intensive business services. Hence, the structure of the European economy acquires the attributes of the system of strongly interconnected industries and regions. Owing to the recent developments in statistics of international production, the study of network configurations of international production at the regional level in Europe becomes feasible. A successful example production statistics compilation for regional economies is the "PBL EUREGIO" database that contains interregional input-output tables for different sectors across EU regions. The tables comprise both WIOD data and regional economic accounts. Additionally, they cover international trade estimations obtained by PBL Netherlands Environmental Agency that are complemented by regional output and economic costs data collected via survey over a specified number of countries. In addition, the quantitative tools allowing for a proper estimation of interregional geographical distances became publicly available. The "EUDISTANCE" project offers an estimable algorithm for measuring of distances between the centroids of European regions and creating of a complete matrix of distances for both NUTS2 and NUTS3 regions. In sum, there is a visible trend towards a formation of empirical toolkit for the regional level research into international production networks.

Given the level of production network sophistication, as well as the presence of relevant quantitative tools and databases, Europe provides a suitable empirical setting to study specifics of the shock propagation in international production networks. The present study aims at the identification of sector-specific features of shock propagation in the European production networks. The role of regional proximity and industrial diversification as factors of shock propagation is examined.

Literature review

The existing research into shock propagation in international and regional production is primarily centred around the network properties of production systems (technological and value connections between suppliers, assemblers, and other intermediaries), inter-industry shock propagation mechanisms, as well as vertical specialization in global value chains.

The above-mentioned GPN theoretical paradigm pays particular attention to the problem of production networks evolution and regional economic development [8; 20]. The researchers note that 'territoriality' in traditional global value chains research is studied at an overly aggregated level with countries being subdivided onto 'core economies' and 'peripheral economies'. GPN concept, in its turn, allows for identification of means whereby various network actors anchor into particular locations. The GPN concept proponents suggest for the production network to be territorially conceived as 'a spatial ensemble of different local and territorially centered value activities' [8]. An ongoing series of discussions on the international production networks' potential to transmit shocks originating from individual firms is present in the modern literature. It is argued that, apart from production network structure and lead firms' actions, external forces also shape shock propagation mechanisms. They include industrial specifics (i.e., technological profile, cost structure and firm competitiveness, industry standards, etc.) and regional properties (i.e., resource endowment, quality of infrastructure, labor market structure, regulatory profile, presence of other firms, etc.). It is stressed, though, that any given GPN research and, in particular, the one covering shock propagation is currently carried out on industry-level data. In other words, the researchers face the requirement to 'scale up' the level of analysis due to operational limitations for assessment of competitive dynamics' explanatory variables (cost-capability ratio, market structure, financial discipline, and external risks).

A significant breakthrough in research into shock propagation in international production networks was the formal modelling of international production networks based on the production function incorporating consumption of intermediates [2]. The main research directions covered studies of shock propagation patterns through the lens of network topologies [7], as well as investigation of the origins of supply and demand shocks and their upstream and downstream propagation channels [1]. The Hulten theorem has gained scholarly attention with respect to modelling the impact of shocks on the economy's output [12]. It posits that the changes in aggregate economy's output in response to a sector-specific shock are proportional to the share of this sector in the aggregate output (or to the so called 'Domar weight'). Several papers highlight the tendency of clustering around the most productive firms while studying shock propagation in GPNs [16]. Modelling of the impact of non-anthropogenic shocks on international production networks has also become a popular strand of the GPN studies. For instance, in [5] the authors study the shocks associated with natural disasters from the point of production networks' potential to amplify or mitigate them. The empirical modelling in the paper relied on the interfirm transactions between large US firms. As the study revealed, the natural disaster shocks had a more ruinous effect for the firms specializing in differentiated goods with higher R&D expenditures or otherwise important in the networks due to the difficulty of their substitution.

Due to data availability restrictions the qualitative assessment at the level of separate economies and their industries remains most widely used. Interregional input-output tables have served in the recent years as an empirical foundation for studying interindustry relations between countries and macroregions. The flagship work enhancing research into international production network studies from the point of inter-industry cooperation and value addition was the paper of Hummels et al. [13]. The authors' theoretical model of vertical specialization considers production as a two-stage process, where the first stage is executed solely by labor force, while the second one is performed by labor with the use of the first stage's output. Thus, production technologies are specified on the basis of the country (be that the country of origin or the other country) hosting the first and the second production stages. The work of Timmer et al. [19] has greatly popularized the input-output analysis of international production networks. The automotive manufacturing served as an example of a sector showing an increase in international production fragmentation seen in the ratio of value-added produced in the domestic economy, its macroregional partners, and other countries. In the paper of Los et al. [14] the research of Timmer et al. was further advanced by adding the emphasis to the dynamics of regional and global value-added components in international production. It has been revealed that there was a sustained growth in the ratio of value-added produced outside of the macroregion to intra-regional value-added for 34 largest economies from the EU, East Asia and North America over the period of 1995-2011. Recently input-output analysis of international production networks has shifted to the problem of risks to national economic performance associated with reliance on foreign partners. Baldwin and Freeman [4] identify two groups of risks – impacting production networks themselves (i.e., exogenous supply and demand shocks, natural disasters, changes in trade policy, entry of new competitors, etc.) and engendered by production networks (i.e., externalities of links' rupture, shock propagation on micro- and macrolevel, etc.). As the authors conclude, a trade-off between diversification of suppliers and reliance on the more quality intermediates is necessary to properly mitigate these risks. It is also articulated in the paper that such diversification hinders post-crisis recovering of production systems while maintaining relations with established partners assists a rapid recovery.

Heterogeneous patterns of shock propagation in specific sectors of international production networks are dissected in the literature. Bahal and Lenzo [3] proposed the 'removal centrality' parameter to measure the sector's potential to transmit and amplify exogenous shocks. The metric is calculated as the difference between the first-order changes in real GDP in the actual economy and in the counterfactual economy where the linkages between the focal industry and the other sectors are severed so that it becomes unable to transmit shocks. As the study revealed, the Domar weight measure substantially underestimates the systemic importance of some economic sectors due to its inability to account for inter-industry network linkages. The systemic importance of industries in the economy has also been considered in terms of the network centrality of a sector. In an earlier paper of Blöchl et al. [6] the authors relied on two measures to capture the sector's centrality, namely the random walk centrality, which is based on the idea of the expected number of steps required to reach another node for the first time, and the counting betweenness, reflecting the frequency of a given node being visited on first-passage walks. According to the study, the random walk centrality has attributed the greatest systemic importance to wholesale and retail trade sectors, while the sector of motor vehicles is more central through the lens of counting betweenness. Therefore, one could assume that the underlying meaning behind systemic importance of a sector suggests alternative results on potential of economic sectors to engender and propagate shocks.

Methods

In the study of shock propagation in international production networks of particular importance is the question of the main determinants of the cross-sectoral heterogeneity. It needs to be investigated if there are any patterns of the regions and industry mutual connections that make them amplify or mitigate propagation of shocks in production networks.

To identify the industry-specific patterns in shock propagation in European production networks the following hypotheses have been formulated:

H0: The differences in propagation of impact of sector-specific shocks on the European regions' outputs are determined by unknown factors.

H1: The differences in propagation of impact of sector-specific shocks on the European regions' outputs are determined by their spatial and economic position relative to other regions in production network.

H2: The differences in propagation of impact of sector-specific shocks on the European regions' outputs are determined by industrial diversification of regional economies.

To test the hypotheses, it is necessary to understand the network origins and mechanisms of shock propagation. In addition, a quantitative assessment of the regions' structural properties (namely, their mutual geographical and economic proximity, as well as industrial diversification) needs to be arranged. Finally, a classification of industries by patterns of shock propagation is performed. It is expected that sector heterogeneity is witnessed in the axes of tangible and intangible production, as well as industries' reliance on advanced infrastructure or broad networks of intermediaries.

Network mechanism of shock propagation

The conceptual approach to studying the effects of sector-specific shocks on the output of European NUTS2 regions in our paper is based on methodology proposed by Giammetti et al. [11]. The authors modelled extreme scenarios of breaking of production linkages of European regions with the non-EU countries by the so-called "hypothetical extraction" [9] (that is, by severing the rows and columns responsible for interregional flows in input-output tables). Despite its inability to precisely capture the network effects of breaking the linkages, this approach is a powerful tool for modelling shock propagation in production networks from the point of the amount of negative impact absorbed by a given region.

The first step of the analysis of shock propagation in international production networks is a specification of the main characteristics of firms participating in international production. The basic production function of a focal industry is represented by Formula 1. Here, y_i is an industry i's output, z_i stands for the Hicks neutral productivity shock, l_i is the labor force employed in sector i, x_{ij} stands for the amount of good j required for production of product i, $a_i > 0$ is the share of labor force under sector i's production technology, ζ_i is a normalizing constant which value is subject to the model's specification.

$$y_i = z_i \zeta_i l_i^{\alpha_i} \prod_{j=1}^{n} x_{ij}^{a_{ij}} \tag{1}$$

Carvalho and Tahbaz-Salehi [7] in their paper postulate that sector i's output depends on the production network's structure, as well as on the productivity shock for firms operating in j sector (Formula 2).

$$\log(y_i) = \sum_{j=1}^{n} \iota_{ij}\epsilon_j + \delta_i \tag{2}$$

In the Formula presented above ι_{ij} is an element of the Leontief matrix multiplier denoting all the possible routes connecting i and j sectors in a production network, ε_j stands for the logarithm of the productivity shock for firms from the j sector, δ_i is a constant independent to the shock.

The second theorem proposed by Carvalho and Tahbaz-Salehi suggests that the value-added in an economy is a derivative of productivity shocks in its separate sectors and the relative sectors' weights in an overall output (Domar weights) (Formula 3).

$$\log(GDP) = \sum_{i=1}^{n} \lambda_i \epsilon_i \tag{3}$$

Here λ_i is the Domar weight of sector i.

The theorems mentioned above allow one to articulate the two critical principles of shock propagation analysis that are significant for our paper. First, interregional multisectoral input-output tables provide sufficient information to study all the possible interconnections between industries in a production network. Second, the sectoral shock's impact for the aggregate region's output is proportional to the industry's weight in the regional economy's structure.

Modelling of sector specific shocks in European production networks

In the present study shocks originating from specific European sectors are modelled by 'hypothetical extraction'. This method implies 'zeroing' of rows and columns respective to a focal industry in the matrix of technological coefficients of input-output table. This way, it is assumed that the given industry curtails operations with other sectors and 'exits' from a production network.

The 'hypothetical extraction' makes it possible to model shock propagation in respect to both the suppliers of intermediates for this industry ('backward extraction') and the buyers of its products ('forward extraction').

The backward extraction for a given region-sector is executed according to Formula 4.

$$E_A = \mathrm{X} - (I - A_{cr})^{-1} f \tag{4}$$

In Formula 4 X denotes the vector of outputs of regions in a network, I is an identity matrix, A_{cr} stands for the matrix of input technological coefficients where rows and columns matching the extracted sector are 'zeroed', f is the vector of final demand for all the regions in a network.

As far as the buyers of a sector's products are concerned, the Formula of forward extraction will be the following (Formula 5).

$$E_B = X - V(I - B_{cr})^{-1} \tag{5}$$

Here, V represents the vector of value-added, B_{cr} stands for the matrix of output technological coefficients where rows and columns matching the extracted sector are 'zeroed'.

In this paper the absolute and relative values of the impact of sector-specific shocks on the regional output are calculated. The relative impact is estimated according to Formula 6.

$$E_{rel} = \frac{E}{X} \times 100\% \tag{6}$$

In our study, extraction is performed simultaneously for all the studied regions. The resulting variable under hypothesis testing is chosen to be the relative impact of sector-specific shock on the regional output, calculated as the ratio between the sum of all the absolute effects for all the sectors and the overall region's output.

Testing of sector heterogeneity hypotheses

The estimation of the correlation between the relative sector-specific shocks' impact and the regional position in the spatial system of intersectoral relations is based on the assumption that regions with higher spatial and economic centrality absorb, on average, a greater negative impact from such shocks. This may be reasoned by the fact that spatial concentration and agglomeration amplify the negative impact for central regions (that is, neighboring regions may transmit a portion of its effect to central regions).

The geographically weighted location quotient [18] has been applied to assess the impact of the spatial factor (Formula 7).

$$WLQ = Wy \tag{7}$$

Here, W denotes the nxn matrix of spatial weights, y stands for nx1 vector of location quotients LQ.

A single element of W spatial weights matrix is defined as follows (Formula 8).

$$w_{ij} = \frac{1}{{d_{ij}}^2} \tag{8}$$

In Formula 8 w_{ij} represents the spatial weight attributable to pair of regions i and j, d_{ij} stands for the distance between regions i and j in kilometers.

Location quotient is calculated according to Formula 9.

$$LQ_{pi} = \frac{{x_{pi}}/{x_i}}{{x_{pn}}/{x_n}} \tag{9}$$

Here, x_{pi} represents the output of sector p of a region i, x_i stands for the overall output of region i, x_{pn} is the output of sector p of all regions, x_n stands for the overall output of all regions.

The Herfindahl-Hirschman index has been used to quantify the degree of industrial diversification of a region (Formula 10).

$$HH_i = \sum_{p=1}^{n} {S_{pi}}^2 \tag{10}$$

In Formula 10 S_{pi} is the share of sector p's output in the overall output of a region i. The higher is the value of this index, the lower is the degree of industrial diversification of a given region.

Hypothesis testing is based on the comparison of the average relative shock effect for two pairs of region samples, namely A and B, as well as C and D. The A sample consists of the 10% of regions with the highest value of HH or WLQ index (separately for each indicator). Thus, the B sample is compiled of the rest 90% of the regions. In contrary, the C sample consists of the 10% of regions with the lowest value of HH or WLQ index (separately for each indicator). Thus, the D sample is compiled of the rest 90% of the regions. The two-sample t-test is applied to check the significance of the difference of the average relative shock effect separately for A and B samples, as well as for C and D ones (Formula 11).

$$H0: \mu_A = \mu_B$$
$$H1: \mu_A \neq \mu_B$$

Here, μ_A and μ_B represent the average values of shock effect for A and B, and C and D groups respectively. The t-statistics is calculated according to Formula 12.

$$t = \frac{\mu_A - \mu_B}{\sqrt{{s_A^2}/{n} + {s_B^2}/{m}}} \tag{12}$$

In Formula 12 s_A^2 and s_B^2 represent the sample variances of the shock impact for A and B (C and D) samples of regions, n and m are the sample sizes of A and B (C and D) respectively.

This test has allowed to group industries into four categories according to whether the relationship between the shock level and the specified indicator is evident or not. The first category comprises the sectors with a strong positive relationship (average regional decrease in industry's output is greater for regions with larger values of the indicator). The second group encompasses sectors with weak positive relationship (the positive relationship is only confirmed by either a single test, or an only one pair of samples). The third category includes sectors with negative relationship, and finally the fourth category comprises only industries that do not demonstrate any relationship between the shock impact and the specified indicator.

The information base of the research conducted was the interregional multisector EUREGIO input-output table for 2010 (the last available year in this database), covering 252 regions of EU-2006 and 12 sectors of the regional economy (the industrial classification is proposed by the project team) [17].

Results

According to Table 1, specific patterns of shock propagation are evident in several groups of economic sectors. For instance, the sectors of real estate, renting and business activities, as well as financial intermediation show strong positive correlation between the idiosyncratic shock impact and their economic and geographic proximity, and industrial diversification. The European regions that are more susceptible to spatial co-location externalities and have a low degree of industrial diversification capture relatively higher shock impact originating from the aforementioned sectors.

Table 1 – The results of two-sample t-test for the significance of mean difference for WLQ and HH

Type of correlation	WLQ	HH
Strong positive correlation	1. Real estate, renting and business activities 2. Financial intermediation 3. Coke, refined petroleum, nuclear fuel and chemicals etc.	1. Real estate, renting and business activities 2. Financial intermediation
Weak positive correlation (proved by one type of testing only)	1. Electrical, optical and transport equipment 2. Construction	1. Hotels and restaurants 2. Transport, storage and communications 3. Distribution
Negative correlation	1. Mining, quarrying and energy supply	-
No correlation	1. Agriculture 2. Distribution 3. Food, beverages and tobacco 4. Hotels and restaurants 5. Transport, storage and communications 6. Textiles and leather	1. Agriculture 2. Electrical, optical and transport equipment 3. Coke, refined petroleum, nuclear fuel and chemicals etc. 4. Construction 5. Food, beverages and tobacco 6. Mining, quarrying and energy supply 7. Textiles and leather

Source: Author

Regarding distribution sector that is the most critical sector for the overall output of European regions, it can be mentioned that the propagation of shocks originating from that sector is not subject to a region's susceptibility to co-location effects, whilst it is positively correlated with industrial concentration. Notably, mining, quarrying and energy supply sector demonstrates inverse interdependence of sector-specific shocks with a region's economic and geographic proximity. The testing shows that shock propagation in agriculture, food, textiles does not depend on the specified parameters of a region's economy.

Overall, there is a strong heterogeneity in shock propagation patterns among studied industries.

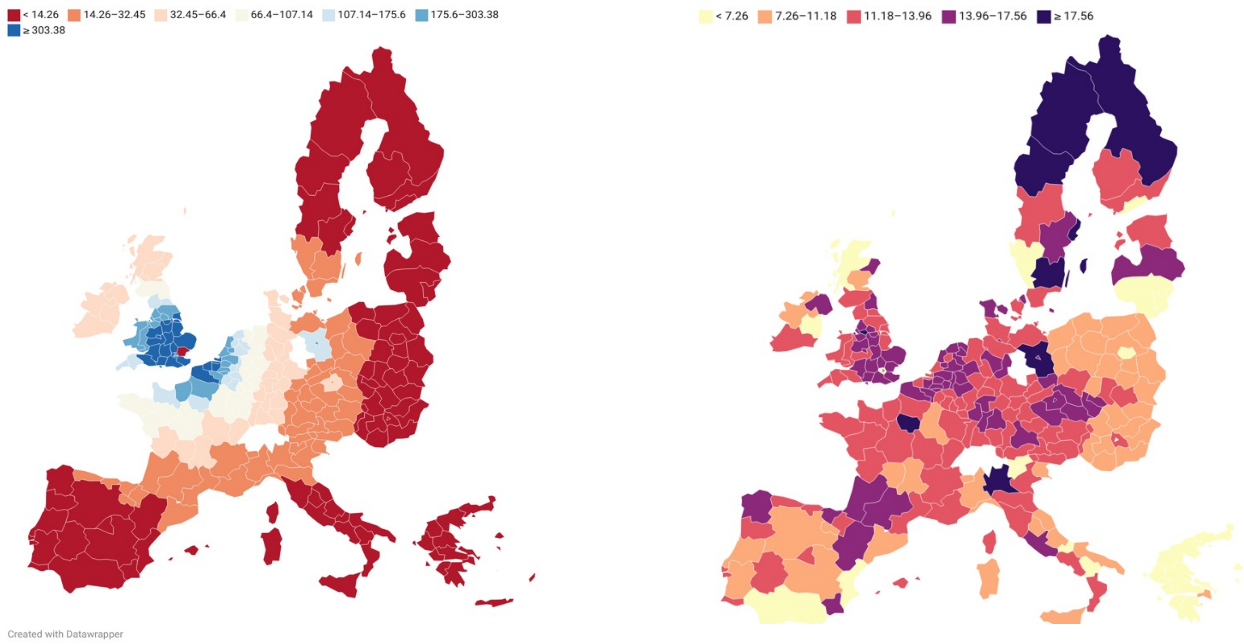
Hypotheses H1 and H2 receive empirical support for advanced services sectors that are essential for stable performance of the regional economy (Table 2). In general, H2 hypothesis is empirically supported only for services sector which implies that shocks origination in intangible production are most harmful for regions that have a narrow specialization. In other words, in industrially diversified regional economy shocks originating from services sectors are more evenly distributed between industries, which in turn contains the overall negative impact on regional economy.

