IT-Driven Transformation of Global Trade and Its Impact on GDP in the Context of the 4IR

Oleksandr Vyshnevskyi[1] and Nataliia Trushkina[2]
[1] *Institute of Industrial Economics of the National Academy of Sciences of Ukraine, Maria Kapnist Str. 2, 03057 Kyiv, Ukraine*
[2] *Sector of Industrial Policy and Innovative Development of the Department of Industrial Policy and Energy Security, Research Center for Industrial Problems of Development of the National Academy of Sciences of Ukraine, Inzhenernyi Lane 1a, 61165 Kharkiv, Ukraine*
allexxandr@gmail.com, nata_tru@ukr.net

Keywords: Global Trade, Gross Domestic Product (GDP), Export, Import, GDP Growth, Import Substitution, Structural Trade Shifts, Fourth Industrial Revolution (4IR), Industry 4.0, Digital Transformation, Digital Ecosystem, Digital Innovation, Digital Technologies.

Abstract: This study evaluates the impact of structural changes in exports and imports on GDP dynamics within the context of the Fourth Industrial Revolution (4IR), contrasting these effects with those observed during the Third Industrial Revolution. Using World Bank data for 1970-2021, the analysis shows that global trade peaked in 2008 at 61.43% of world GDP, followed by a gradual shift toward deglobalization driven by trade wars and import substitution policies. A comparative methodological approach is applied to examine GDP growth trajectories in relation to changes in the shares of exports and imports in GDP. The findings confirm that GDP growth rates are significantly influenced by both countries' income levels and structural trade shifts. The study demonstrates that 4IR amplifies GDP growth when export expansion outpaces import growth, while also increasing the volatility of GDP responses to structural changes in trade flows. Income-specific patterns are identified: low- and lower-middle-income countries tend to benefit from export-led substitution strategies, whereas upper-middle- and high-income countries gain more from balanced trade expansion. Future research will focus on exploring the role of artificial intelligence in shaping global economic growth.

1 INTRODUCTION

Today, the global economy is undergoing a rapid transition toward digital and smart technologies. This transition drives the intensification of digital transformation processes across modern ecosystems in the era of the Fourth Industrial Revolution (4IR), powered by information systems as well as digital and intelligent technologies [1] - [4].

Artificial intelligence, machine learning, blockchain, the Internet of Things, big data analytics, augmented and virtual reality, cloud computing, robotics, and digital twins are reshaping the rules of doing business and transforming how companies interact with customers and various stakeholder groups.

The digital economy has evolved from Industry 3.0 to Industry 4.0, which is characterized by qualitatively new features. Traditional companies are no longer the central actors in economic reality; instead, a new economic entity has emerged – the digital ecosystem. This stage of digital economic transformation involves integrating digital and smart technologies, innovative solutions, and advanced management approaches into all areas of activity. Such technological change requires companies to fundamentally transform their operations, customer relationships, and strategic management models.

These transformations contribute to the modernization and reorganization of business processes and business models within the Industry 4.0 paradigm.

It should be emphasized that the development of 4IR is closely interconnected with the evolution of global trade processes. From the standpoint of Schumpeterian economic theory, the Great Recession of 2007-2008 can be interpreted as a

"positive disruption" and as a marker of the transition from the Third to the Fourth Industrial Revolution.

Statistical analysis shows that in 2008, total exports and imports reached their maximum relative value of 61.43% of world GDP for the entire 1970-2021 period. After this point, the long-term upward trend in global trade – stable since the mid-1980s – was disrupted (Fig. 1) [5] - [7]. A new global trend began to emerge: deglobalization, marked by trade wars, reindustrialization, and import substitution. The synchrony between the onset of 4IR and the reversal of world trade dynamics suggests a hypothesis that the former may have influenced the latter.

Given this context, the present article examines the impact of global trade (including structural import substitution processes) on changes in GDP dynamics under the conditions of the Fourth Industrial Revolution.

2 LITERATURE REVIEW

Over the past decade, issues related to the development of the Fourth Industrial Revolution (4IR) have attracted considerable scholarly attention [8]-[16]. At the same time, the question of when the 4IR actually began remains open. There is no universal criterion for its determination, which is not surprising, as any historical periodization is inherently conditional. The boundaries between the First, Second, and Third Industrial Revolutions are also blurred.