Table 2 – Hypotheses testing for specified industries under study

No.	Industry	Hypothesis confirmed		
		H0	H1	H2
1	Real estate, renting and business activities		+	+
2	Financial intermediation		+	+
3	Coke, refined petroleum, nuclear fuel and chemicals etc.		+	
4	Electrical, optical and transport equipment		+	
5	Construction		+	
6	Mining, quarrying and energy supply		+	
7	Distribution			+
8	Hotels and restaurants			+
9	Transport, storage and communications			+
10	Textiles and leather	+		
11	Agriculture	+		
12	Food, beverages and tobacco	+		

Source: Author

More granular results can be obtained at the regional level analysis of shock propagation patterns in Europe. Particular attention is paid on the factor of geographic and economic proximity of regions as it represents the spatial distribution of business activities and their concentration around certain regions.



WLQ | Shock impact (% of regional output)

Figure 1. Geographically weighted location quotient and backward shock impact for real estate, renting and business activities

Source: Author

In Figure 1 it can be seen that regions located nearby Pas de Calais bulk, separating the United Kingdom and France, share higher WLQ values and relative shock impact coming from the sector of business operations. By and large, the sector demonstrates strong spatial concentration around Pas de Calais bulk. While shock distribution generally follows the path of geographic distribution of business operation in the sector, several regions prove susceptible to such shocks (i.e., regions of Finland and Sweden, and Northern parts of Italy).

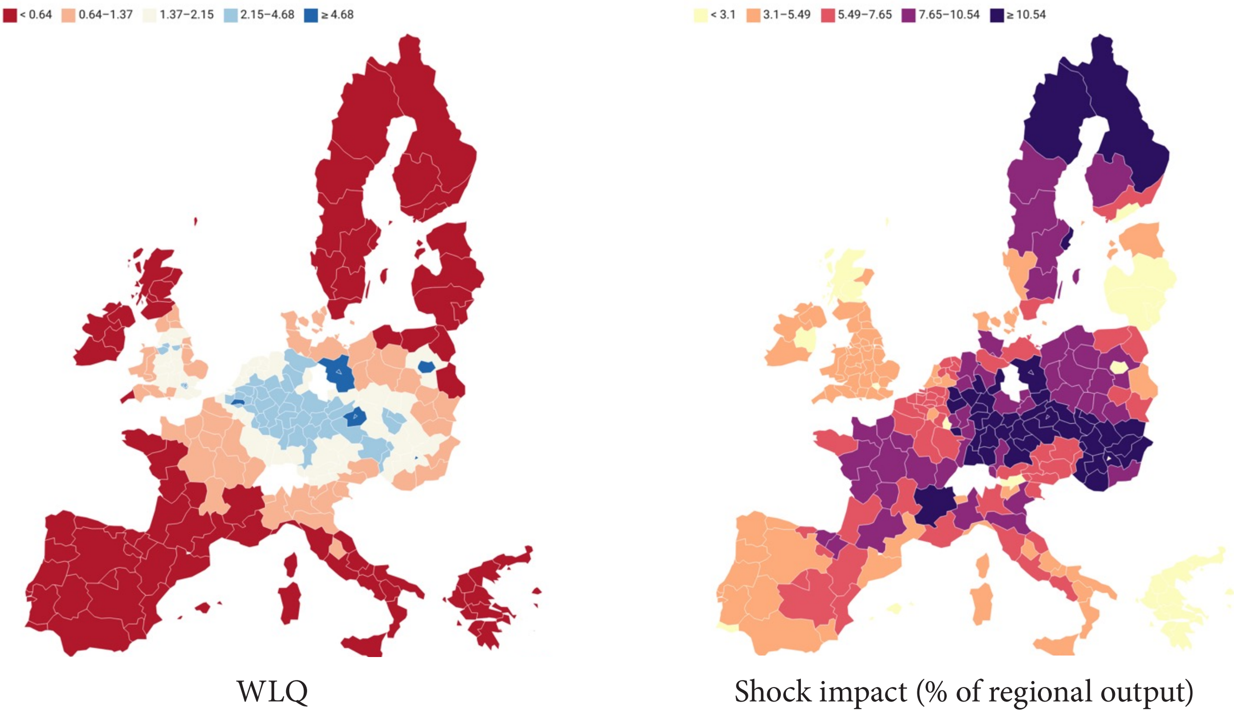
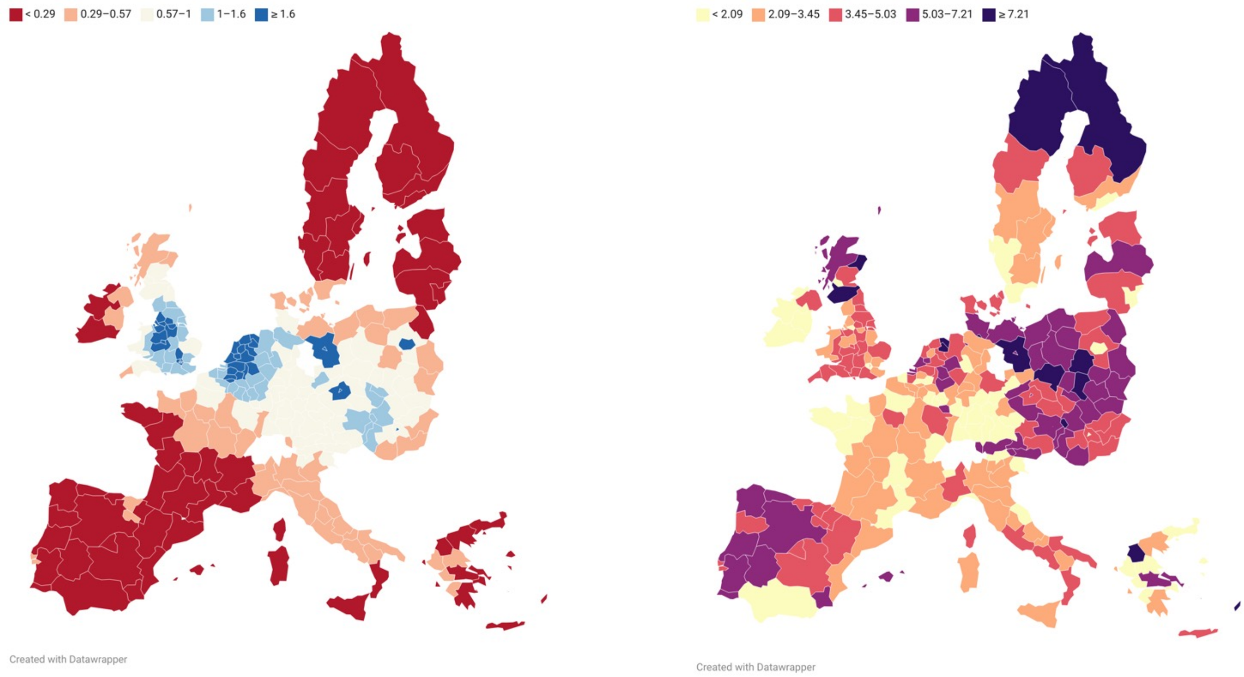


Figure 2. Geographically weighted location quotient and backward shock impact for electrical, optical and transport equipment

Source: Author

Despite the fact that German regions have higher economic and geographic concentration of activities in electrical, optical and transport equipment, Czech and Slovak regions also demonstrate high relative figures of shock impact (Figure 2). Thus, the correlation between WLQ and shock impact in that sector is only partially verified. Considering the nature of production networks in European transport manufacturing, the observed phenomenon might be explained by a subordinate position of Eastern European countries to Germany as a leading economy in the industry [15]. Hence, Czech and Slovak regions, occupying relatively low-end operations (assembly, maintenance, simple component production) and thus possessing weak bargaining power in production networks, absorb a large portion of shocks originating from the industry.

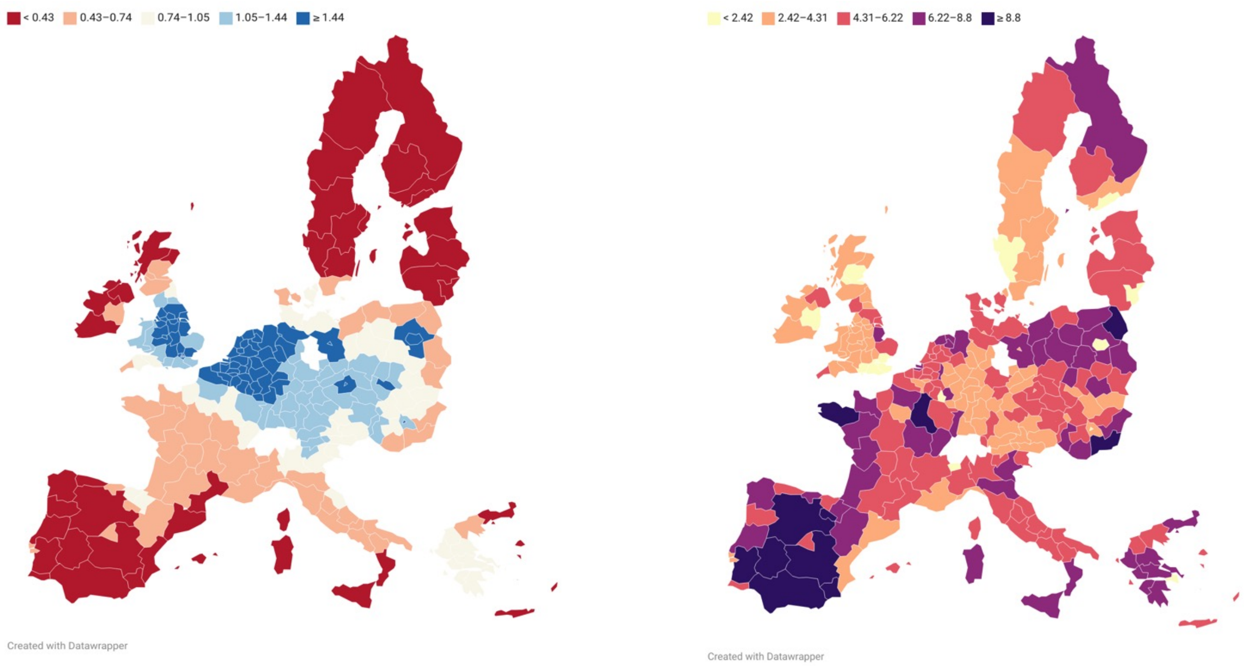
In 2010 the regions of the United Kingdom, the Netherlands, and Belgium were superior to other regions with respect to concentration of mining, quarrying and energy supply (Figure 3). At the same time, the highest relative shock impact produced by this sector was captured by Spain, Portugal and East Europe. This suggests an inverse relationship between the specified indicators for that sector. It is worth noting that the regions absorbing such shocks (apart from Finland and Sweden) primarily specialize in labor- and energy-intensive activities. Hence, their economic performance is largely dependent on foreign supplies of primary resources, which can be seen as a critical dependency in international production networks demanding state actions to increase self-sufficiency in energy and raw materials supplies.



WLQ Shock impact (% of regional output)

Figure 3. Geographically weighted location quotient and backward shock impact for mining, quarrying and energy supply

Source: Author



WLQ Shock impact (% of regional output)

Figure 4. Geographically weighted location quotient and backward shock impact for food, beverages and tobacco

Source: Author

The highest economic and geographic proximity in food, beverages and tobacco, according to Figure 4, is attributable to the regions of the United Kingdom, Germany, Belgium and the Netherlands. However, the regions of Spain, Greece, as well as West and East Europe absorb the largest share of negative impact from this sector. Here, a clear relationship between the specified indicators is not apparent. Yet one can assume that the WLQ calculation methodology used in our research may have an important limitation. In essence, it captures the level of concentration of value-addition in the industry, not the actual situation of productive capacities. Hence, if this indicator measured the second feature, the correlation might be positive since regions in Southern Spain, strongly hit by the shock in our model, traditionally specialize in this industry [10].

Discussion

Overall, the conducted empirical analysis has allowed to test the hypotheses of the research. Generally speaking, the results obtained match our prior expectations. Particularly, propagation of shocks originating from services sectors is dependent on the regions' economic and geographical proximity – the shock is transmitted in the form of 'concentric circles' hitting first regions closely tied with the main locations of value-addition in the industry. At the same time, shocks from tangible sectors do not possess universal features of propagation. In some cases, it reveals the intrinsic characteristics of international production networks, namely the mismatch between the geography of capacities and the geography of value creation in the same industry.

The strong positive association between shock level and economic and geographical properties of a region is most evident and valid in real estate, renting and business activities. According to the data collected, the 'center of mass' of this industry in the EU economy in 2010 was situated in Benelux countries, and in the UK. In part the revealed positive correlation between WLQ and a relative level of shock in the industry can be explained by the fact that provision of such services is associated with geographical concentration of firms. This ensures co-location and agglomeration positive externalities, as well as accelerates inter-regional flows of knowledge and innovations, which is essential for a stable performance of the industry.

At the same time, the business services sector is closely tied with other industries of a region, which enhances negative spillovers on other industries thus amplifying the overall shock impact on the region's economy. Positive correlation between absorbed amount of shock and HH indicator in this sector is largely determined by the level of economic sophistication of regions that specialize in real estate, renting and business activities.

A similar trend is observed in coke, refined petroleum, nuclear fuel and chemicals. One of the main specific features of the sector is high level of geographical clustering of production. In Europe the manufacturing of nuclear fuel and chemicals is largely localized in several regions of France and Germany. The technology used in the sector does not demand spatially distributed production networks. In addition, petrochemical industry greatly contributes to the regional product, and this in turn motivates positive correlation between negative shock impact and degree of regional industrial diversification.

The results obtained suggest that in several sectors, such as agriculture or textiles, no patterns of shocks propagation were observed. Such observation may be explained by the consideration that these industries are not critical for the economy of the most of EU regions. Besides, their technological process does not demand geographical co-location of productive resources, and it is mostly located in regions that traditionally specialize in these sectors (for food industry it is Spain and Eastern Europe, for textiles and apparel – Italy, Greece, and Portugal).

It is worth noting that in the majority of analysed cases the distribution of negative shock impact was asymmetrical. For instance, in electrical, optical and transport equipment the distribution was right-hand asymmetrical and leptokurtic. It suggests a presence of 'fat tails' in distribution of shock effect among analyzed regions, which in turn complicates an unbiased analysis of propagation of shock originated in this industry.

Last but not least, the research conducted revealed a duality in shock propagation depending on the region's specialization in a given industry. It has been shown that in services sectors such dependence is absent, which suggest a more stochastic character of shock propagation in these sectors compared to material production industries. In our opinion, susceptibility of services sectors to external production network shocks should be studied more carefully with an account of a growing role of services in the modern economy.

Conclusion

In the present study the problem of sectoral heterogeneity in shock propagation in international production networks has been studied. A special emphasis was paid to the case of European production networks that were dissected at the regional level for twelve industries covering both tangible and intangible activities. It has been tested if such heterogeneity in the case of Europe was determined by structural characteristics of regions, namely their geographic and economic proximity to other regions and level of industrial diversification of regions' economies.

The modelling of a shock occurrence in production network was based on the 'hypothetical extraction' method which implied a simultaneous breaking of production linkages between the given industry and the rest of the economy. To quantify the relative proximity of a region to other regions in the economy the weighted location quotient (WLQ) was calculated, whereby the ordinary geographical distance has been calibrated by the level of industrial specialization of the neighbouring regions. The level of industrial diversification of a region's economy was identified by calculating the Herfindahl-Hirschman index (HHI). Generally, it was expected that a region's susceptibility to production network shocks is weaker for regions that are more remote from the most specialized regions and/or which economic structure is more industrially diversified.

As the obtained results suggest, the correlation between shock impact on the region's economy and its economic and geographic proximity to other regions in the same industry is evident only in specific industries. Low industrial diversification of a region's economy amplifies shocks occurring in services sectors. Considering a growing role of services in the modern economy, maintaining resilience of the regional economy demands industrial diversification. Importantly though, shocks originating in labour-intensive industries (such as agriculture, textiles and food) do not follow some specific propagation pattern. Given their relatively small contribution to the regional product, such uncertainty does not imply significant problems for policymaking.

Important limitations of the conducted research need to be stated. First, the dataset used in empirical section is limited both temporarily and geographically. As a result, several countries that accessed EU in the recent years were not analysed, while all calculations were done on the 2010 yearly data. Second, the 'hypothetical extraction' method requires a strong assumption that the shock occurs simultaneously in all regions and a given industry completely breaks all production ties with other economic sectors.

As for future studies, we suggest that our estimations can be replicated on recent data to check the robustness of our results and potentially identify some additional patterns in shock propagation in international production networks. Apart from that, the role of industrial policy measures in promoting resilience of regions' economies can also be critically assessed by extending our research framework with inclusion of governmental support measures as explanatory variables.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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Modern models of international competitiveness of Big Tech corporations: internal drivers versus external shocks

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Abstract. This paper examines the contemporary models of international competitiveness adopted by Big Tech corporations between 2010 and 2025. The study aims to identify the internal drivers underpinning the resilience of technological giants and to assess their capacity to withstand external shocks, including sanctions, geo-economic fragmentation, and regulatory shifts. To achieve this objective, the authors employ a comprehensive methodological framework that integrates financial performance analysis (revenue, return on assets), market metrics (market share, international footprint), innovation activity (R&D intensity, patenting), and qualitative attributes such as network effects, lock-in effects, and corporate dynamic capabilities. The empirical basis of the research draws on data from Statista, IDC, and Omdia concerning global smartphone shipments by key vendors from 2009 to 2026. The findings indicate that the primary internal drivers of competitiveness are data network effects, ecosystem-based user lock-in, control over strategic infrastructure (data centers, chips, submarine cables), and sustained R&D investments that often exceed the national budgets of entire countries. External shocks, such as the sanctions imposed on Huawei, have laid bare the vulnerability of even the largest players: the company's shipments plummeting from 240.5 million units in 2019 to 35 million in 2021 underscores a critical dependence on global supply chains and access to digital ecosystems (Android, Google Services). At the same time, Samsung has managed to maintain a stable position (62.8 million units in Q1 2026) owing to its vertical integration and diversification. The conclusions drawn are relevant for the development of corporate strategies and state industrial policy in the context of digital transformation.

Keywords: international competitiveness; Big Tech; network effects; lock-in effect; dynamic capabilities; digital ecosystems; geo-economic fragmentation, technology giants

JEL codes: F23, L10, O32, O33, M16

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Introduction

Between 2010 and 2025, the global economy underwent a fundamental transformation driven by the ascendance of Big Tech corporations. A defining feature of these companies' operations is their use of data as a core resource and the proliferation of network effects [5]. In 2007, not a single digital platform ranked among the world's top ten companies by market capitalization; by 2023, such firms occupied seven of those ten slots [12]. These corporations have evolved into not merely the largest players on the global stage but also pivotal actors shaping technological trajectories, establishing new standards of competition, and exerting substantial influence over institutional environments at both national and supranational levels. In the context of rapid digitalization, the rollout of 5G networks, the advance of generative artificial intelligence, and mounting geo-economic fragmentation, understanding the mechanisms that secure the enduring competitive positions of tech giants holds both theoretical significance and practical import for devising effective strategies at the firm level and for state industrial policy. This underscores the relevance and necessity of investigating the Big Tech phenomenon.