By early 2016, however, the concept of the Fourth Industrial Revolution had already been clearly articulated, as evidenced by such publications as Industry 4.0 [17] and The Fourth Industrial Revolution [18]. This suggests that the processes identified by these authors had begun somewhat earlier.

As T. Philbeck and N. Davis noted, "the idea of 4IR is often taken to be a synonym for 'Industry 4.0', an initiative that emerged in Germany between 2011 and 2015, focusing on the application of digital technologies to manufacturing.

These two terms are not unrelated, but they describe different things. Industry 4.0 is an important component within the larger framing of 4IR, with its narrower, vital focus on the relationship between digitalization, organizational transformation, and productivity enhancement in manufacturing and production systems" [17]. During this period, a symbolic shift occurred in 2012, when a technology company (Apple) became the world's most valuable firm, surpassing ExxonMobil for the first time [20].

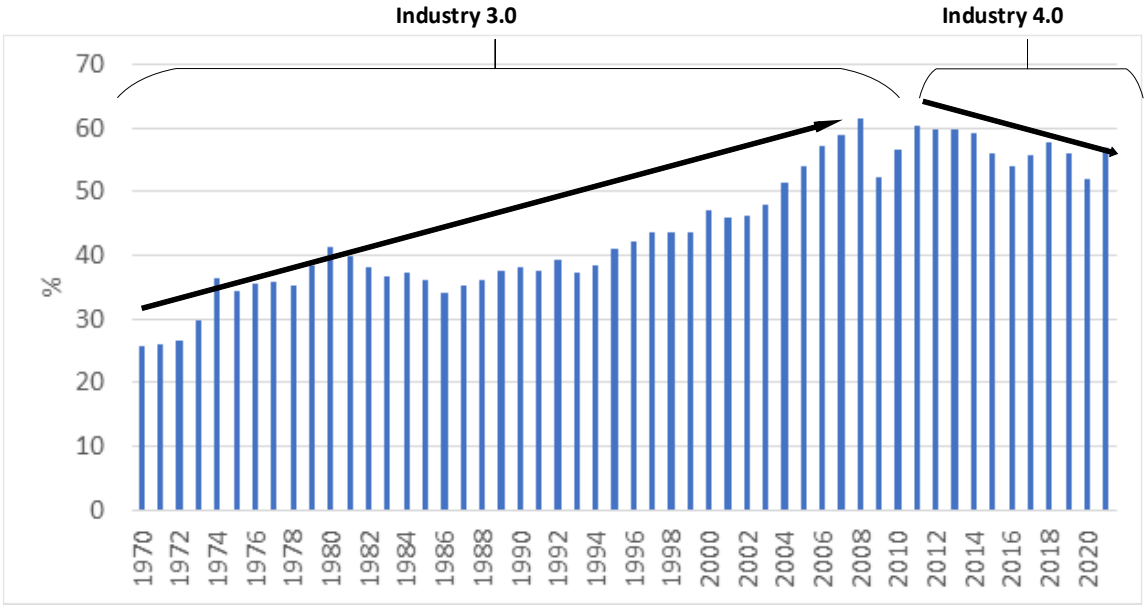

Figure 1: Exports and imports relative to world GDP in 1970-2021, %. Built on data [5] - [7].

This trend has only intensified. By mid-2024, the world's five most valuable companies were all technology firms (Microsoft, Apple, NVIDIA, Alphabet (Google), Amazon), with a combined market capitalization of nearly 14 trillion dollars. Meanwhile, ExxonMobil, once the leader, had fallen to 17th position [20].

The large-scale diffusion of new technologies has historically been associated with the redistribution of global economic power. During the transition from the Second to the Third Industrial Revolution, for example, leadership shifted from Great Britain to the United States.

Recent scholarship frequently employs such concepts as artificial intelligence, cyber-physical systems, big data, Industry 4.0, Industry 5.0, open innovation, Society 5.0, and the super-intelligent society. The transition from Society 4.0 to Society 5.0 is expected to be driven by the implementation of Internet of Things technologies, robotics, and big data, transforming society into an integrated smart environment (Society 5.0). The concept envisions the adaptation of services and industrial activities to the real needs of individuals, as well as the development of advanced digital platforms integrated into all spheres of life.

Researchers also emphasise that Industry 5.0 should not be viewed as a new industrial revolution but rather as an extension of Industry 4.0 technologies, achieved through increased collaboration between humans and intelligent machines. Within Industry 5.0, the nine core elements of Industry 4.0 are expanded by placing creativity and human well-being at the centre of industrial systems, thus combining the efficiency of machine technologies with human ingenuity.

A growing number of publications indexed in leading scientometric databases address these themes [21]-[28]. These works explore key characteristics and challenges for producers in the age of Industry 4.0 and 5.0, assess innovative models of adaptability for modernisation, and discuss long-term evolutionary trajectories such as the transition from Industry 4.0 to Nature 4.0 within the broader context of Society 5.0.

Some scholars also examine the relationship between 4IR development, global trade, and GDP. However, a search conducted in the Scopus database for 2009–2024 revealed only 12 publications that simultaneously addressed the keywords "Global Trade", "Gross Domestic Product", and "Industry 4.0/4IR/Fourth Industrial Revolution". The most frequently used keywords in the retrieved publications include: Gross Domestic Product, International Trade, Global Trade, Climate Change, Innovation, Environmental Impact, Urbanisation, and Theoretical Models.

The institutions most actively engaged in research on this topic include University College London; Tsinghua University; The Bartlett Faculty of the Built Environment; the International Institute for Applied Systems Analysis (IIASA); the Collaborative Innovation Center for Emissions Trading System; University of East Anglia; Univerzita Hradec Králové; Agricultural Research Council (Pretoria); the Ministry of Education of the PRC; and Zhejiang University. Most contributing authors are affiliated with China, the United Kingdom, the United States, Austria, Canada, the Czech Republic, Japan, Poland, South Africa, South Korea, and Switzerland. Notable contributions include works by M. Burri & T. Cottier [29]; C. M. T. Johnston & J. Buongiorno [30]; Y. Sun et al. [31].

Major funding organisations supporting research on the relationship between global trade and GDP in the context of Industry 4.0 include the National Natural Science Foundation of China; the UK Department for Business, Energy and Industrial Strategy; the Environmental Restoration and Conservation Agency; the Fundamental Research Funds for the Central Universities; the Japan Society for the Promotion of Science; the Ministry of Education, Culture, Sports, Science and Technology (Japan); the National Office for Philosophy and Social Sciences; the Natural Environment Research Council; the Science and Technology Research Partnership for Sustainable Development; and Zhejiang University.

Another group of scholars analyses the impact of structural changes in import substitution on GDP dynamics and economic growth. Among them are M. P. Abreu, S. A. Bevilacqua & M. D. Pinho [32]; A. R. Adewale [33]; J. A. Datas-Panero [34]; D. Irwin [35] - [36]; and A. Mendes, M. Bertella & R. Teixeira [37]. The problem of import substitution is particularly relevant in developing countries such as Pakistan, Indonesia [38], Chile [39], and Nigeria [40] - [41]. For instance, researchers in Nigeria argue that "the strategy of import substitution is relevant for rapid industrialization in the country" [40].

Despite these contributions, comparative studies analysing GDP growth trajectories against the backdrop of structural changes in export and import shares remain limited. Existing research predominantly focuses on the relationship between economic growth and the expansion of international

trade, while import substitution is usually examined solely within industrial sectors, overlooking the service sector. Moreover, few studies approach this issue from the standpoint of the macroeconomic structure of GDP, and the structural nature of import substitution remains largely understudied.

The transition to the Fourth Industrial Revolution has fundamentally reshaped global value creation, altering both the structure and geography of international trade. Digitalisation, artificial intelligence, automation, and advanced data analytics have enabled new forms of production, logistics, and services that diverge significantly from the patterns characteristic of Industry 3.0. Recent studies highlight that 4IR technologies reduce information asymmetries, improve supply chain efficiency, encourage reshoring and nearshoring, and stimulate the rapid expansion of digital services trade. These technological shifts influence the elasticity of GDP growth with respect to export and import dynamics, increasing both the speed and volatility of structural adjustments.