Within the scholarly domain, a debate persists concerning the applicability of microeconomic theories of competitiveness – particularly Michael Porter's framework – to the analysis of platform-based digital ecosystems. The networked nature, data-driven scale effects, and multi-sided markets fundamentally alter conventional understandings of entry barriers and market power, necessitating either an adaptation of existing theoretical constructs or the development of novel approaches [9]. Porter's classic model, formulated to analyze traditional "pipeline" businesses where value is created through a largely controllable linear chain of value addition, proves inadequate for capturing the dynamics of platforms. In platform ecosystems such as Apple iOS, Google Android, or Huawei HarmonyOS, the key asset resides not in internal resources but in the external community of users and complementors. Competitive advantage is forged less through the optimization of internal processes and more through the orchestration of interactions among the different sides of the platform (consumers, developers, advertisers) and the stimulation of positive network effects [17]. This reorients strategic focus from resource control to the management of relationships and the ecosystem itself.

A crucial shift in entry barriers in the digital era is the emergence of data network effects. In traditional industries, barriers to entry are erected by economies of scale in production or capital intensity. A second distinctive feature of Big Tech competitiveness is the lock-in effect – namely, the strategy of ensconcing users within closed ecosystems [3]. Corporations aspire not merely to sell a product but to integrate the consumer into a web of complementary services, from which exit entails considerable cost. For instance, Apple's competitive edge is closely tied to the deep integration of its devices (iPhone), operating system (iOS), and services (App Store, iCloud). Samsung, in turn, relies on the vertical integration of its manufacturing capacities, including its own semiconductor fabrication plants, ensuring command over its value chain. Huawei is forging its own technological ecosystem through the HarmonyOS operating system, the AppGallery application store, and cloud services.

In the Big Tech sector, dominant players can leverage accrued data troves to perpetually refine their algorithms and service offerings. Expanding audiences amass more data, thereby enhancing product quality, attracting new users, and creating a self-reinforcing cycle of growth [4]. This erects hurdles for new entrants that are extraordinarily difficult to surmount with a cheaper or technologically superior alternative alone. Nevertheless, some scholars observe that data scale effects are not absolute barriers, and their potency is contingent on context. Critical factors include not merely volume but also data quality, uniqueness, and the firm's capacity to analyze and monetize that data effectively[1]. "Multihoming" is a scenario, in which users simultaneously engage with several competing platforms, can substantially weaken a leader's market power by lowering switching costs and opening up opportunities for new players [4].

In response to the inadequacy of classical models, researchers have proposed adaptations. For example, work on adapting the Five Forces model for digital streaming platforms reveals that contemporary entry barriers are shaped as much by technological infrastructure and sustainability (including access to green energy) as by financial capital [9]. Supplier power undergoes transformation: within ecosystems, holders of intellectual property and creators of original content assume pivotal roles. Consumer power, conversely, is amplified by algorithmic personalization but simultaneously constrained by it, as algorithms can generate 'filter bubbles' and reduce the visibility of alternatives. Novel threats also arise – substitutes can emerge from

[1] *Iansiti, M. (2021). The value of data and its impact on competition (Harvard Business School NOM Unit Working Paper No. 22-002). Harvard Business School. Source: https://www.hbs.edu/ris/Publication%20Files/22-002submitted_835f63fd-d137-494d-bf37-6ba5695c5bd3.pdf (accessed on 12.04.2026)*

adjacent industries (e.g., video games as substitutes for video content).

This ongoing debate has given rise to extended conceptual models. The 'Five Forces Plus' model, for instance, proposes supplementing Porter's original five forces with three new ones: control over data and algorithms, platform governance (including access rules for complementors), and geopolitical/regulatory pressure [2]. This approach acknowledges that competitive dynamics in the Big Tech era are significantly shaped not only by market but also by non-market factors, encompassing antitrust regulation (such as the EU's DMA/DSA acts) and technological rivalry between jurisdictions (e.g., US sanctions policy against Huawei).

Conceptually, Teece's dynamic capabilities framework is regarded as highly promising for analyzing the competitiveness of digital platforms. Unlike Porter's static model, which captures industry structure at a given moment, dynamic capabilities focus on how firms can create, extend, and transform their resource bases amid rapid technological change. Teece delineates three key micro-foundations of dynamic capabilities: the capacity to sense and identify opportunities, the ability to seize new possibilities, and the capacity for continuous transformation [16]. In this vein, platform ecosystems face three tasks: promptly and accurately recognizing technological trends (e.g., the adoption of the Internet of Things, sensor usage, the transition to AI), timely restructuring the business model (e.g., shifting from device sales to service provision and subscriptions), and reconfiguring the ecosystem of interacting players. Huawei's development of HarmonyOS in response to losing access to Android serves as a compelling illustration of exercising transforming capabilities in the face of an exogenous shock.

Thus, the contemporary academic discourse is pivoting from whether Porter's model is applicable to how it must be modified and which concepts – dynamic capabilities [16], multi-sided market theory [15], or network effect analysis [10] – should complement it to adequately capture competitive processes within digital ecosystems. There is now a general recognition that traditional industry analysis is giving way to ecosystemic, dynamic, and interdisciplinary approaches.

The present study is positioned squarely within this logic. In contrast to works that focus on a single theoretical lens, we propose an integrated model for assessing Big Tech's international competitiveness, merging conventional financial and market metrics with qualitative characteristics inherent to digital platforms: data network effects, the lock-in effect of closed ecosystems, dynamic capabilities for reconfiguring business models in response to technological waves, and the consideration of external regulatory and geopolitical shocks.

The purpose of this research is to identify the internal factors underpinning the international competitiveness of Big Tech corporations and to assess their resilience to external shocks (sanctions, regulatory constraints, geo-economic fragmentation) through an analysis of financial, market, innovation, and non-financial indicators over the period from 2010 to 2025. The object of the study comprises the largest multinational corporations in the Big Tech sector, including Apple, Samsung, and Huawei, alongside other digital platforms and technology firms that define the global competitive environment in the development of smartphones, semiconductors, operating systems, cloud services, and communications infrastructure.

Main Part

An examination of definitions in contemporary economic literature reveals that the concept of "competitiveness" is not universal and must be strictly defined according to the level of aggregation. A typical methodological error is transferring the logic of the micro-level, where competition ends with the bankruptcy of a firm, to the macro-level, where the state does not exit the market by similar rules and where welfare is determined by long-term productivity and the quality of institutions [11]. Following this logic, competition as a rivalry for market share is based on rational resource use and innovation [18], while the competitiveness of a firm itself, according to Porter's classic definition, lies in its capacity to sustain advantages through unique value and proper positioning [13].

Competitive advantages are further subdivided into lower-order ones, which are easily imitable and dependent on external circumstances, and higher-order ones, which are internally cultivated and more durable [13]. The international competitiveness of corporations represents a specific case, entailing the capacity for cross-border operations and benefiting from differences across locations [6]. In studying Big Tech competitiveness, it is essential to distinguish between the macro-level (national productivity and institutions), the meso-level (the sector's position in global value chains), and the micro-level, where the results and strategic potential of individual firms are assessed [7].

At the micro-level, it is appropriate to employ a system of complementary indicators, including financial metrics – revenue, net profit, and return on assets (ROA) (CFA Institute) – as well as market metrics – market share and the scale of international presence[2]. Of paramount importance is the innovation component, measured through R&D intensity and patent activity[3], along with intangible assets such as brand, customer base, and digital ecosystems that create barriers to entry for competitors (IAS 38). Thus, the proposed approach to assessment through a combination of financial, market, innovation, and non-financial indicators enables the consideration of both current operational results and long-term drivers of sustainability for global technology corporations.

Between 2010 and 2025, the scale of investment in research and development became a critical barrier to entry into the industry. In 2024, the five largest US technology companies allocated approximately USD 227 billion to R&D, surpassing the civilian research budgets of most developed nations [1]. A specific feature of competition was the willingness of corporations to fund strategically important yet loss-making projects for years, including developments in artificial intelligence, quantum computing, and autonomous systems. A special place in the competitive struggle was occupied by control over strategic infrastructure – data centers, submarine cable systems, and specialized chips for training neural networks. Huawei, relying on state support and substantial subsidies, managed to take a dominant position in the 4G network market in Africa, controlling up to 70% of the continent's network infrastructure [1]. Control over physical infrastructure is gradually transforming into geopolitical influence: countries that have integrated their digital economies into Big Tech platforms find themselves obliged to follow technical standards set by these corporations.

The competitiveness of the sector is closely linked to dynamic capabilities – the ability to rapidly reallocate resources and reconfigure business models under the influence of new technological waves [3; 8]. The strategic deployment of artificial intelligence enables operational efficiency fundamentally unattainable for traditional firms, making the speed of adaptation an independent competitive advantage. A significant dimension of the competitive struggle remains the role of state industrial strategy, particularly in the context of US-China rivalry. Chinese corporations' benefit from subsidies and the closed nature of the domestic market, allowing them to ramp up R&D investments: in 2023, Huawei's R&D expenditure exceeded the combined spending of European competitors Nokia and Ericsson [1]. By the mid-2020s, the sector faced systemic challenges, including antitrust investigations, data protection legislation, issues of algorithmic bias and disinformation, and the environmental agenda related to the high energy consumption of data centers and water usage for cooling AI systems [1; 12].

Let us consider the development of the smartphone market since 2009 in its dynamics (Fig. 1).

Based on the presented data on worldwide smartphone shipments from the fourth quarter of 2009 to the first quarter of 2026, several well-founded conclusions can be drawn. The global smartphone market expanded rapidly from 53.9 million units in Q4 2009 to a peak of 430.7 million in Q4 2016, driven by the proliferation of smartphones and the replacement of feature phones. After 2016, however, growth slowed and gave way to saturation. The COVID-19 shock caused shipments to drop to 275-277 million units in early 2020. The subsequent recovery was incomplete: the 2016 peak was never regained, and by 2022-2023 the market had entered stagnation, with figures declining from 314.5 million in Q1 2022 to 268.5 million in Q1 2023. A modest rebound in late 2023 proved temporary. In 2024-2025, shipments stabilized within a 292-336 million range, yet remained well below the 2016 high. By Q1 2026, another decline followed (289.7 million).

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[2] *OECD/Eurostat. (2018). Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation. Paris: OECD Publishing; Luxembourg: Eurostat. Source: https://www.oecd.org/content/dam/oecd/en/publications/reports/2018/10/oslo-manual-2018_g1g9373b/9789264304604-en.pdf (accessed on 02.03.2026)*

[3] *OECD. (2015). Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development. Paris: OECD Publishing. Source: https://www.oecd.org/content/dam/oecd/en/publications/reports/2015/10/frascati-manual-2015_g1g57dcb/9789264239012-en.pdf (accessed on 02.03.2026)*

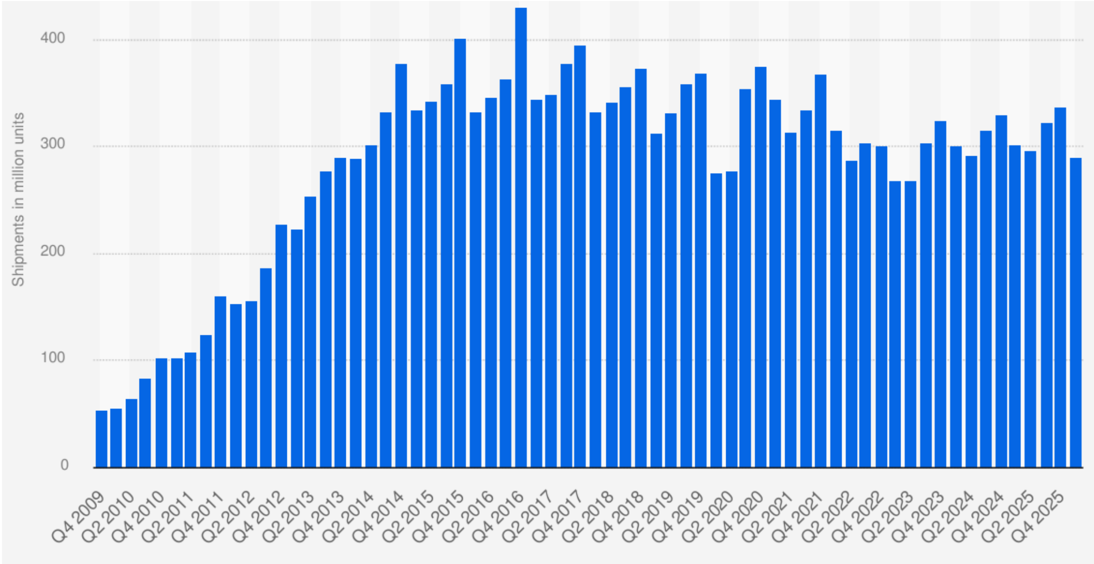

Figure 1. Smartphone shipments worldwide from 4th quarter 2009 to 1st quarter 2026 (in million units)
Source: based on IDC[4]

Over the entire 2009-2026 period, the market thus passed through three distinct phases: rapid growth in the early 2010s, saturation and peak volumes in the mid-2010s, and cyclical instability with pronounced external shocks from the late 2010s onwards. A key finding is that the smartphone market, being highly saturated in developed economies, no longer exhibits its former growth rates, with its dynamics now largely determined by macroeconomic conditions, device replacement cycles, and geopolitical factors affecting global supply chains.

The smartphone market features multiple suppliers whose market shares shift over the analyzed period under the influence of a combination of factors (Fig. 2).

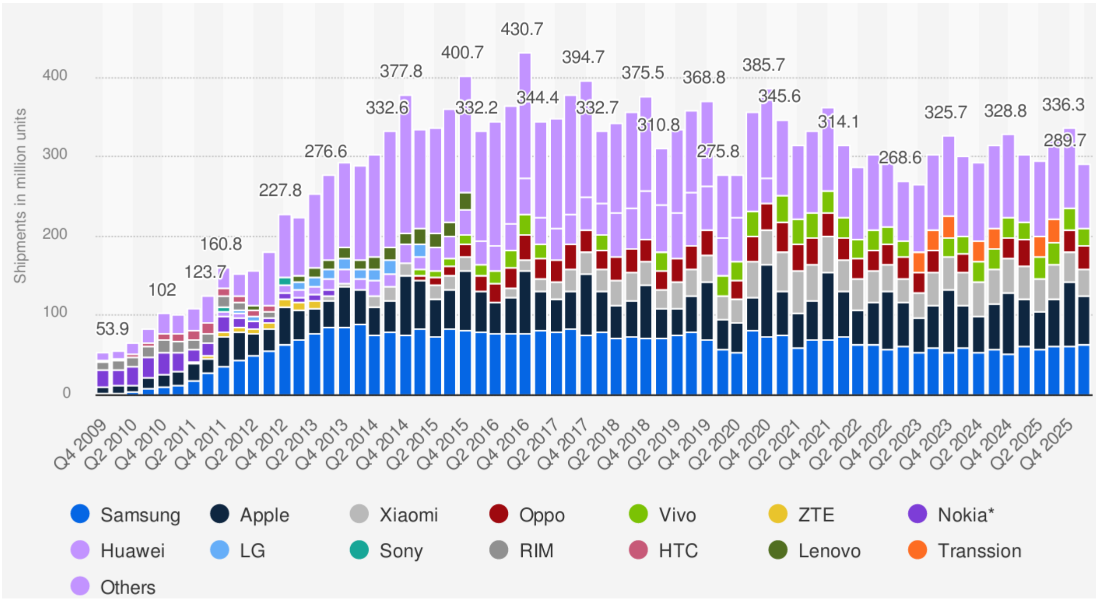

Figure 2. Smartphone shipments worldwide from 1st quarter 2009 to 1st quarter 2026, by vendor (in million units)
Source: based on IDC[5]

Overall, the market structure underwent radical changes over the sixteen years under review. At the

[4] *IDC. (2026). Smartphone shipments worldwide from 4th quarter 2009 to 1st quarter 2026 (in million units). Source: https://www.statista.com/statistics/728644/quarterly-global-smartphone-shipments-by-quarter/ (accessed on 02.03.2026)*
[5] *IDC. (2026). Smartphone shipments worldwide from 1st quarter 2009 to 1st quarter 2026, by vendor (in million units). Source: https://www.statista.com/statistics/271490/quarterly-global-smartphone-shipments-by-vendor/ (accessed on 02.03.2026)*

beginning of the period, Nokia and RIM (BlackBerry) dominated, but they had completely lost their positions by the mid-2010s. They were supplanted by Chinese manufacturers Xiaomi, Oppo, Vivo, and Transsion, which by 2025-2026 consistently rank among the leaders, although they do not achieve the volumes of Samsung and Apple. The "Others" category, which constituted a significant market share at the beginning of the period (up to 174 million units in Q4 2014), gradually shrank as the market consolidated around a few major vendors; however, it had risen again to 80.1 million units by Q1 2026, possibly indicating market fragmentation due to the emergence of new brands, especially from China and India.

Throughout almost the entire period under consideration, Samsung was the unequivocal leader in shipment volume, demonstrating steady growth from 1.8 million units in Q4 2009 to peak values around 85-88 million units in 2013-2014. Samsung's shipments gradually declined after 2015, fluctuating between 53 and 83 million units, yet by Q1 2026 it still led the market with 62.8 million units, albeit without its earlier growth momentum.

Apple followed a different pattern, with pronounced seasonality tied to annual iPhone launches and year-end holiday demand. In Q4 2025, Apple posted a record 81.3 million units. Unlike other vendors, Apple consistently raised its quarterly peaks over time – from 8.7 million units in 2009 to over 80 million in 2025 – reinforcing its premium-segment strength.

Huawei showed the most dramatic trajectory. The company grew from 5.7 million units in Q4 2011 to an all-time high of 66.6 million in Q4 2019, becoming a major global player and a direct rival to Samsung and Apple. However, after 2019, coinciding with the imposition of US sanctions, Huawei's shipments plummeted: in Q4 2020, they amounted to 32.2 million units, and from 2021 onward, the company disappears entirely from the IDC statistics for leading vendors. This disappearance is a direct consequence of losing access to key components, including mobile processors and Google services, which forced Huawei to refocus on the domestic Chinese market and develop its own HarmonyOS ecosystem.

In summary, the key observation is a radical transformation of the competitive landscape: Samsung retained volume leadership but lost its growth momentum; Apple consolidated its position in the premium segment with stable seasonality and record peaks; Huawei made a rapid ascent to leadership before, under external constraints, practically vanishing from global statistics, vividly illustrating the vulnerability of even the largest tech corporations to geopolitical and regulatory shocks.

As noted, Apple is one of the leading smartphone manufacturers, and analyzing its production dynamics suggests significant influence from various factors (Fig. 3).