AI-driven supply-chain optimisation reduces transaction costs and supports more efficient resource allocation, enabling firms to adjust import needs and diversify export markets. Automation reduces dependence on offshore manufacturing, contributing to partial reindustrialization in high-income economies. Meanwhile, digital platforms and cloud-based services accelerate the growth of intangible exports, creating new sources of value for advanced economies while intensifying competition for middle-income countries. Consequently, the relationship between structural trade changes and GDP growth has become increasingly heterogeneous across income groups, reinforcing the need for differentiated empirical assessment.

In this regard, the structure of the present study involves two key stages: (1) demonstrating that GDP dynamics follow different trajectories depending on structural changes in the export and import shares of GDP; and (2) comparing GDP growth rates during the emergence of 4IR with the period dominated by the Third Industrial Revolution.

Therefore, the purpose of this study is to assess changes in GDP dynamics in the context of structural shifts in exports and imports during the development of the Fourth Industrial Revolution.

3 METHODOLOGY

Although this study relies on descriptive and comparative methods rather than regression modelling, such an approach is appropriate for analysing long-term structural trends over 1970–2021. Conducting regression analysis would require harmonised global panel data on structural breaks, technological adoption rates, and institutional differences – datasets that extend beyond the scope of this research. Instead, the comparative structural approach employed here allows the authors to identify generalisable patterns across income groups and industrial eras. This methodological choice is consistent with existing macro-comparative studies on long waves of technological change and global trade restructuring.

Traditionally, import substitution has been viewed as an instrument of industrialisation and economic growth. However, the key methodological challenge concerns how to “record” the occurrence of import substitution. At the micro level, this process is straightforward: goods and services previously produced or purchased abroad are subsequently produced and purchased domestically. At the macroeconomic level, however, this process is far less transparent.

Based on the classical expenditure approach to GDP:

$$Y = C + I + G + E_x - I_m, \quad (1)$$

where Y – Gross Domestic Product (GDP), C – consumption, I – investment, G – government spending, E_x – export, I_m – import.

At first glance, one might argue that, ceteris paribus, a decrease in imports should lead to an increase in GDP, and thus the maximisation of GDP would occur when imports approach zero and exports reach a maximum. However, this proposition is incorrect; the optimum exists under entirely different structural conditions.

Changes in the absolute values of imports also do not allow us to determine whether import substitution has occurred. For instance, a simultaneous decrease in both exports and imports cannot be interpreted as import substitution. Therefore, it is more appropriate to consider relative indicators – namely, changes in the shares of exports and imports in GDP.

Let us examine (1) at two moments in time, t and $t + 1$:

$$Y_t = C_t + I_t + G_t + E_{xt} - I_{mt}, \quad (2)$$

$$Y_{t+1} = C_{t+1} + I_{t+1} + G_{t+1} + E_{xt+1} - I_{mt+1}, \quad (3)$$

GDP growth between periods is defined as:

$$y_{t+1} = \frac{(Y_{t+1} - Y_t)}{Y_t}, \quad (4)$$

Export and import shares in GDP at time t:

$$exp_t = \frac{E_{xt}}{Y_t}, \quad (5)$$

$$imp_t = \frac{I_{mt}}{Y_t}, \quad (6)$$

Changes in export and import shares:

$$\Delta exp_{t+1} = exp_{t+1} - exp_t, \quad (7)$$

$$\Delta imp_{t+1} = imp_{t+1} - imp_t \quad (8)$$

Thus, the main hypothesis of this study is that the GDP growth rate (y_{t+1}) depends on changes in exports and imports in GDP structure (Table 1).

In this research, a strong quantitative criterion of import substitution is defined as a decrease in the import share in GDP accompanied by an increase in the export share. A weak quantitative criterion is defined as a decrease in both import and export shares in GDP, with the decrease in imports exceeding the decrease in exports.

The statistical basis of the study consists of World Bank data:

1) Exports of goods and services (% of GDP) [5];
2) Imports of goods and services (% of GDP) [6];
3) GDP growth (annual %) [42];
4) World Trade Statistical Review 2021 [7].

Data extraction and pre-processing were performed using a Python-based program capable of analysing large datasets, visualising trends, applying machine learning techniques, and automating data-processing routines.

The principal method applied in this study is comparative analysis. It is used to compare GDP dynamics under conditions of structural changes in export and import shares. The analytical logic progresses from general global patterns to specific income-group trajectories.

Table 1: Options for structural import substitution (changes in exports and imports).

Option	In the GDP structure		Description of the option from the perspective of import substitution
	Export	Import	
1	Increase $\Delta exp_{t+1} > 0$	Increase $\Delta imp_{t+1} > 0$	
1.1	The share of exports is growing faster than the share of imports ($\Delta exp_{t+1} > \Delta imp_{t+1}$)		Harmonious structural import substitution (by export) is taking place
1.2	The share of exports is growing at the same level as the share of imports $\Delta exp_{t+1} = \Delta imp_{t+1}$		The status quo is maintained
1.3	The share of exports is growing more slowly than the share of imports $\Delta exp_{t+1} < \Delta imp_{t+1}$		Structural export substitution (by import) is taking place
2	Increase $\Delta exp_{t+1} > 0$	Decrease $\Delta imp_{t+1} < 0$	Active (effective) import substitution is taking place
3	Decrease $\Delta exp_{t+1} < 0$	Increase $\Delta imp_{t+1} > 0$	Export substitution by import is taking place
4	Decrease $\Delta exp_{t+1} < 0$	Decrease $\Delta imp_{t+1} < 0$	
4.1	Exports are falling faster than imports in the GDP structure ($\Delta exp_{t+1} < \Delta imp_{t+1}$)		Passive (negative) export substitution occurs
4.2	Imports are falling faster than exports in the GDP structure ($\Delta exp_{t+1} > \Delta imp_{t+1}$)		Passive (negative) import substitution is taking place
4.3	Imports and exports in the GDP structure decrease equally ($\Delta exp_{t+1} = \Delta imp_{t+1}$)		The status quo is maintained

4 RESULTS

The dynamics of import changes in the GDP structure, at first glance, agree with the dynamics of the GDP itself (Fig. 2). However, this is not the case. The correlation coefficient between the dynamics of GDP and the structural dynamics of exports (imports) is only 60%. The synchronicity of structural changes in exports and imports is observed only at the global level.

Table 2 shows the number of cases of structural changes in exports and imports.

Table 2: The number of cases falling into each of the quadrants of structural change in exports and imports.

Export	Import	
	Decrease $\Delta imp_{t+1} < 0$	Increase $\Delta imp_{t+1} > 0$
Increase $(\Delta exp_{t+1} > 0)$	1280 (16%)	2947 (36.84%)
Decrease $\Delta exp_{t+1} < 0$	2421 (30.26%)	1352 (16.90%)

As presented in Table 2, in 2421 cases there is a trend of reduction in exports and imports. The largest group (2947 cases) shows simultaneous growth in both exports and imports, which might suggest overall trade expansion.

The calculations given in Table 3 prove that the value of average GDP growth is significantly influenced by structural changes in exports and imports. At the same time, the greatest GDP growth is observed when the share of exports increases and the share of imports decreases. As the calculations show, under such conditions, the average GDP growth is 4.17%. Under conditions of a simultaneous increase in the share of exports and imports, the average GDP growth is estimated at 3.98%. On average, under conditions of an increase in the export share and a decrease in the import share, as well as a simultaneous increase in both export and import shares, GDP growth is 4.38% and 4.68%, respectively (Table 4).

The highest GDP growth is observed in cases involving countries with upper middle income or high income levels and a simultaneous increase in the shares of exports and imports (Table 4). In these cases, the average annual GDP growth is 5.61%.

Table 3: Average GDP growth under conditions of structural change in exports and imports, *%*.

Export	Import	
	Decrease $\Delta imp_{t+1} < 0$	Increase $\Delta imp_{t+1} > 0$
Increase $(\Delta exp_{t+1} > 0)$	4.17	3.98
Decrease $\Delta exp_{t+1} < 0$	2.75	3.72

With a middle income level, an increase in the export share and a decrease in the import share, the average GDP growth is slightly lower but still significant, at 5.41%. It is important to note that for countries with high income or upper middle income levels, the maximum GDP growth is achieved with a simultaneous increase in exports and imports within the GDP structure. For other countries, with middle income, lower middle income, or low income levels, the optimal approach for ensuring economic growth is an increase in exports in the structure alongside a structural decrease in imports.