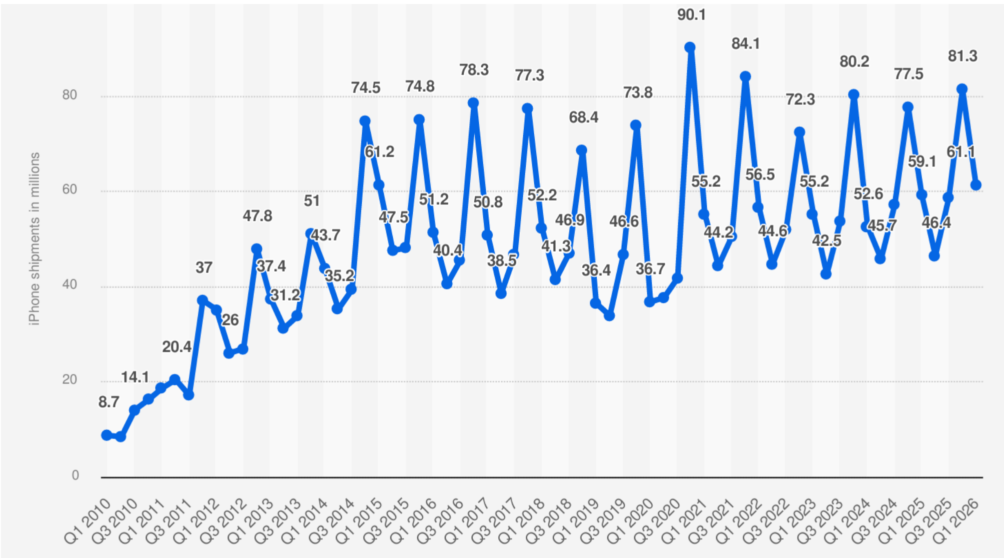

Figure 3. Apple shipments of smartphones worldwide from 1st quarter 2010 to 1st quarter 2026 (in million units)

Source: based on IDC[6]

[6] *IDC. (2026). Apple shipments of smartphones worldwide from 1st quarter 2010 to 1st quarter 2026 (in million units). Source: https://*

Apple demonstrates a resilient business model characterized by predictable seasonality, long-term growth in peak shipments, and a capacity to recover swiftly from external shocks. A key strategic advantage for Apple is not the pursuit of volume leadership in any given quarter, but the ability to generate maximum sales during the industry's most critical fourth quarter, ensuring high-capacity utilization and stable cash flow. At the same time, the Q1 2026 figure of 61.1 million units aligns with the long-term trend, confirming the absence of abrupt negative changes in consumer demand for its products.

The pronounced and robust seasonality of Apple's shipments is striking. Apple's Q4 peaks are driven by annual iPhone launches and holiday sales. In 2011, Q4 shipments reached 37 million units, up from 18.6 million in Q1; by 2015 the gap widened from 61.2 million to 74.8 million; and in 2020 Q4 hit a record 90.1 million, nearly 2.5 times the 37 million posted in Q4 2011. Although Q4 figures dipped to 72.3 million in 2022 and 80.2 million in 2023, they recovered to 81.3 million in Q4 2025, underscoring sustained premium demand despite overall market saturation.

Even off-peak quarters show growth: Q2 shipments rose from 26 million in 2012 to 46.4 million in 2025, reflecting a broadening customer base and some flattening of seasonal swings in absolute terms. An exception was Q2 2019 with 33.8 million units, which may be attributed to the anticipation of new models and upgrade delays.

The COVID-19 pandemic, contrary to initial pessimistic forecasts, did not lead to a long-term decline in Apple's shipments. After a dip in the first half of 2020 (36.7 million and 37.6 million in Q2), the company posted a historic high of 90.1 million units in Q4 2020. This phenomenon can be explained by pent-up demand, the shift to remote work and learning that spurred device upgrades, and the successful launch of the 5G-capable iPhone 12 lineup.

Regarding the consolidation of Apple's global position, its share of worldwide smartphone shipments stood at approximately 15.7% in Q1 2010 (8.7 million out of 55.4 million total shipments), whereas by Q1 2026, with shipments of 61.1 million out of a global total of 289.7 million, its share had risen to roughly 21%. Thus, Apple has managed not only to maintain but also to strengthen its market position amid intense competition from Samsung and Chinese manufacturers.

A sale dynamic unusual for a rapidly developing market is observed for Huawei (Fig. 4).

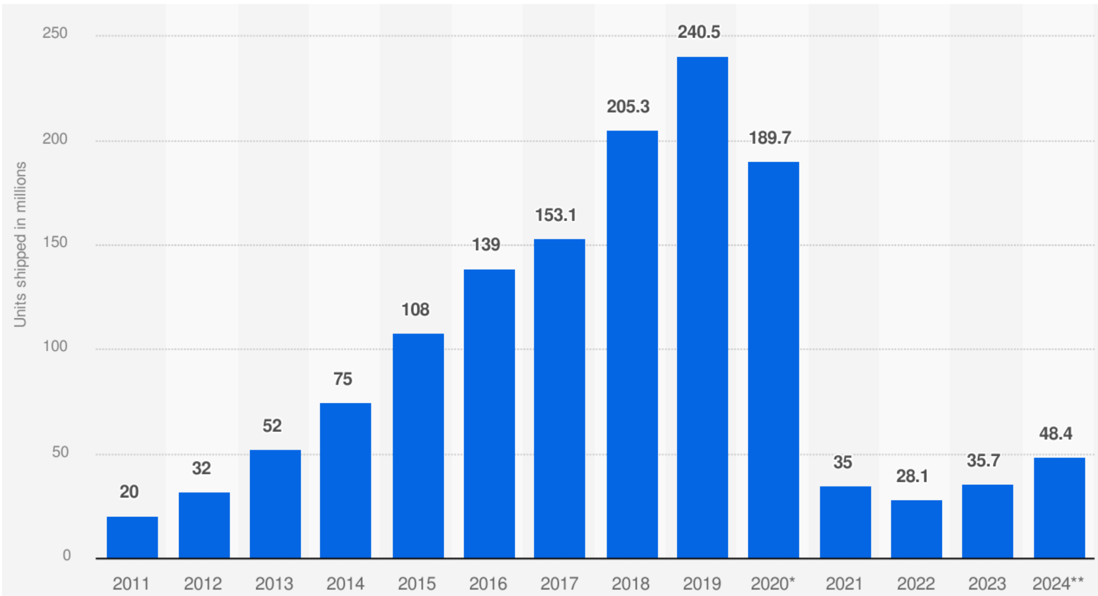

Figure 4. Huawei smartphone shipments worldwide from 2011 to 2024 (in millions of units)
Source: based on Omdia[7]

Huawei demonstrated consistent growth, from 20 million units in 2011 to its historical peak of 240.5

www.statista.com/statistics/299153/apple-smartphone-shipments-worldwide/ (accessed on 02.03.2026)

[7] *Omdia. (2025). Huawei smartphone shipments worldwide from 2011 to 2024 (in millions of units). Source: https://www.statista.com/statistics/1636119/number-of-smartphones-distributed-worldwide-by-huawei/ (accessed on 02.03.2026)*

million units in 2019. However, from 2020 onwards, a sharp drop in shipments occurred – down to 35 million in 2021 – linked to sanctions and the sale of the Honor brand. In subsequent years, shipments stabilized at a low level (28-48 million units). In 2024, a 35.8% growth to 48.4 million units was noted, yet this figure remains five times lower than the 2018-2019 peaks.

We contend that the decline in shipment volumes from 2020 can be attributed to several factors, principally the US-imposed sanctions. Starting in May 2019, the company was placed on the "Entity List", prohibiting US manufacturers from supplying Huawei with components, software, and technologies without special licenses [14]. A key consequence was the loss of access to Android and Google Mobile Services, rendering new Huawei smartphone models devoid of Google Play, YouTube, Gmail, and other services, thus making them less appealing to users outside China.

From 2020, sanctions were tightened: the ban extended to the production of its own Kirin processors, as TSMC and other foundries could not use US equipment to manufacture chips for Huawei. In November 2020, the company sold its sub-brand Honor to shield it from restrictions; prior to 2020, statistics included Honor shipments, and after – did not, which also accentuated the apparent decline. As a result, Huawei was compelled to retreat from the global market almost entirely, concentrating on China, and lost ground in Europe, India, and other regions. The development of its own HarmonyOS operating system could not swiftly compensate for the absence of Google's ecosystem overseas. Even the recovery to 48.4 million units in 2024 is largely attributable to the domestic Chinese market; without access to cutting-edge technologies and global distribution, reaching previous volumes exceeding 200 million units is no longer feasible for Huawei.

Samsung is one of the leaders among global smartphone suppliers (Fig. 5).

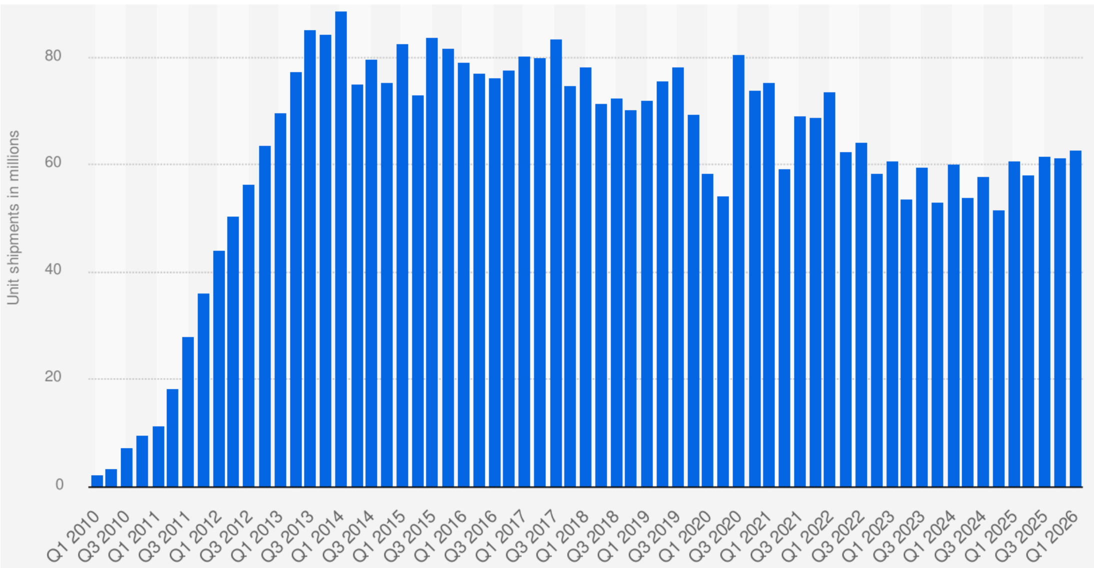

Figure 5. Smartphone unit shipments of Samsung worldwide from 1st quarter 2010 to 1st quarter 2026 (in million units)

Source: based on IDC[8]

Samsung exhibited stable growth in smartphone shipments from 2010, peaking in Q1 2014 (88.5 million units). Thereafter, some volatility in the indicator was observed, but values generally remained high. From 2020, shipment volumes declined and stabilized in the 50-75 million units per quarter range. In Q1 2026, shipments reached 62.8 million units, indicating a recovery from lower values in 2023-2024. Despite fluctuations, the company maintains a strong market position globally.

The empirical analysis is based on an annual panel dataset covering three major Big Tech companies – Apple, Samsung and Huawei – over the period 2010-2025; for Huawei, the series ends in 2024 due to data availability constraints. Financial indicators are drawn from the companies' official reports and consolidated statements, while information on global smartphone market dynamics is taken from industry statistics. This

[8] *IDC. (2026). Smartphone unit shipments of Samsung worldwide from 1st quarter 2010 to 1st quarter 2026 (in million units). Source: https://www.statista.com/statistics/299144/samsung-smartphone-shipments-worldwide/ (accessed on 02.03.2026)*

combination of firm-level and market-level data makes it possible to assess how innovation activity, financial efficiency and selected external factors affect profitability in the core smartphone segment.

Gross profit margin, calculated as gross profit divided by revenue, is used as the dependent variable. This indicator is chosen because it captures the ability of a firm to transform strategic and innovation-related decisions into sustainable profitability in its main line of business. The explanatory variables include indicators of innovation activity, overall financial performance and the external business environment. Innovation activity is proxied by R&D intensity, measured as R&D expenditure as a share of revenue, and by the logarithm of absolute R&D spending. Financial performance is represented by net profit margin and return on assets (ROA). In addition, the model includes several controls reflecting institutional and market conditions, namely sanctions dummy for Huawei after 2019, the growth rate of the global smartphone market and the share of foreign revenue in total revenue.

To control for unobserved firm-specific characteristics that remain relatively stable over time, such as business model, brand strength and the home-country institutional setting, the study employs a fixed-effects panel model with standard errors clustered at the firm level. The initial specification includes a broader set of regressors, after which a more parsimonious version is selected as the baseline following multicollinearity diagnostics. Therefore, the regression table reports both the extended and the compact specifications, whereas the discussion below focuses primarily on the baseline model (Table 1).

Table 1 – Fixed-effects Estimates for Gross Profit Margin, 2010-2025

	(1) Extended model		(2) Baseline model	
Variable	Coef.	Std. err.	Coef.	Std. err.
R&D intensity	0.895***	(0.083)	0.685***	(0.059)
ln R&D spending	-3.616***	(1.192)	-1.269***	(0.329)
Net profit margin	0.242*	(0.129)	0.517***	(0.038)
Operating margin	–	–	–	–
Foreign revenue share	0.058	(0.076)	–	–
Sanctions dummy	1.48	(2.104)	–	–
Market growth	-0.065	(0.040)	–	–
Revenue per employee	–	–	–	–
Revenue growth	0.00	(0.016)	–	–
ROA	0.486***	(0.090)	0.319***	(0.035)
Net income per employee	–	–	–	–
Observations	47			
Within R2	0.78		0.73	
F-statistic	15.98***			

*Notes: *** p < 0.01, ** p < 0.05, * p < 0.10.*
Source: Authors

The estimation results indicate that innovation activity is one of the main determinants of profitability in the Big Tech sector. In the baseline specification, R&D intensity has a positive and statistically significant effect on gross profit margin. This result implies that companies allocating a larger share of revenue to research and development are more likely to sustain higher margins in the smartphone business. In economic terms, the finding suggests that innovation is not only a technological necessity but also an important source of competitive advantage and financial resilience.

At the same time, the logarithm of absolute R&D expenditure enters the model with a negative and statistically significant coefficient. This indicates that an increase in the scale of R&D spending does not automatically improve profitability and may, in the short run, put additional pressure on margins if commercialization does not keep pace with investment. The result therefore points to the importance of the efficiency of innovation spending rather than its absolute size alone.

The analysis also shows that broader measures of financial efficiency matter for profitability outcomes. Net profit margin and ROA have positive and statistically significant coefficients in the baseline model, indicating that better cost control and more efficient use of assets are associated with higher gross profitability. This pattern appears particularly relevant for large technology firms, where the monetization of intangible assets, ecosystem services and product differentiation play a central role in maintaining margins.

The additional controls included in the extended specification do not alter the main pattern of results. The sanctions dummy has a negative sign, which is consistent with the additional constraints faced by Huawei after 2019, yet this effect does not overturn the broader relationship between innovation effort and profitability. Similarly, market growth and the share of foreign revenue appear less influential than the internal indicators of innovation and financial efficiency. This suggests that, in the case of Big Tech firms, sustainable profitability depends to a greater extent on internal capabilities than on short-term changes in external conditions.

A closer look at the firms under study helps to clarify these relationships. Apple appears to benefit most strongly from higher R&D intensity and stronger asset efficiency, which is consistent with its premium positioning and ecosystem-based business model. Samsung also demonstrates positive returns to innovation, although its performance seems more sensitive to market cycles because of its more diversified structure. Huawei, by contrast, operates under stronger institutional constraints and maintains a relatively high level of R&D effort, which makes the effective allocation of innovation resources especially important for its profitability dynamics.

Overall, the econometric analysis confirms that the most stable determinants of gross profit margin in the Big Tech sector are R&D intensity, net profitability and efficient use of assets. External and institutional factors also matter, but their role appears secondary compared with firm-level capabilities. The findings therefore support the argument that the long-term competitive advantages of major technology companies are shaped primarily by the quality of innovation management and by the efficiency with which strategic resources are transformed into financial outcomes.

Conclusion

The conducted research establishes that the international competitiveness of Big Tech corporations during 2010-2025 has been determined not so much by traditional factors (low costs, resource access) as by unique internal drivers, including data network effects, ecosystem lock-in, long-term mega-scale R&D investments, and control over pivotal digital infrastructure.

The empirical analysis, focusing on the global smartphone shipments of Apple, Samsung, and Huawei, has demonstrated that companies that have succeeded in building closed ecosystems (iOS, HarmonyOS) or maintaining technological independence (Samsung's vertical integration) show greater resilience to external shocks. At the same time, the Huawei case vividly illustrates that even an industry leader with peak shipments exceeding 240 million units can be significantly weakened by sanctions and the loss of access to global service ecosystems, leading to a fivefold reduction in shipment volumes by 2024. External shocks, including antitrust investigations, data protection legislation, and environmental requirements for data centers, are becoming new normal operating conditions for the sector.

Promising avenues for future research include the quantitative assessment of the contribution of each internal driver to the overall competitiveness of Big Tech, as well as a comparative analysis of the adaptive strategies of American, Chinese, and European technology corporations amidst intensifying geo-economic fragmentation.

CONFLICT OF INTEREST

One of the authors of the article is the editor-in-chief of the journal.

AUTHORS' CONTRIBUTION

Svetlana N. Rastvortseva – conceptualization, project administration, writing – original draft.
Yulia A. Tyushkevich – investigation, writing – review & editing.
Zlata S. Salushkina – formal analysis, writing – original draft.

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Business process digitalisation in improvement of industrial enterprise performance

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ORIGINAL ARTICLE

Abstract. The article examines the impact of digitalisation of key business processes of an industrial enterprise on production, financial efficiency, and the indicators determining its competitiveness. The purpose of the research is to develop an integrated approach to improve the activities of an industrial enterprise based on the digitalisation of business processes and assess its impact on regional and international competitiveness. The methodological framework includes systematic and process approaches, investment analysis methods (NPV, IRR, ROI, payback period), and a comparative analysis of indicators influencing on the introduction of digital solutions. The empirical basis is the data of OOO Novakhim, Ivanovo, Russia, specialising in the production of industrial chemicals. The introduction of an integrated ERP system, MES module, digital logistics, and management analytics provides a reduction in the production cycle, reduces losses and downtime, increases productivity, and improves working capital turnover with positive NPV values and an acceptable payback period for the project. The proposed approach to digitalisation and assessment of the effectiveness can be used by industrial enterprises to justify investments in digital transformation aimed at strengthening their regional and international competitiveness. It ensures the practical significance of the research.

Keywords: digitalisation; industrial enterprise; business processes; digital transformation; regional competitiveness; international competitiveness

JEL codes: O33, L60, M11, D24

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Introduction

The digital economy, globalisation, the competitiveness of an industrial enterprise is determined by the volume of production and product quality, the level of its digital maturity, adaptability to changes in the external environment, and the speed of innovation. The development of the Industry 4.0, cyber-physical systems, industrial Internet of Things, big data, and cloud services transformed traditional production and management models. Therefore, the digitalisation of business processes is becoming a strategic factor in the sustainable development of enterprises and strengthening their positions in regional and international markets [1; 2; 3].

According to Industry 4.0, issues of digitalisation and automation of production processes are becoming extremely relevant today. This stage of the industrial revolution is characterised by the integration of cyber-physical systems, cloud computing, and Internet of Things technologies. They enable real-time interaction between physical and computing components. These technologies help to optimise business processes. However, their implementation concerns cyber-attacks and unemployment [5; 6].

The development of Industry 4.0 forms the technological basis of digitalisation. The modern economic conditions (i.e. sanctions) increase the importance of these processes for Russian enterprises.

The global economic instability and uncertainty caused by unprecedented sanctions pressure provide new challenges and opportunities for the development of Russian enterprises technological potential. One of the key tasks is to achieve technological sovereignty. It implies the priority development of import-substituting industries and the active introduction of innovative developments to enhance the efficiency of enterprises [7].

The logical continuation of the development of Industry 4.0 is the transition to Industry 5.0. It is determined by deeper consideration of the human factor in production systems. Its main goal is to establish human-centred production models involving the interaction between humans and automated systems. Industry 5.0 focuses on the individualisation of production processes, environmental sustainability, and business social responsibility [14].

This study provides a retrospective analysis of Russia's achievements in the field of Industry 4.0 and assesses the trends for transition to Industry 5.0. There is an increase in internal costs for the development of the digital economy, the dynamics of technologies introduction, cloud services, and big data. The research concerns the factors contributing to the transition to Industry 5.0, including the flexible and custom production, the increasing pace of technological progress, environmental sustainability, and human capital.

Therefore, it is necessary to develop a digital infrastructure, staff training system, and integrate the advanced technologies. The application of Industry 5.0 principles could improve sustainable development, competitiveness, and efficiency of the Russian economy.

Therefore, the transition to Industry 5.0 is a multi-pronged process that requires an integrated approach and integration of government, business, and educational institutions.

The modern industrial enterprises operate in a turbulent external environment characterised by unstable demand, rising costs, increased competition, stricter requirements for quality and delivery time, international standards, etc. The traditional management approaches based on fragmented automation of individual functions do not provide the required level of efficiency and transparency. It ensures the transition to a comprehensive digital transformation involving the integration of production, logistics, financial, and management processes into a single information system [8].

Digitalisation of business processes involves the implementation of individual software solutions, process reengineering, the formation of end-to-end information flows, and the use of analytical tools to support management decisions. This transformation increases operational transparency, reduces time and resource costs, minimises production risks and increases the flexibility of the enterprise. Indeed, it is a key source of increasing regional competitiveness and expanding their presence in foreign markets for regional industrial enterprises facing limited investment resources and dependence on local conditions.

Moreover, the analysis of the impact of digitalisation of business processes on indicators directly related to competitiveness: the level of costs, the production cycle, labour productivity, financial stability, and consumer demands, etc. In the scientific literature, the issues of digital transformation are actively studied in the context of strategic management, innovative development, and productivity improvement. However, literature mainly focuses on the macroeconomic level or analyses individual technologies without a comprehensive assessment of their impact on the activities of a particular enterprise and its competitive position[1].

Digitalisation in the Russian Federation is particularly specific in terms of modern international politics and sanctions. To increase technological independence and modernise industrial processes, the Russian government actively supports software import substitution initiatives. Approved in 2017, the Digital Economy of the Russian Federation program is the basis for the implementation of measures aimed at developing digital infrastructure and establishing conditions for IT sector grow. As part of this program, the government supports domestic developers of various technologies, including production process management systems and automation solutions[2].

The government support for digital transformation includes both financial and non-financial instruments. For instance, starting in 2021, tax incentives and grants for the implementation of digitalisation projects have been introduced for companies implementing innovative solutions. In 2022, investments in the development

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[2] *European Commission. (2022). A report on the digital economy and society. https://doi.org/10.2759/51177*

of digital infrastructure in Russia amounted to approximately RUB 3 trln; it is 8% more than in 2021[3]. These funds finance AI, cloud computing, and big data analytics to improve the efficiency of production processes.

However, there are a lot of challenges. The shortage of qualified IT personnel, limited access to advanced foreign developments due to the sanctions imposed are significant obstacles to digital transformation. According to the Center for Strategic Research, training the in IT is one of the key tasks for a successful transition to new technological standards.

Therefore, digitalisation in Russia is a multidimensional process that requires an integrated approach and active cooperation between governments, businesses, and educational institutions. Import substitution strategies and government support for the formation of the digital economy are crucial for ensuring the long-term competitiveness of Russian enterprises worldwide. It involves R&D investments attraction, addressing issues of ecosystem interaction between various participants of the process.

In the scientific literature, the issues of industrial digitalisation and business process transformation are considered within the framework of various research areas: the theory of digital economy, the concepts of Industry 4.0 and 5.0, strategic management, innovative development, and increasing the competitiveness of enterprises. A significant contribution to the formation of digital transformation theoretical foundations was made by Vial, P. Verhoef, A. Bharadwaj, E. Brynjolfsson, and E. McAfee. They consider digitalisation as a complex process of changing business models, organisational structure, and management decision-making mechanisms [1; 2; 3; 11].

The research on Industry 4.0 focuses on the integration of cyber-physical systems, the industrial Internet of Things, cloud technologies, and big data analytics into production processes. According to the works of H. Kagermann, A. Frank, S. Xu, and V. Kritzinger, the introduction of digital technologies contributes to productivity growth, reduction of production losses, and increased flexibility of enterprises [5; 6; 7; 10]. The development of Industry 5.0, presented in the studies of the European Commission and K. Shwab, focused on the formation of human-centered and sustainable production systems combining automation and the development of human capital [8; 14].

A special area of research is related to the analysis of the impact of digitalisation on the competitiveness and sustainability of enterprises. For example, M. Porter considers digital technologies as a factor of long-term competitive advantages formation [13]. Indeed, D. Teece studies digital transformation with the development of the dynamic abilities of the organisation [4]. In the works of D. Ivanov and A. Dolgui the role of digital supply chains in ensuring the sustainability of industrial production and adaptation to external shocks is being investigated [9].

Moreover, the special attention is paid to the issues of economic efficiency of digital transformation. The researches of A. Damodaran reveal approaches to assessment the investment attractiveness of digital projects and analysing their financial performance [15]. The reports of the OECD, the European Commission, and McKinsey examine global trends in industrial digitalisation, the impact of digital technologies on productivity, investment activity, and the development of national economies[4,5].

In the Russian scientific literature, the issues of digital transformation of industry are considered in the works of A.V. Babkin et al. They analyse the features of digitalisation of enterprises in terms of of import substitution, sanctions restrictions, and Russian technological sovereignty [16].

However, the issue of digitalisation impact comprehensive assessment on the competitiveness of a particular industrial enterprise remains understudied[6].

The relevance of this research consists in the development of the applied approach to the digitalisation of business processes of an industrial enterprise and a comprehensive assessment of its impact on indicators of regional and international competitiveness. The purpose of the research is to develop an integrated

[3] *Organisation for Economic Co-operation and Development. (2022). Digitalisation of industry and its impact on the economy. OECD Publishing. https://doi.org/10.1787/9789264305576*

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approach to improving the activities of an industrial enterprise through the digitalisation of key business processes, followed by an assessment of the impact of the changes on its competitiveness at the regional and international levels.

The research tasks are as follows: to analyse the theoretical foundations of the digital transformation of industry, identify priority areas of digitalisation at the enterprise level, develop and test a model for assessing the economic effectiveness of digitalisation in terms of competitiveness, assess production, financial, and organisational effects of digital transformation based on empirical data from OOO Novakhim, Ivanovo, Russia.

Methods

The methodological basis of the research was developed in terms of the interdisciplinary nature of digitalisation of industrial enterprise business processes. It based on a combination of general scientific and specialised analytical methods. Their choice was determined by comprehensive assessment of the organisational and economic consequences of digital transformation.

As a theoretical basis, a systematic approach was used. It allows use to consider an industrial enterprise as an open socio-economic system functioning in interaction with the external environment. This approach analyses the interrelationships between production, logistics, financial, and management processes through the introduction of digital technologies.

The approach was used to identify, structure, and optimise the company's key business processes. The company's activities were decomposed into main (production, procurement, sales), auxiliary (logistics, personnel management, IT support), and management processes. Process mapping and value stream mapping were used for the analysis. It revealed bottlenecks, duplicate functions, and redundant operations.

Methods of economic and mathematical modelling and investment analysis were used to substantiate the economic feasibility of digitalisation.

The effectiveness of digital solutions was assessed in terms of the following indicators:
– Net present value (NPV);
– Internal rate of return (IRR);
– Payback period;
– Return on investment (ROI).

The NPV was calculated by the formula:

$$\text{NPV} = \sum_{t=1}^{t} \frac{CF_t}{(1+r)^t} - I_0 \tag{1}$$

where CF t is the projected cash flow in the period t;
r is the discount rate,
I_0 is the initial investment cost.

The return on investment was determined as follows:

$$\text{ROI} = \frac{\Delta P}{I_0} \times 100 \tag{2}$$

where ΔP is the increase in profits as a result of the introduction of digital solutions;
I_0 is the amount of investment in digitalisation.

The indicators of labour productivity, return on assets, working capital turnover ratio, and production cycle duration were used to assess production efficiency. To quantify the changes, we made a comparative analysis of the introduction of digital tools effect [15].

To assess the long-term financial viability of a business process transformation, NPV, ROI, and the internal rate of return (IRR) were used. Indeed, IRR was defined as the discount rate at which the total present value of cash flows is zero.

$$\sum_{t=1}^{n} \frac{CF_t}{(1+IRR)^t} - I_0 = 0 \tag{3}$$

A discounted payback period (DPP) was also calculated. It allows the time value of money to be taken into account when making a return on investment. The discount rate of 13% adopted in the researchs based on a cumulative calculation method including a risk-free government bond yield rate, an inflationary premium, and a specific risk of introducing innovative IT solutions in the industrial sector.

The empirical basis of the research was the data of OOO Novakhim, Ivanovo, Russia: financial statements, management accounting data, production statistics, and internal regulations of business processes. Additionally, interviews with experts and managers were used to clarify the organisational aspects of digital transformation.

For data processing, methods of horizontal and vertical analysis of financial statements, correlation analysis of the relationship between the level of digitalisation and performance indicators, scenario analysis were used. It provides an assessment of an investment project sensitivity to changes in key parameters (discount rate, investment volume, profit growth rate, etc.).

The reliability of the results obtained is ensured by using the company's official financial statements, proven investment analysis methods, and comparing calculated indicators with actual data from similar digitalisation projects in the industrial sector.

Therefore, the selected set of methods ensures a comprehensive assessment of business processes digitalisation impact on the efficiency of an industrial enterprise and development the practical recommendations.

Results

We consider the effects of business processes digitalisation theoretically, economically, and empirically. On the one hand, digital transformation is a systemic factor to change the logic of an enterprise's work, affecting innovation activity, the structure of competition, demand generation mechanisms, and investment attractiveness. On the other hand, these changes directly correlate with the dynamics of the company's production and financial indicators [10].

In this regard, the analysis of OOO Novakhim, Ivanovo, Russia results is based on a combination of the theoretical provisions of modern economics on digital transformation and empirical data reflecting the consequences of the introduction of digital solutions in a real production system. This approach allows us to capture the quantitative effects achieved, explain them in terms of the perspective of changes in the internal mechanisms of the enterprise's functioning and its interaction with the external environment.

In the context of the analysis of an enterprise's innovation activity, digitalisation of key business processes is a mechanism for formation a stable internal environment for generating and implementing innovations. The introduction of integrated information systems, such as ERP and MES, ensures the accumulation and structuring of significant amounts of production and management data. It establishes the basis for making informed management decisions and selecting priority areas for technological development [9].

Moreover, digital transformation is a continuous improvement process based on data analysis and feedback. It allows the company to shorten the time for the implementation of new solutions, reduce the level of uncertainty during their implementation, etc. As a result, digitalisation accelerates the commercialisation of innovations and increase the efficiency of investments in research activities.

The results of an empirical study demonstrate the following: digital transformation accelerates the commercialisation of innovations, increases the share of R&D costs in total investments, and promotes faster market launch of new digital services and improved production techniques. Totally, these enhance enterprise flexibility.

Moreover, the integrated digital platform provides increased transparency and reliability of management reporting data. It reduces the risk of information distortion and promotes more predictable market behaviour. In a competitive environment, the requirements for transparency of prices and delivery times, digitalisation is a powerful factor of pressure on competitiveness both within the region and at the level of international supply chains. For instance, cost reduction, acceleration of working capital turnover, and reduction of supply cycle time form the flexible competitive conditions, forcing competitors to reconsider their pricing and management strategies, inventory management, and time of response to changes in demand. Therefore, digital transformation is a system tool for increasing transparency and competitive strength of an enterprise in a dynamically developing market. It is extremely relevant for enterprises operating in industry segments with a high degree of technological involvement and integration of production processes [4].

The shift to marketing, demand analysis, and consumer behaviour shows that digitalisation reduces transaction costs, and enriches a set of tools for more accurate customer base analysis, market segmentation, and demand forecasting. The development of management analytics panels and digital channels for customer interaction provides real-time data acquisition on consumer preferences, demand dynamics, and sales channel effectiveness. It ensures adaptive channel strategies, adjusts the assortment, supply conditions, and service support depending on changes in consumer preferences. Moreover, digital supply chain management tools contribute to lower inventory and shorter lead times. It directly affects customer satisfaction and loyalty. Therefore, OOO Novakhim, Ivanovo, Russia can respond more quickly to fluctuations in demand in the industrial chemicals market, improve the accuracy of demand forecasting, and adapt production planning to consumer requirements. In the long run it has a positive effect on the company's market share and reputation.

According to the results, digitalisation as an investment initiative demonstrates an acceptable risk profile and limited uncertainty in terms of the long-term sustainability of the project, capital market analysis, risk, profitability, and project selection. The calculated indicators of profit, internal rate of return, payback, and discounted payback period confirm the economic feasibility of the digital transformation project: a positive net present value within a five-year horizon, an internal rate of return higher than the accepted discount rate, and the payback of the project within a reasonable time. This combination of financial indicators makes digitalisation a long-term investment capable to generate stable cash flows and increase the cost of an enterprise's capital. However, sensitivity analysis shows the project viability at a significant decrease in the projected economic effect. Indeed, the project is resistant to external fluctuations in market conditions and changing financing conditions. According to the results, digitalisation of business processes is a strategic direction to improve financial stability, reduce operational risks, and form the long-term competitive advantages [13].

Hence, implemented digital solutions strengthen the company's innovation base through structured data use and management decision support, improve its competitive position on a regional and international scale by reducing costs, speed up production and supply cycles and increasing business flexibility, and enable a more accurate analysis of demand and consumer behaviour. It optimises sales channels and customer satisfaction, attracts investors and shareholders. As a result, digitalisation is a key factor in the formation of a sustainable competitive advantage integrated into the company's development strategy and investment policy at the regional and global levels.

In our further research, we plan to consider expanding the methodology for assessing the economic effectiveness of digitalisation, including industry models of digital maturity, comparing effects in different regions, and analyse the long-term impact of digital transformation on export potential and integration into global value chains. We will summarise empirical data on various industrial sectors and expand the applicability of the methodology for assessing the economic effectiveness of digitalisation. Practically, business digitalisation is a systemic factor in strengthening regional and international competitiveness. It costs reduction and shortening the production cycle, decreases price and time competitiveness in the regional market. Indeed, product growth and management transparency form conditions for participation in international supply chains, contractual obligations, and increased customer and partners loyalty. The prospects for further research include the development of industry models of digital maturity, a comparative analysis of digitalisation effects in different regions, and an assessment of the long-term impact of digital transformation on export potential and the degree of integration of enterprises into global value chains. It will provide the implementation of effective management strategies and methods of financing digital projects adapted to the specifics of the industry and regional conditions [11; 12].

The theoretical effects of digitalisation resulted in the implementation of digital solutions in a specific industrial enterprise. To assess the applied aspect of digital transformation, empirical research was conducted on OOO Novakhim, Ivanovo, Russia to quantify the impact of digitalisation on key performance and competitiveness indicators.

The company operates in a highly competitive domestic market and depends on fluctuations in raw material prices. It requires increased operational efficiency and lower costs. OOO Novakhim, Ivanovo, Russia is a limited liability company engaged in the production of industrial chemicals and chemical components for enterprises in the petrochemical, paint, and construction industries. The main activities of the company are the production of chemical reagents, the production of specialised technological mixtures, supply of chemical products to industrial consumers in regional and interregional markets.

The company involved into a high competition from large domestic chemical manufacturers and regional suppliers focused on the B2B segment. The competitive environment is highly depended on fluctuations in commodity prices, increasing demands on product quality, and delivery deadlines. Therefore, production efficiency, order processing speed, stability of logistics chains, and digitalisation of management processes are key factors of the company's competitiveness.

The structure of the company includes production, logistics, supply, commercial, financial, and IT departments. The number of employees in the analysed period was about 240 people; more than 60% are directly involved in the production process.

1. Analysis of the current state of business processes

As part of the process analysis, the company's activities were divided into primary and secondary processes. The key problem areas identified at the diagnostic stage included the following:

– fragmentary automation of individual functions without integration into a single management system;
– long production cycles (average 28 calendar days);
– excess stocks of raw materials and finished products;
– low transparency of production indicators in real time;
– a significant proportion of manual operations in the preparation of management reports.

The turnover ratio of working capital was 3.1 turnover per year; the coefficient of production losses was 4.8% of the output; the equipment downtime reached 9% of the calendar time.

2. Development and implementation of digital solutions

Based on the analysis, a comprehensive digitalisation program was proposed. It includes the following:

– implementation of an integrated ERP system for combining financial, production, and warehouse accounting;
– implementation of the MES module for operational management of production and monitoring of machinery;
– automation of warehouse logistics through a barcode system and digital inventory accounting;
– design a management analytics dashboard to monitor key performance indicators (KPIs) in real time.

The total investment in digitalisation is RUB 32 mln, including software costs, server infrastructure upgrades, staff training, and consulting support.

3. Assessment of economic efficiency

The investment efficiency calculations include a 5-year planned horizon at a discount rate of 13%; it corresponds to the weighted average cost of the company's capital.

The introduction of digital solutions shows the following quantitative indicators:

– reduction of production cycle time from 28 to 23 days (-17.9%);
– reduction of production losses from 4.8% to 3.2%;
– reduced equipment downtime from 9% to 5.5%;
– increase of labour productivity by 14.6%;
– increase of the turnover ratio of working capital from 3.1 to 3.8 per year.

The total annual economic benefit (due to lower costs, reduced inventories, and increased production) amounted to RUB 9.4 mln.

According to the calculation results:

– the net present value (NPV) of the digitalisation project over 5 years is RUB 11.2 mln;
– internal rate of return (IRR) – 21%;
– payback period – 3.4 years;

– the return on investment (ROI) is 29.4%.

The positive NPV and IRR values exceed the discount rate. It demonstrates the economic feasibility of the digitalisation.

4. Organisational and managerial effects

Additionally, the qualitative changes were recorded. They are as follows:

– increasing the transparency of management reporting and reducing the time required to compile it from 5 to 1 business day;

– reducing the number of management errors related to data inconsistencies;

– increasing discipline in the performance of production tasks;

– development of digital competencies among the staff.

The integration of information flows provides the transition from a reactive management model to a proactive one based on data analysis and forecasting of production indicators.

5. Scenario analysis of project sustainability

According to the scenario analysis, 20% reduction in the projected annual economic effect, the project remains viable: the net present value (NPV) remains positive (RUB 3.6 mln), the payback period increases to 4.2 years. It demonstrates sufficient financial stability to make an investment decision.