It is also necessary to highlight that for countries with middle income, lower middle income, or low income levels, a simultaneous decrease in both exports and imports in the structure is more preferable (from the perspective of GDP growth) than a structural decrease in exports under conditions of structural import growth. For example, for countries with middle income, in the first case, GDP growth is 4.4%, while in the second, it is 3.75%. For countries with high income or upper middle income levels, the situation is diametrically opposite. Thus, for high income countries in the case ($\Delta exp_{t+1} < 0$; $\Delta imp_{t+1} > 0$), GDP growth is 3.18%, while in the case ($\Delta exp_{t+1} < 0$; $\Delta imp_{t+1} < 0$), it is significantly lower, at only 1.24%.

Thus, it can be stated that the income level and structural changes in exports and imports have a substantial impact on GDP growth, and there are different growth patterns for two groups of countries.

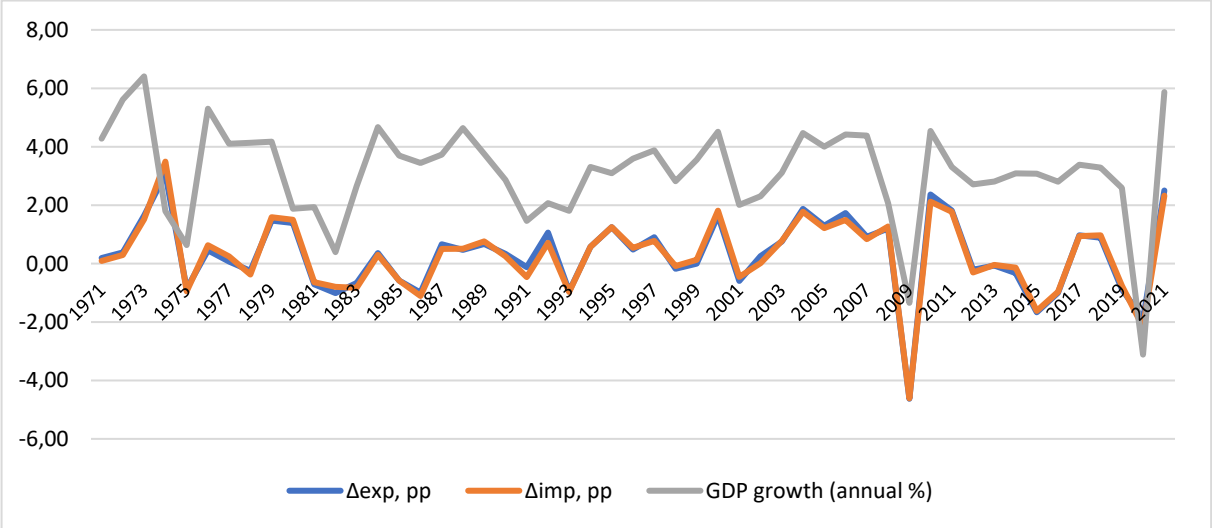

Figure 2: GDP growth, exports and imports relative to world GDP in 1970-2021, %. Built on data [5] - [7].

Table 4: Average GDP growth depending on the average income level under conditions of structural change in exports and imports, %.

Income level	$\Delta exp_{t+1} > 0$ $\Delta imp_{t+1} < 0$	$\Delta exp_{t+1} > 0$ $\Delta imp_{t+1} > 0$	$\Delta exp_{t+1} < 0$ $\Delta imp_{t+1} > 0$	$\Delta exp_{t+1} < 0$ $\Delta imp_{t+1} < 0$
1. High income	1.80	3.27	3.18	1.24
2. Upper middle income	5.15	5.61	4.81	4.62
3. Middle income	5.41	5.24	3.75	4.40
4. Lower middle income	4.97	4.92	3.17	3.83
5. Low income	4.54	4.38	3.04	3.68
Average	4.38	4.68	3.59	3.55

The first group includes countries with upper middle income or high income levels, while the second includes countries with middle income, lower middle income, or low income levels. The change in growth patterns occurs during the transition from middle income levels to upper middle income levels.

As shown in Table 5, the scenario of a structural increase in exports alongside a decrease in imports is most typical for countries with middle income or lower middle income levels. It is least typical for countries with high income levels.