These changes form a number of sustainable competitive advantages for OOO Novakhim, Ivanovo, Russia. They are as follows: reducing the cost of production and the production cycle, increasing price and time competitiveness in the regional market. The increased productivity and managerial transparency expand the potential for participation in international supply chains and meeting stricter contractual requirements for quality and delivery time.

Therefore, OOO Novakhim, Ivanovo, Russia integrated digitalisation significantly increases production and financial efficiency, reduces operational risks, and forms sustainable competitive advantages. The data obtained demonstrate the practical applicability of the developed assessment methodology and its adaptability to enterprises in other industries.

Conclusions

The implemented digital transformation of OOO Novakhim, Ivanovo, Russia provides a systematic strengthening of competitiveness at the regional and international levels due to the synergy of operational efficiency, innovative dynamics, and financial stability. According to the analysis of innovation and industry, digitalisation of key business processes is a set of technological measures. Moreover, it is a systemic process ensuring a stable innovation base of an enterprise, structured data, the ability to select and prioritise promising projects, accelerating commercialisation processes and increasing flexibility in responding to changes in demand and technological shifts. According to the research results, digital transformation contributes to an increase in the share of investments in R&D within the overall investment portfolio, accelerates the launch of new digital services, and improved production techniques to the market. Totally, it enhances the sustainability and competitiveness of the enterprise in a volatile market environment.

In terms of competition and antitrust regulation, the implemented digital platform provides increased transparency and reliability of management data. It reduces the risk of information distortion and promotes more predictable market behaviour. The competitive pressure and transparency of prices and delivery dates make digitalisation a factor in increasing efficiency and speed of reaction to market changes both within the region and in global supply chains. Lower costs, faster working capital turnover, and shorter supply cycle times form flexible competitive conditions and force market participants to reconside their pricing, inventory management, and supply strategies. Therefore, digital transformation becomes a systemic tool for increasing transparency and competitive strength of an enterprise in a rapidly developing market. It is extremely relevant for industries with a high degree of technological involvement and deep integration of production processes.

In terms of marketing, demand analysis, and consumer behaviour, the transition to digitalisation provides an accurate analysis of the customer base, market segmentation, and demand forecasting. The development of management analytics panels and digital channels for customer interaction provides real-time data acquisition on consumer preferences, demand dynamics, and sales channel effectiveness. It ensures adaptive channel strategies, adjusts the assortment, supply conditions, and service support depending on changes in consumer preferences. Moreover, digital supply chain management tools contribute to lower inventory and shorter lead times. It directly affects customer satisfaction and loyalty. It allows OOO Novakhim, Ivanovo, Russia to quickly respond to fluctuations in demand, improve forecasting accuracy, and adapt production plans to meet customer requirements. Indeed, in the long run, it enhances the company's market share and reputation.

Furthermore, the results show an acceptable risk profile and the project's resilience to external fluctuations in market conditions in terms of the capital market issues, risk, profitability, and project selection. The estimated profit, payback, and discounting indicators confirm the economic feasibility of the digitalisation project: positive cost, exceeding IRR thresholds, and acceptable payback periods. This combination of financial indicators makes digitalisation a long-term investment capable to generate stable cash flows and increase the cost of an enterprise's capital. The sensitivity analysis demonstrates the resilience of the project to significant reductions in the projected economic impact. It supports the continuing investments in digitalisation in terms of strategic direction and tools of reducing operational risks.

Indeed, the implemented digital solutions strengthen the company's innovation base through structured data use and management decision support, improve its competitive position at the regional and international levels by reducing costs, speeding up production and supply cycles, and increasing business flexibility. It provides an accurate analysis of demand and consumer behaviour, helps to optimise sales channels, increases customer satisfaction and partner trust. An important part is to form an attractive financial profile of the project in terms of investors and shareholders. It hepls to increase confidence in the implementation of digital transformation as a systemic direction of the company's development.

The prospects for further research expand the methodology for assessing the economic effectiveness of digitalisation. It involves the development of digital maturity industry models, compares the effects in different regions, and analyses the long-term impact of digital transformation on export potential and integration into global value chains. It summarises the empirical data on various industrial sectors and expands the applicability of the methodology for assessing the economic effectiveness of digitalisation. The proposed approach to digitalisation and assessment of the effectiveness can be used by industrial enterprises to justify investments in digital transformation aimed at strengthening their regional and international competitiveness. It ensures the practical significance of the research. According to the research results, digitalisation a systemic factor in strengthening market positions thorough cost reduction, shortening of the production cycle, and improvement of price and time competitiveness in the regional market. Moreover, increased productivity and managerial transparency establish prerequisites for increased participation in international supply chains and contractual requirements [16].

Therefore, the research provides a deeper understanding of business processes in terms of digitalisation, affects the indicators determining regional and international competitiveness, and demonstrates the practical applicability of an approach to a comprehensive assessment of the economic effectiveness of digitalisation for enterprises in a modern economic environment.

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The work was done on a personal initiative.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

Marina B. Abramova – writing – original draft.
Polina S. Volkova – data curation, formal analysis, validation.>

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Features of the financial policy of Russian telecommunications companies

Alexander E. Chistyakov SPIN code: 9140-1119

ORIGINAL ARTICLE

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Abstract. The purpose of the research is to identify the features of the financial policy of the largest Russian telecommunications companies and assess the impact of financial decisions on their sustainability and development. The objects of the study are MTS, Megafon, and VimpelCom. The methodological basis of the work was the methods of comparative, financial, economic, analysis of accounting (RAS), and consolidated (IFRS) financial statements of these companies, 2018-2025. The study analyses revenue dynamics, profitability indicators, cash flows, debt structure, investment activity, and dividend policy of mobile operators. The companies under study have steady revenue growth at relatively low growth rates. However, MTS has a tendency to increase the debt burden through the cost of servicing borrowed capital and raise of financial risks. The telecommunications companies have a high level of capital investments due to continuous infrastructure modernisation. Nevertheless, significant investment costs, high dividend burden, and higher cost of credit resources limits the possibilities of their financing development from internal sources. The research identifies key features of the financial policy of Russian telecommunications companies, the main factors affecting their financial stability, and practical importance for improving financial resource management, investment and dividend policy in an unstable macroeconomics.

Keywords: financial policy; telecommunications companies; financial stability; debt burden; investment activity; dividend policy; mobile operators

JEL codes: G32, G31, G35, L96, M21

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Introduction

The telecommunications industry is one of the key components of the modern digital economy. It ensures the functioning of the information infrastructure, the development of digital services, and increasing the competitiveness of the national economy. Indeed, rapid digitalisation, fifth-generation (5G) information technologies, development of cloud services, artificial intelligence, and the Internet increase the volume and quality of investment in telecommunications infrastructure. At the same time, mobile operators work in conditions of high capital intensity, significant dependence on debt financing, and constant updating of fixed assets and software.

Recently, the financial policy of Russian telecommunications companies has been shaped by a complex of external factors, including changes in monetary policy, rising borrowing costs, sanctions restrictions, transformation of equipment supply chains, and technological import substitution. The financial decisions have a direct impact on the sustainability of companies, their investment potential, and a competitive position in the market. Therefore, it is very important to ensure the optimal balance between investment activity, debt burden, and dividend policy.

There are a lot of research devoted to the financial analysis of telecommunications industry enterprises. However, many works consider certain aspects of financial activity or outdated. Therefore, a comprehensive comparative study of the financial policies of the largest Russian mobile operators based on up-to-date financial statements is relevant on. It identifies general trends and industry-specific features of financial resource formation, debt management, investment activities, and profit sharing.

A comparative analysis of the financial condition of enterprises representing a particular industry or sub-sector includes corporate finance, industry economics, and strategic management. It also concerns with the growth of the industry and its constituent companies, financial stability, valuation, investment activity, etc.

In Russia, this particular issue is considered by Brigham E.F. & Gapenski L.C. [2], Kovalev V.V. & Kovalev Vit.V. [6], etc. The foreign researchers are as follows: Ross S.A., Westerfield R.W., Jordan B.D. [10], Buffett W. [1], Siegel J.J. [11]. Moreover, Zubkova L.D. & Dyachkov S.M. [5], Kuzovkova T.A. & Terekhova Yu.S. [7], Nikolskaya N.V. [8], Radchenko M.V. & Andreeva A.S. [9] made a financial analysis of the telecommunications industry.

The purpose of the research is to identify the features of the financial policy of the largest Russian telecommunications companies based on a comprehensive analysis of revenue dynamics, profitability, cash flows, debt burden, investment, and dividend policies. It determines their impact on the financial stability and development prospects.

Main part

For comparative analysis we selected MTS, Megafon, and VimpelCom – 'Big Three'. T2 is a part of Rostelecom; Rostelecom has different technological and product specifics, therefore, we except it from this analysis.

The comparative analysis of Big Three identifies the following methodological features: MTS is a mixed holding company; the parent company conducts its main business (telecommunications services), and owns MTS Bank. Accordingly, the consolidated IFRS financial statements include indicators of MTS Bank. It prevents their comparing with other Big Three companies. Therefore, we can use RAS reports as a source, since VimpelCom and Megafon have approximately the same revenue under RAS and IFRS (there are no large subsidiaries like MTS). In 2025 MTS has RUB 166 out of 807 bn in accordance with IFRS by the bank's revenues. The RAS reporting includes only the parent company. However, it has many advantages. In case of bankruptcy of a subsidiary, the parent company will not be liable, but may receive dividends from the subsidiary. According to RAS analysis, parent company also affects the business. 2018-2025 is the period analysed.

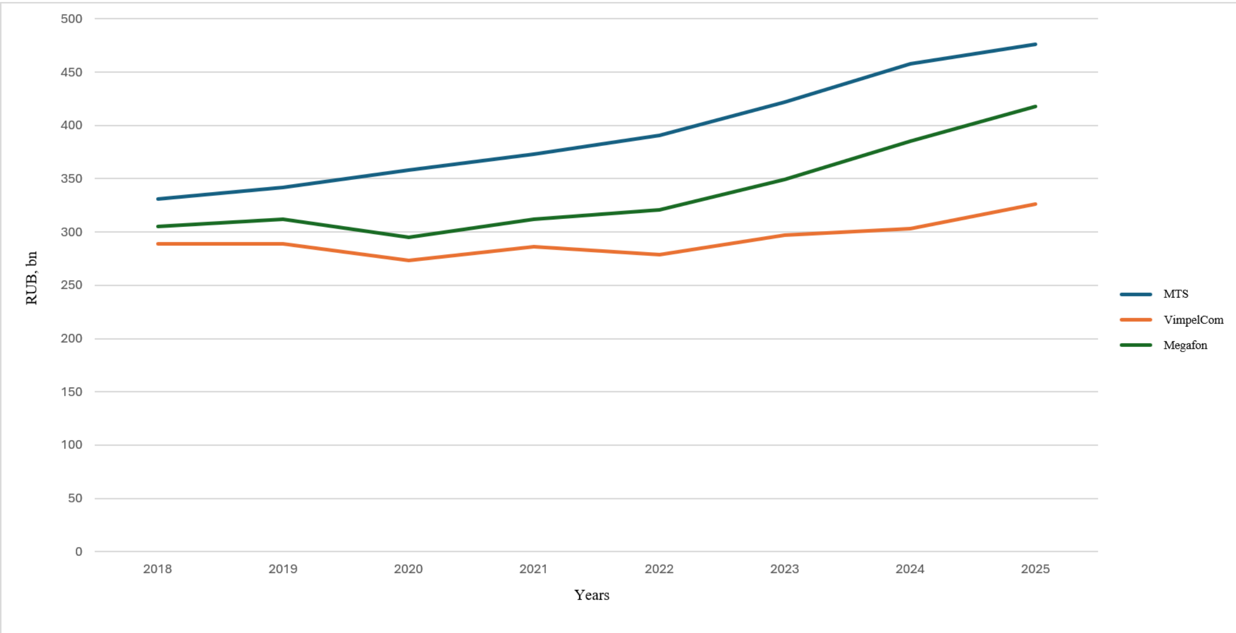

Figure 1. Mobile communications company revenue dynamics, 2018-2025
Source: compiled according to the annual reports, 2018-2025

This period can be divided into 3 stages. Until 2020 – years of stable economic growth before the COVID-19 pandemic; 2020 – is epidemic; 2021 – recovery; since 2022 – sanctions policy against Russia. In 2020 VimpelCom and Megafon had a slight profit decrease. From 2018 to 2023, VimpelCom had a slight decrease and stagnation of profit; at 2025 the company revenue begins to grow.

This kind of delay in such a market is undesirable. Over the past 8 years, all the operators show the growth of profit: Megafon and MTS revenue show a third growth; VimpelCom has weak growth; MTS has a significant growth.

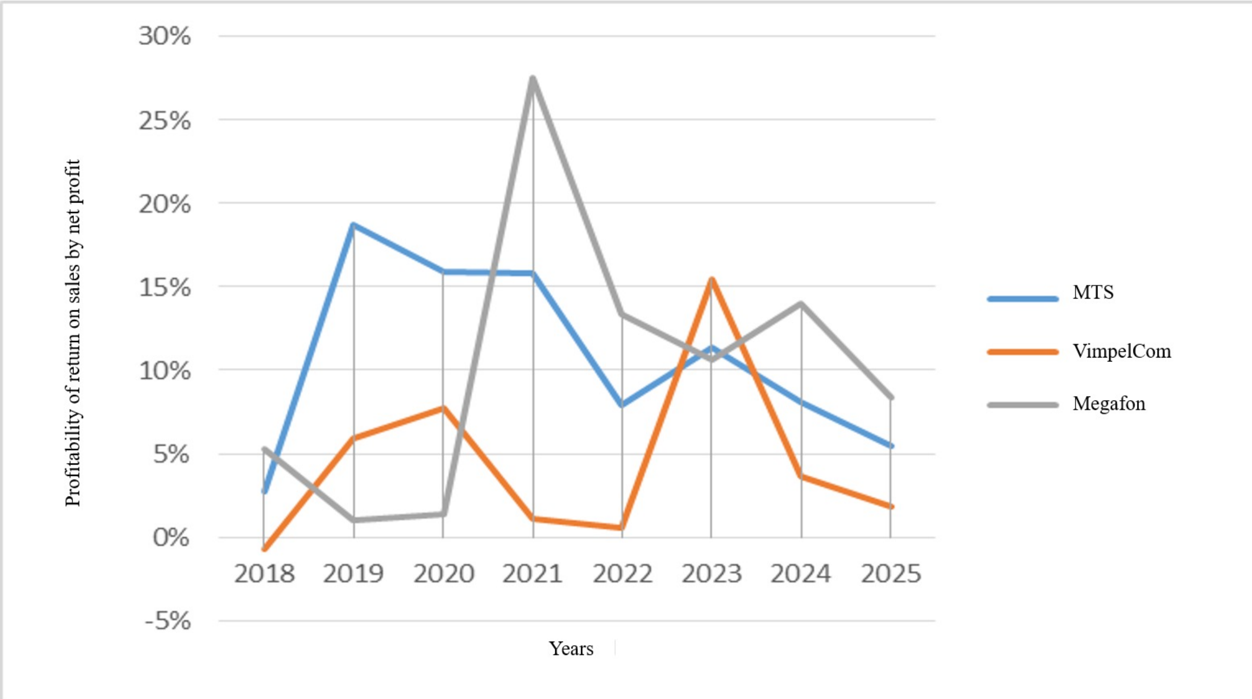

Figure 2. Dynamics of return on sales by net profit

Source: compiled according to the annual reports, 2018-2025

According to the analysis of the net profit margin indicator, the companies' net profit is in a positive zone for 8 years. However, MTS revenue does not fall below 5%; Megafon and VimpelCom indicators are lower ones. Nevertheless, the company's net profit assessment is based on the use of depreciation and revaluation of assets in calculations. It is not precisely valid. For these companies, the share of depreciation is very high – about a quarter or a third of the costs. The high degree of moral depreciation of tangible and intangible assets, this calculation can be very conditional. Therefore, it is better to use indicators from the cash flow statement to assess effectiveness. In particular, we will analyse the current account balance. It is similar to the value of net cash flow (net profit and depreciation).

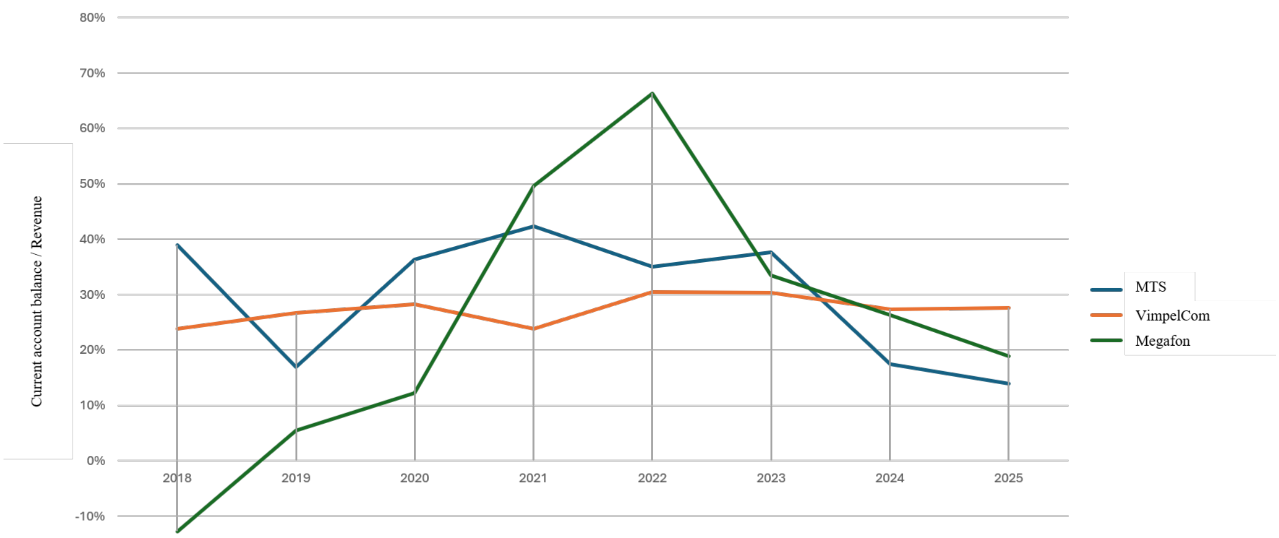

Figure 3. The share of the current account balance of revenue

Source: compiled according to the annual reports, 2018-2025

The balance of companies is positive for 8 years except Megafon in 2018. Comparing the balance, MTS has a relatively small one. VimpelCom's performance is the most stable in 2025, despite the lowest revenue; it surpassed MTS and Megafon.

However, loan repayments to the current account balance (Fig.9) are higher for MTS. Therefore, MTS is a leader in terms of revenue. Indeed, MTS is highly efficient with a high debt burden.

The debt burden of companies (Fig. 4, 5).

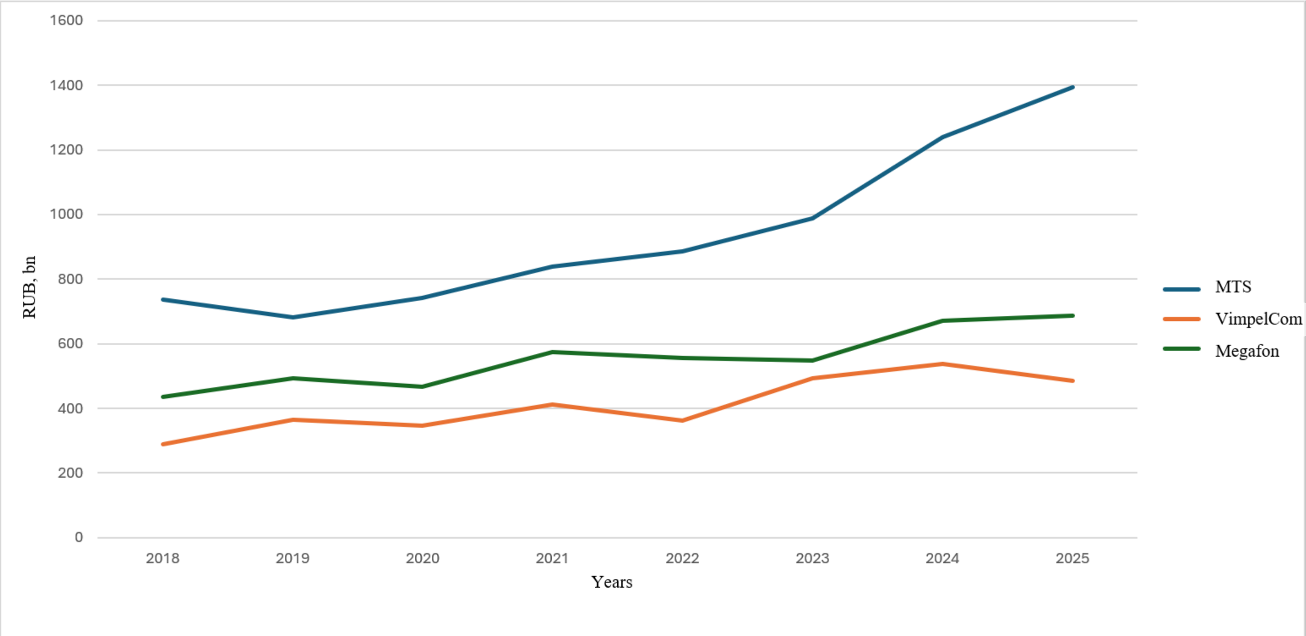

Figure 4. Dynamics of short-term and long-term liabilities for 8 years

Source: compiled according to the annual reports, 2018-2025

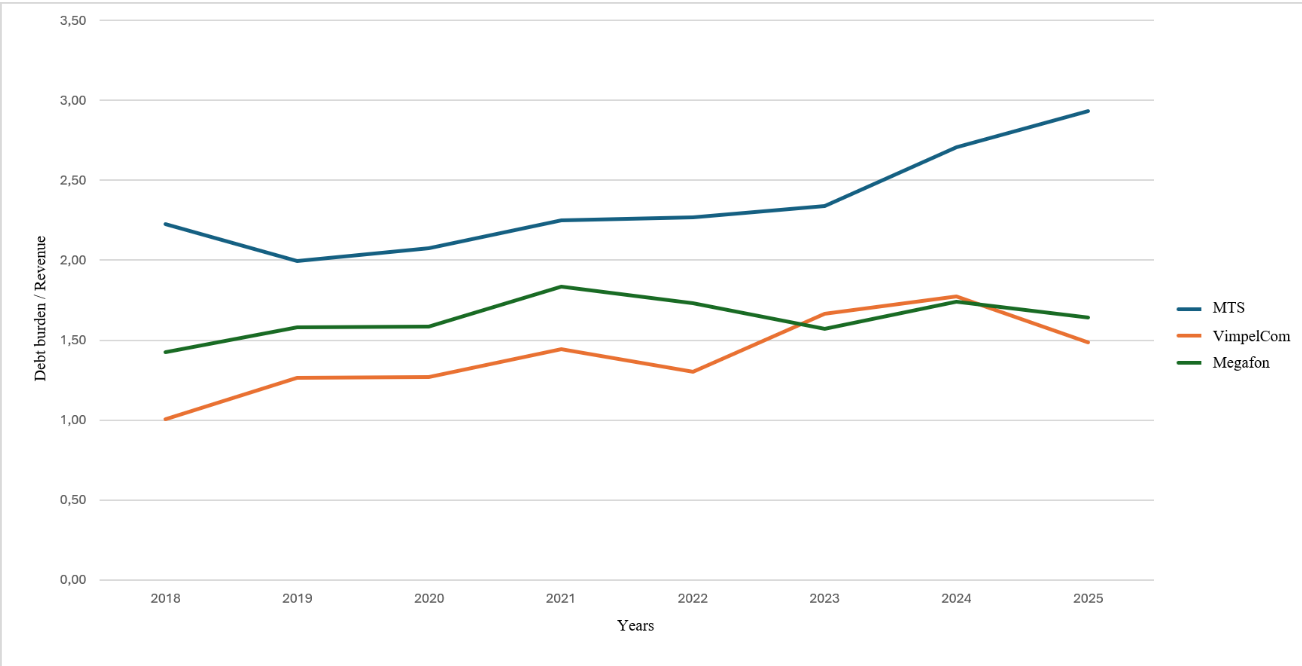

Figure 5. Debt-to-revenue ratio for 8 years

Source: compiled according to the annual reports, 2018-2025

MTS has a growing debt burden both absolutely and relative to revenue as the increase in loans exceeds the growth in revenue. In the future, the loan refinancing system may have a financial crisis, lack of liquidity, disapproval of another loan due to the increased risks of the company, etc.

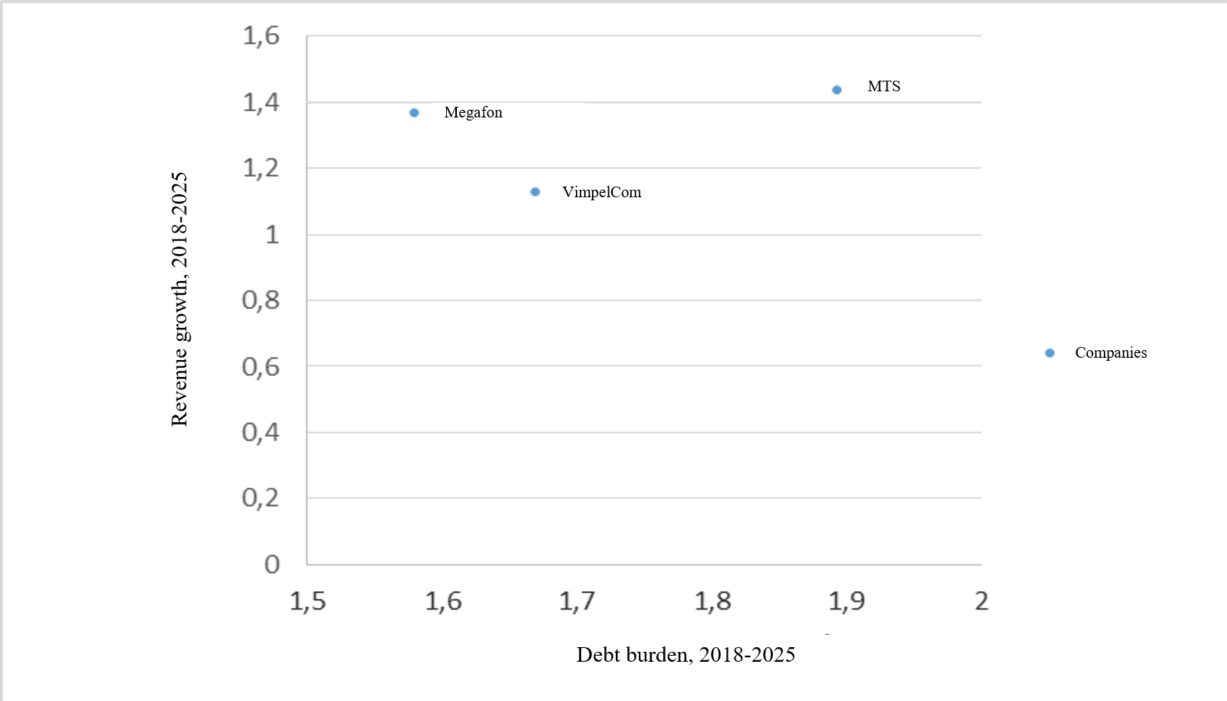

Figure 6. The relationship between revenue growth and debt burden, 2018-2025
Source: compiled according to the annual reports, 2018-2025

In Figure 6, Megafon and MTS have approximately the same revenue growth. However, Megafon's debt burden growth is significantly lower. By the results of Megafon, it is possible to have revenue growth without significant debt growth.

MTS debt growth consistently prevails a revenue growth. However, in 2025, the growth of short-term and long-term liabilities slowed down. Indeed, the increase in interest on the loan, a significant part of the current account balance and profits decreases. Debt service interest is about 40% of revenue.

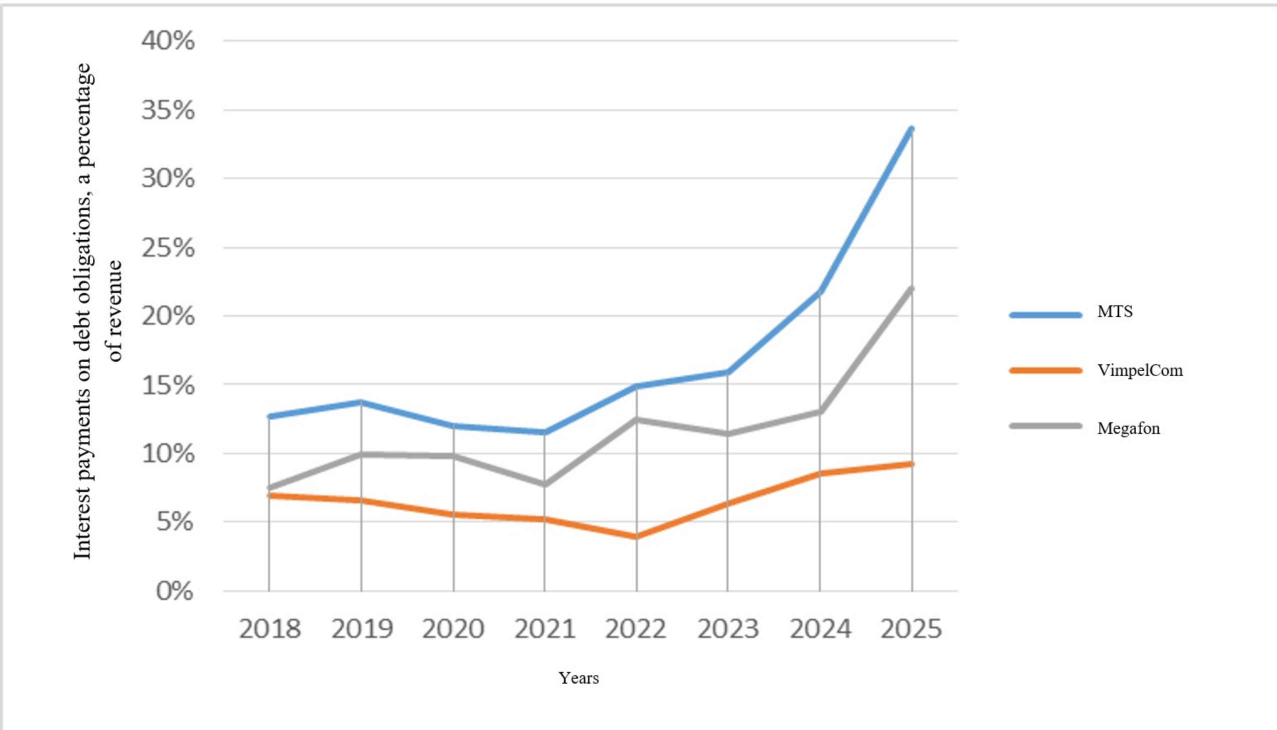

Figure 7. Interest payments on debt obligations, a percentage of revenue
Source: compiled according to the annual reports, 2018-2025

According to the graph, MTS and VimpelCom have the largest increase. Its the reason for the decrease in profitability and investment Figure 7.

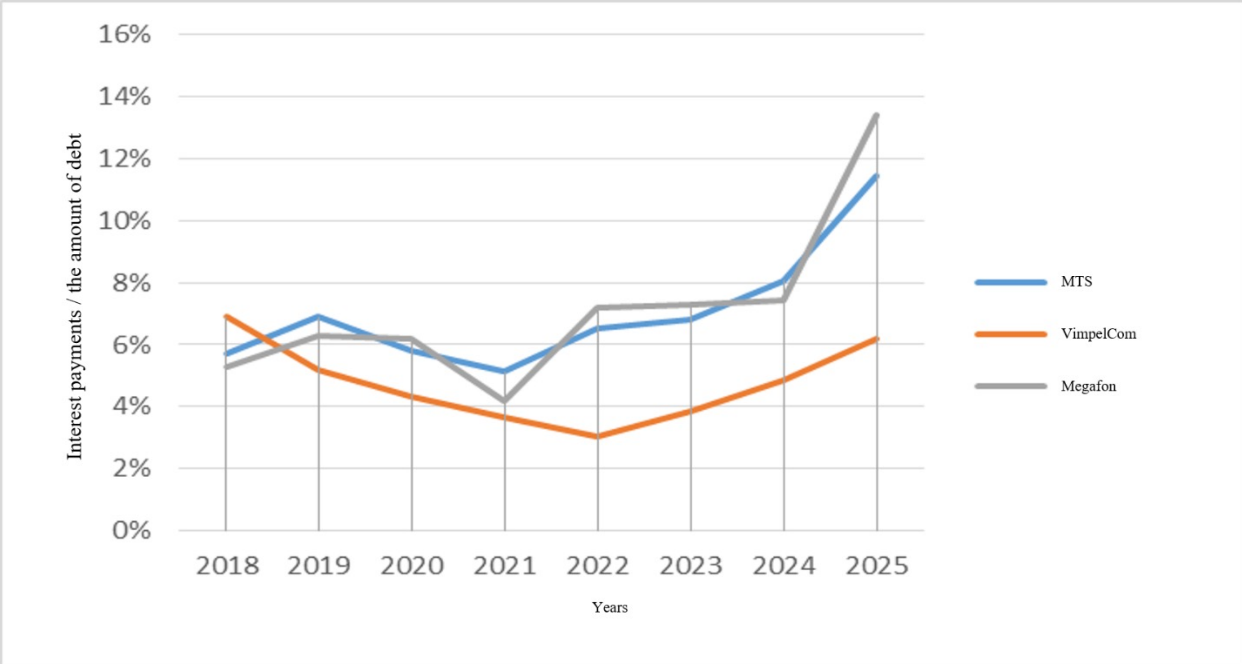

Figure 8. The ratio of interest payments to the amount of debt
Source: compiled according to the annual reports, 2018-2025

According to the graph (Fig.8), by 2022 the cost of borrowing from companies was decreasing followed by a sharp increase. Therefore, the increase in interest payments is due to two factors: the growth of debt and interest on servicing. MTS increases the percentage from 5% to 11% in 4 years, respectively. It is a key factor in increasing interest payments. At the same time, 50% decrease of interest will reduce the share of interest payments in revenue from about 34% to about 20%, respectively. It will provide about 15% of revenue. Cancelling the payment of dividends (MTS has the most significant ones) will not affect the situation.

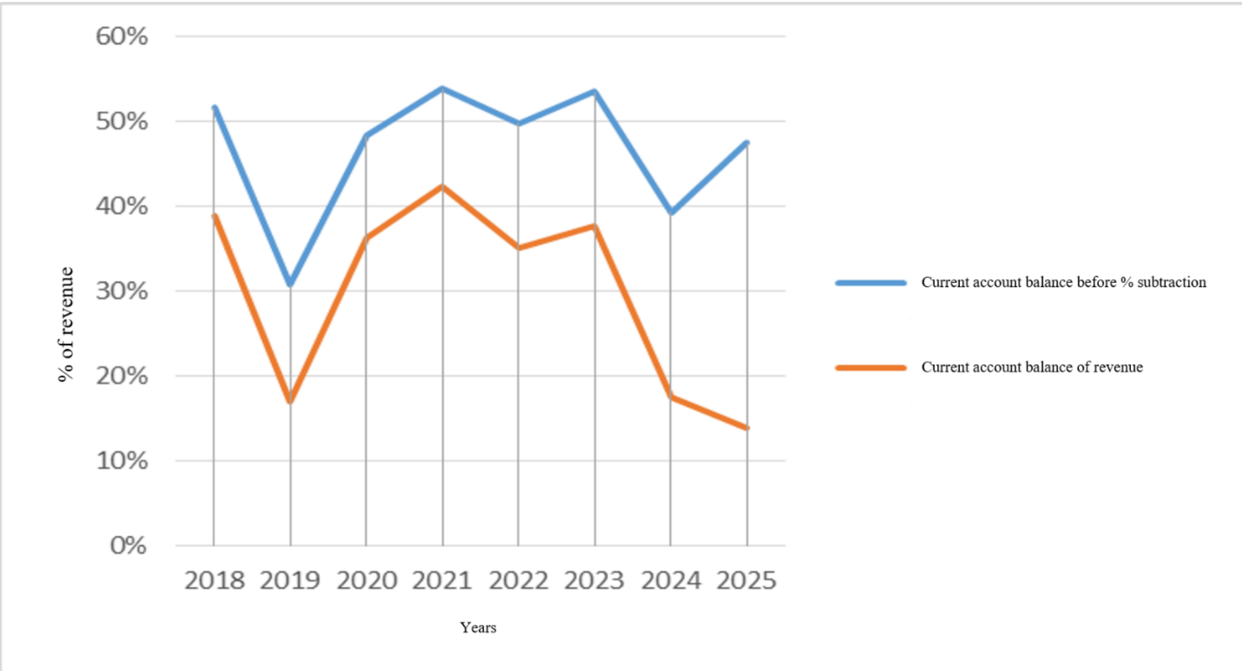

Figure 9. Dynamics of the share of MTS's current account balance of revenue from the cash flow statement
Source: compiled according to the annual reports, 2018-2025

There are no investment indicators in the financial statements. However, there are similar ones, for example, investments in non-current assets in the cash flow statement. Investments can also include investments in subsidiaries (i.e., company can buy 10 machines, or can buy a company that owns 10 machines). However, this indicator is not included in the investment in this research.