The scenario of a simultaneous increase in the shares of exports and imports within the GDP structure is most typical for countries with high income levels. It is least typical for countries with low income levels.

The scenario of a decrease in exports in the structure alongside an increase in imports is most typical for countries with lower middle income levels. It is least typical for countries with high income levels.

The scenario of a simultaneous decrease in the shares of exports and imports within the GDP structure is most typical for countries with upper middle income levels. It is least typical for countries with low income levels.

The study illustrates (Table 6) that, without accounting for structural changes in exports and imports, GDP growth was faster under the conditions of Industry 3.0 than under Industry 4.0 (3.91% and 2.5%, respectively). However, the maximum growth during the era of Industry 3.0 occurs in scenarios of structural export growth alongside a reduction in the import share within the GDP structure, reaching 4.46% annually. In the era of Industry 4.0, the emphasis shifts. The highest growth is observed in countries where the share of exports grows faster than the share of imports.

Table 5: The Distribution of Observations by Income Level in the Context of Structural Changes in Exports and Imports within GDP.

Income level	$\Delta exp_{t+1} > 0$ $\Delta imp_{t+1} < 0$	$\Delta exp_{t+1} > 0$ $\Delta imp_{t+1} > 0$	$\Delta exp_{t+1} < 0$ $\Delta imp_{t+1} > 0$	$\Delta exp_{t+1} < 0$ $\Delta imp_{t+1} < 0$
1. High income	2 (6.9%)	31 (26.5%)	2 (10%)	16 (18.6%)
2. Upper middle income	7 (24.1%)	25 (21.4%)	5 (25%)	23 (26.7%)
3. Middle income	8 (27.6%)	27 (23.1%)	3 (15%)	22 (25.6%)
4. Lower middle income	8 (27.6%)	23 (19.7%)	7 (35%)	16 (18.6%)
5. Low income	4 (13.8%)	11 (9.4%)	3 (15%)	9 (10.5%)
Total	29 (100%)	117 (100%)	20 (100%)	86 (100%)

Table 6: GDP growth depending on the direction and speed of structural change in exports and imports, *%.*

Option	In the GDP structure		Industry 3.0 (before 2011)	Industry 4.0 (2012-2021)
	Export	Import		
	Without taking into account the structure of exports and imports		3.91	2.50
1	Increase $\Delta exp_{t+1} > 0$	Increase $\Delta imp_{t+1} > 0$	4.07	3.60
(1.1)	The share of exports is growing faster than the share of imports ($\Delta exp_{t+1} > \Delta imp_{t+1}$)		4.08	3.75
(1.2)	The share of exports is growing more slowly than the share of imports $\Delta exp_{t+1} < \Delta imp_{t+1}$		4.06	3.50
(1.3)	The share of exports is growing at the same level as the share of imports $\Delta exp_{t+1} = \Delta imp_{t+1}$		n/d	n/d
2	Increase $\Delta exp_{t+1} > 0$	Decrease $\Delta imp_{t+1} < 0$	4.46	3.09
3	Decrease $\Delta exp_{t+1} < 0$	Increase $\Delta imp_{t+1} > 0$	4.19	1.94
4	Decrease $\Delta exp_{t+1} < 0$	Decrease $\Delta imp_{t+1} < 0$	3.22	1.56
(4.1)	Imports are falling faster than exports in the GDP structure ($\Delta exp_{t+1} > \Delta imp_{t+1}$)		3.07	2.14
(4.2)	Exports are falling faster than imports in the GDP structure ($\Delta exp_{t+1} < \Delta imp_{t+1}$)		3.42	0.72
(4.3)	Imports and exports in the GDP structure decrease equally ($\Delta exp_{t+1} = \Delta imp_{t+1}$)		n/d	1,49*

Notes: * one observation.

In the most disadvantageous position during the era of Industry 4.0 are countries where exports fall faster than imports in the GDP structure. The average annual GDP growth in such cases is 0.72%. The analysis of deviations from average GDP growth rates shows that the transition from Industry 3.0 to Industry 4.0 is characterized by a significant increase in volatility in the context of structural changes. Specifically, the coefficient of variation under Industry 4.0 more than doubled compared to Industry 3.0, rising from 1.39 to 3.03 percentage points (Table 7).