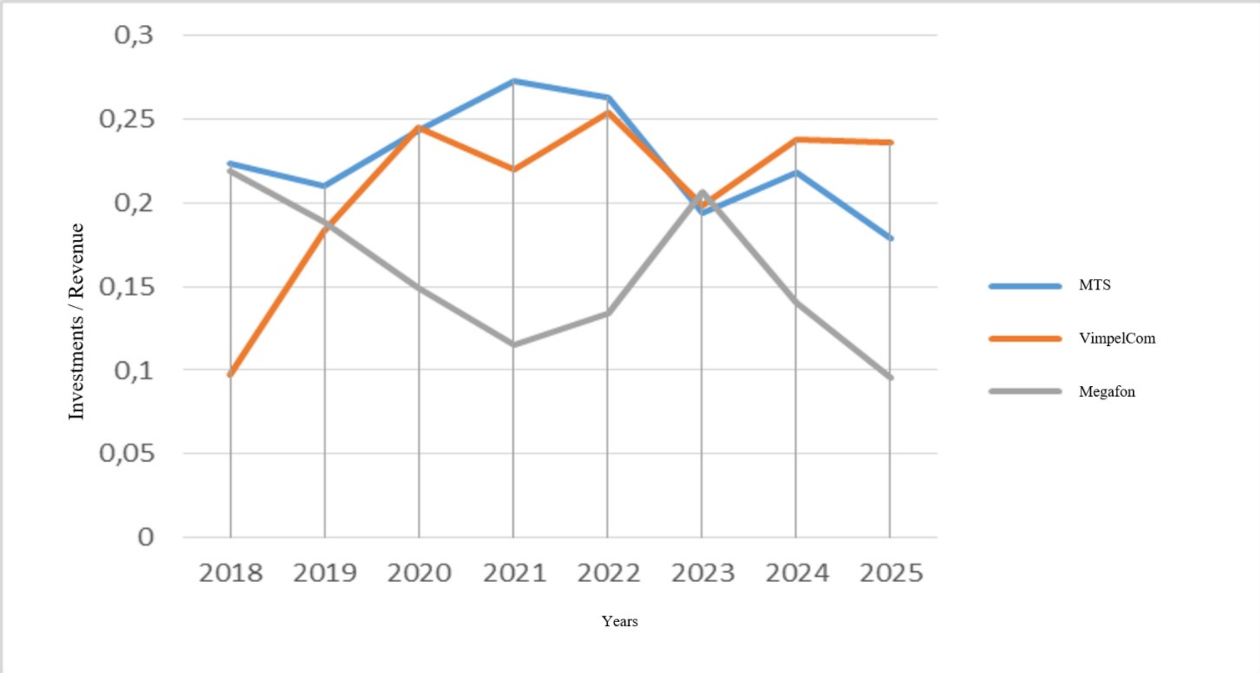

Figure 10. Share of investment expenses from revenue
Source: compiled according to the annual reports, 2018-2025

According to the graph, MTS has a relatively high and stable level of investment. However, after 2022 it began to decline. Nevertheless, it is at a consistently high level of 20-25% of revenue. We can note the relatively low level of Megafon, and the high volatility of the indicator. In particular, these fluctuations are achieved due to the drawdown of the indicator, but peak investment values usually reach the average values for MTS and VimpelCom.

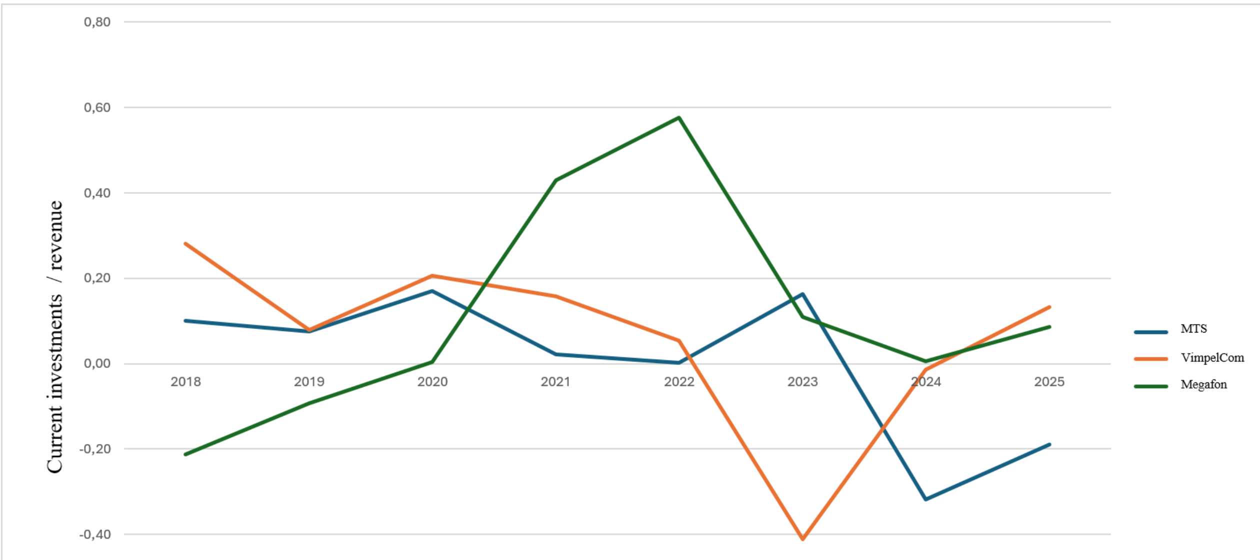

Figure 11. Dynamics of the share of current and investment balances in the revenue of companies
Source: compiled according to the annual reports, 2018-2025

According to the graph, the indicators of all three companies are quite volatile ones. In 2019 Megafon indicators are positive; VimpelCom indicators are positive, too; only in 2023 there was a significant drop;

MTS has a significant drop in 2024 and 2025, with a high negative balance from investment operations. Usually, the balance from current activities covers the negative result from investment activities (except in certain cases, for example, placing funds on deposit, etc). The presence of the total indicators in the negative zone is a signal for the company to borrow or withdraw funds from the current account, sell non-core assets unrelated to the core business. The negative balance is a factor of company's crisis.

Figure 12. Dynamics of the share of investment, current account, and dividends in the revenue of companies
Source: compiled according to the annual reports, 2018-2025

Figure 12 shows the total indicators of the current, investment balance, and dividends. Dividends serve as a reserve and can be retained in the company in case of problematic situations. MTS is being repaid through new loans.

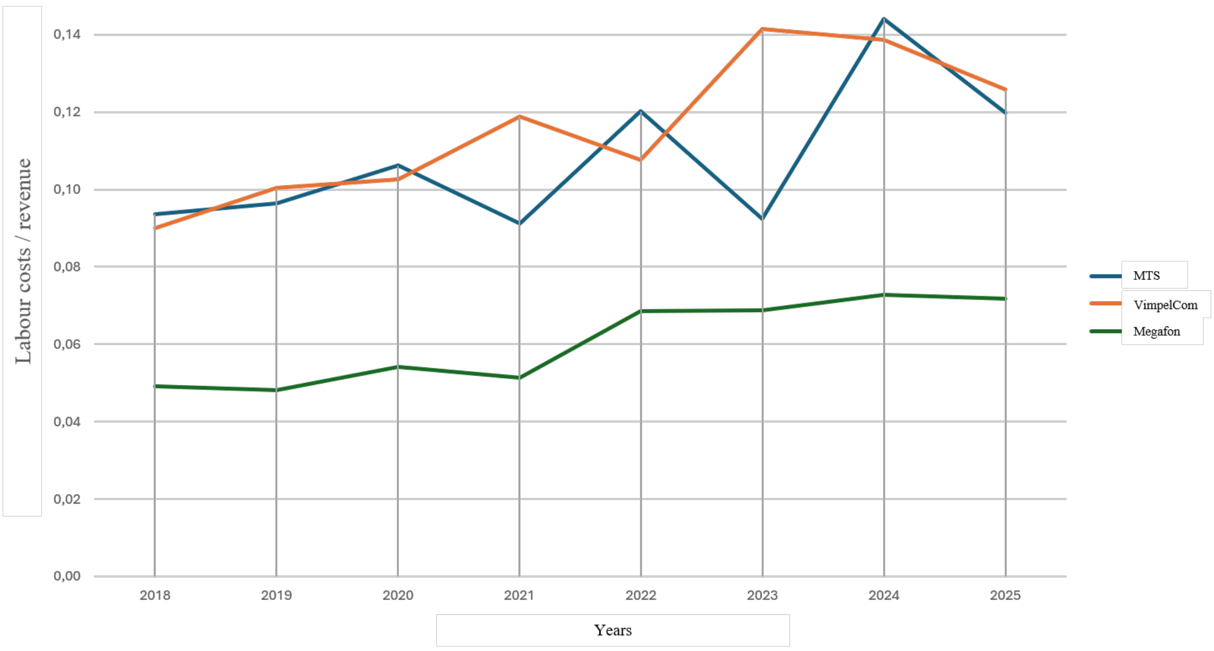

Figure 13. The share of labour costs from revenue
Source: compiled according to the annual reports, 2018-2025

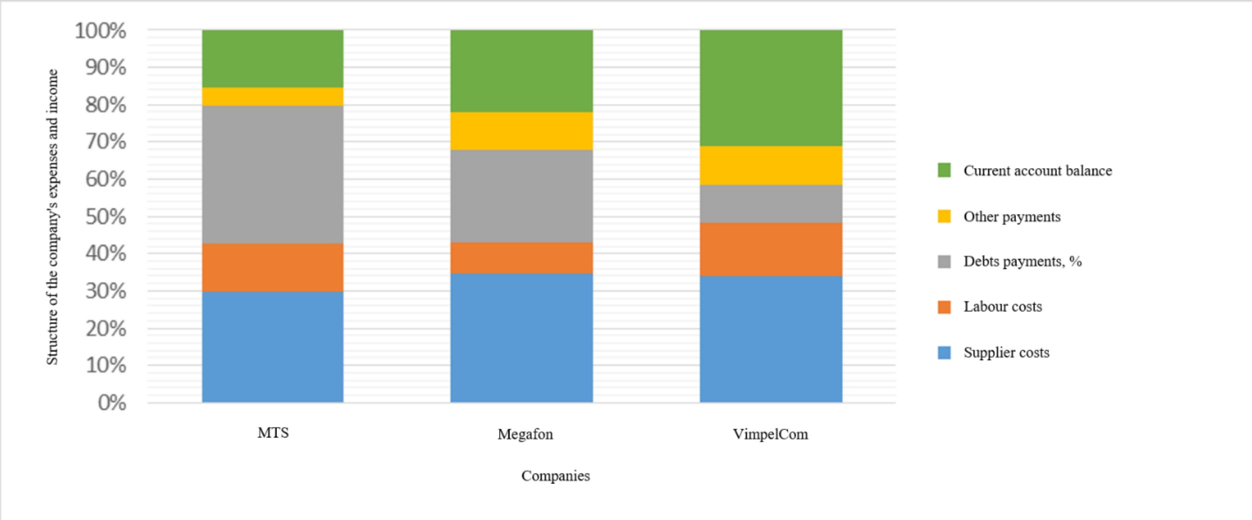

Figure 14. The cost structure of MTS, Megafon, and VimpelCom, 2025
Source: compiled according to the annual reports, 2018-2025

The structure of the company's expenses according to the cash flow statement. According to the income and expenses from current operations section, the company's income can be represented as Income = expenses + current account balance (all companies have a positive balance). Expenses are grouped.

Based on the results of 8 years, 3 companies have a range of values ranging from 5% to 14% of revenue. MTS has the highest values, and Megafon has the lowest ones – 5-7%. However, Megafon's activities can be performed by third-party organisations. Therefore, the labour costs may be lower due to expenses to third-party organisations. Telecommunications companies have relatively low labour costs. They are stable but regular ones. There is also a tendency to increase the share of labour costs from revenue. Costs to suppliers and other payments are relatively stable and do not exceed 40%. The companies' dividend policy is analysed below:

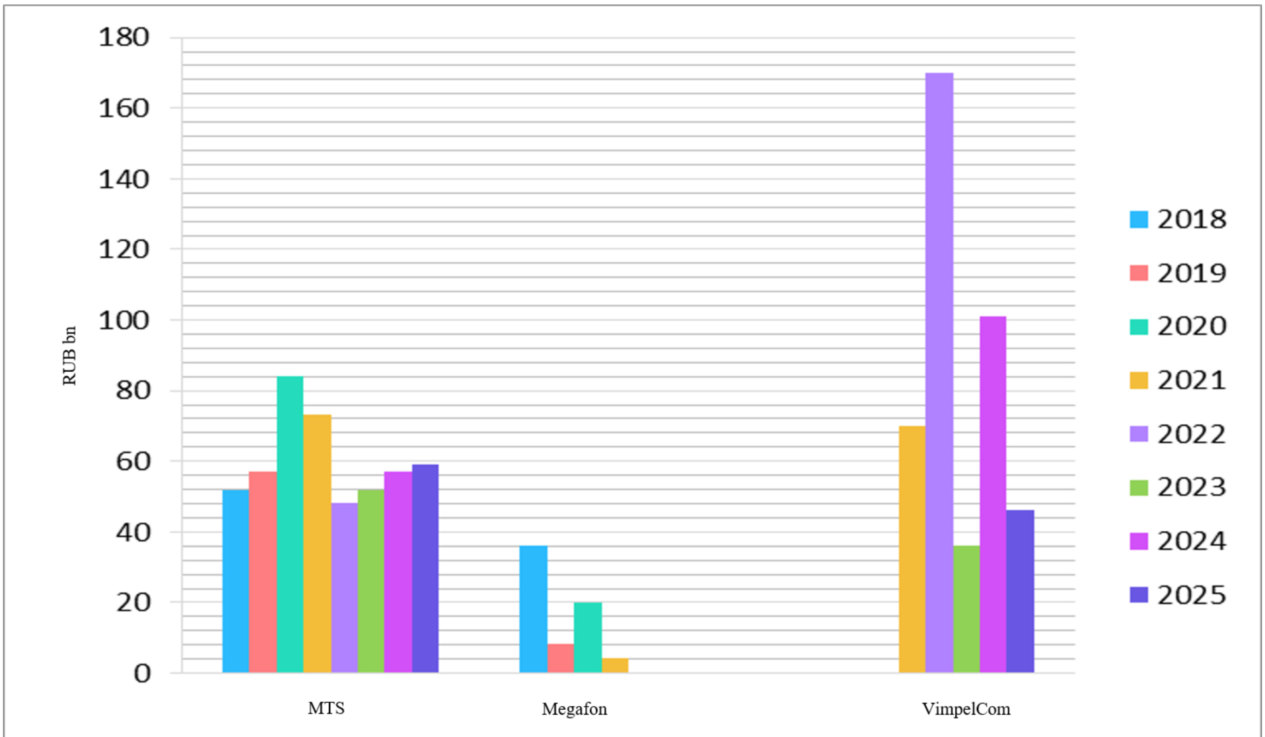

Figure 15. Dividend payments, RUB bn
Source: compiled according to the annual reports, 2018-2025

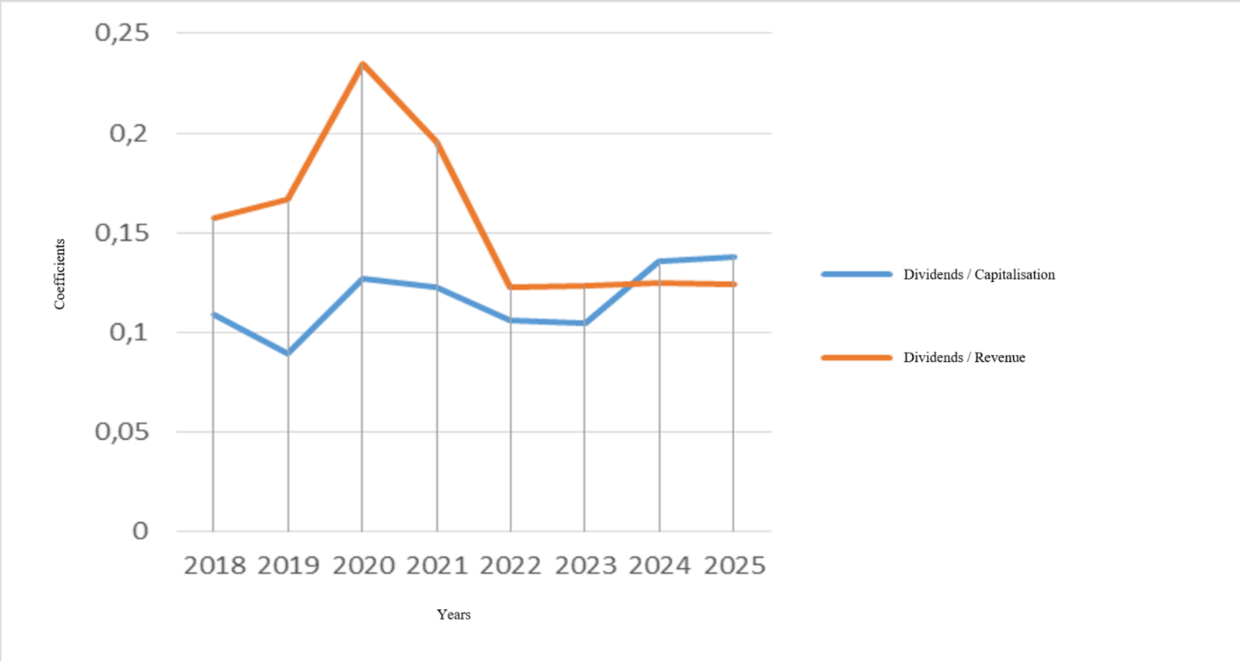

Figure 16. Dynamics of dividend payments in relation to revenue and capitalisation
Source: compiled according to the annual reports, 2018-2025

According to the graphs (Fig. 15, 16), MTS has the most stable dividend policy. This policy ensures the cash flows of shareholders (AFK Sistema for MTS) and capitalisation (for MTS only). Figure 16 shows the dividend/revenue ratio of the total burden of dividend payments on the company's resources. The dividend/capitalisation ratio shows the profitability of investors. According to the graph, at the absence of income from stock growth, shareholders have a stable dividend income of about 10-13% of the share price. Until 2022, it was similar to a bank percentage or higher. However, significant funds are being withdrawn from the company – from 13 to 20% of revenue. They could be spent on investments and the development. It can be assessed in terms of the development of AFK Sistema's parent company. In addition, despite the high dividend yield for investors, it has little effect on capitalisation. The dynamics of revenue and profit are important to investors. Moreover, earlier MTS used dividends as a significant reserve for paying off debt servicing costs; now their value is decreasing.

Therefore, the following features were identified during the research:

1. Steady revenue growth.
2. High level of debt burden and its growth.
3. Relatively high level of dividend payments (especially for MTS and Megafon).
4. High investment costs (investments in fixed assets and intangible assets): about a quarter of the revenue. It has certain advantages, since part of the investment can be postponed for a certain period of time, unlike paying salaries, taxes, and other payments. However, companies may have a loss of competitiveness in the future.
5. Relatively average capitalization in comparison with the Russian market by multipliers

Conclusion

The research studies the main features of the financial policy of the largest Russian telecommunications companies and identify key trends in their development in the context of the transformation of the economic environment. According to a comparative analysis of the financial and economic indicators of MTS, Megafon, and VimpelCom in 2018-2025, the companies under study have stable market positions and positive revenue dynamics. It shows a stable demand for telecommunications services and the continued development of the digital economy. At the same time, revenue growth rates remain relatively low. It shows the high degree of saturation of the mobile communications market and increased competition.

The one of the most characteristic features of the financial policy of the industry is a significant debt burden due to the high capital intensity of the telecommunications business and the need for regular infrastructure updates. MTS mostly depends on borrowed capital; the growth of debt obligations is accompanied by a significant increase in debt servicing costs. It provides the additional financial risks at high interest rates and limited access to external sources of financing.

All the companies under study have a significant amount of investment in fixed assets and intangible assets. It is a prerequisite for maintaining technological competitiveness. However, high investment activity, significant dividend payments, and an increase in the cost of borrowed resources reduces the possibility of financing development from internal sources and raise the dependence of companies on credit capital.

According to the results obtained, it is necessary to form a balanced financial policy aimed at maintaining an optimal balance between investment activity, debt burden, and dividend payments. In modern macroeconomic conditions, to increase the financial stability of companies by optimizing the capital structure, the efficiency of using cash flows, and improving investment management mechanisms is extremely relevant. The development of a corporate financial strategy, assessing the investment attractiveness of telecommunications industry enterprises, making managerial decisions aimed at their long-term sustainable development ensure the practical significance of the research.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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