Accordingly, the maximum positive deviation in the era of Industry 3.0 was 0.55 percentage points, while in Industry 4.0 it was 1.25 percentage points. The maximum negative deviations were -0.84 percentage points and -1.78 percentage points, respectively. Thus, against the background of slowing economic growth, the role of structural changes in exports and imports within GDP has strengthened.

5 DISCUSSION AND LIMITATIONS OF THE RESEARCH

The empirical findings indicate that the transition from Industry 3.0 to Industry 4.0 has substantially reshaped the relationship between export–import structures and GDP growth. These results should be interpreted in the context of current research on digital transformation, global value chains, and technological restructuring.

Table 7: Deviation from average GDP growth depending on the structural change in exports and imports, *p.p.*

Option	In the GDP structure		Industry 3.0 (before 2011)	Industry 4.0 (2012-2021)
	Export	Import		
1	Increase $\Delta exp_{t+1} > 0$	Increase $\Delta imp_{t+1} > 0$	0.16	1.10
(1.1)	The share of exports is growing faster than the share of imports ($\Delta exp_{t+1} > \Delta imp_{t+1}$)		0.17	1.25
(1.2)	The share of exports is growing more slowly than the share of imports $\Delta exp_{t+1} < \Delta imp_{t+1}$		0.15	1.00
(1.3)	The share of exports is growing at the same level as the share of imports $\Delta exp_{t+1} = \Delta imp_{t+1}$		n/d	n/d
2	Increase $\Delta exp_{t+1} > 0$	Decrease $\Delta imp_{t+1} < 0$	0.55	0.59
3	Decrease $\Delta exp_{t+1} < 0$	Increase $\Delta imp_{t+1} > 0$	0.28	-0.56
4	Decrease $\Delta exp_{t+1} < 0$	Decrease $\Delta imp_{t+1} < 0$	-0.69	-0.94
(4.1)	Imports are falling faster than exports in the GDP structure ($\Delta exp_{t+1} > \Delta imp_{t+1}$)		-0.84	-0.36
(4.2)	Exports are falling faster than imports in the GDP structure ($\Delta exp_{t+1} < \Delta imp_{t+1}$)		-0.49	-1.78
(4.3)	Imports and exports in the GDP structure decrease equally ($\Delta exp_{t+1} = \Delta imp_{t+1}$)		n/d	-1.01
Range of variation			1.39	3.03

First, the observed increase in GDP growth volatility under 4IR can be attributed to accelerated technological diffusion and digitalisation. AI-driven optimisation improves responsiveness to market fluctuations but simultaneously heightens exposure to global disruptions, including supply-chain bottlenecks, geopolitical tensions, and technological shocks. This dual effect contributes to the higher coefficient of variation documented in the study.

Second, the results reveal two distinct growth models. High-income and upper-middle-income economies benefit most from a balanced expansion of both exports and imports. This aligns with their deep integration into global value chains, where they rely on technologically sophisticated intermediate imports while exporting high-value-added goods and digital services. Their comparative advantage is rooted in innovation capacity, digital platforms, and advanced manufacturing systems.

In contrast, middle-income and low-income economies exhibit stronger GDP growth under export-led substitution, particularly when import shares decline. This reflects ongoing efforts to strengthen domestic production capacity, reduce dependence on imported intermediates, and leverage cost or resource advantages. However, for these economies, AI and automation may generate additional challenges by shifting global production toward more technologically advanced centres, increasing the need for targeted export development strategies.

Third, the structural break associated with 4IR suggests that global trade has become more sensitive to technological disruptions. Automation, robotics, and digital platforms reshape comparative advantages more rapidly than in previous industrial eras, making the structural composition of trade flows a critical determinant of macroeconomic performance.

Several limitations of the study should be acknowledged:

1) The analysis does not include regression modelling, lag structures, or instrumental variables; therefore, causal inference remains limited.
2) The use of aggregate country-level data does not allow for capturing micro-level mechanisms of 4IR adoption, such as firm-level productivity or sectoral digitalisation.
3) The Industry 4.0 period (2012–2021) is relatively short and includes major shocks such as the COVID-19 pandemic, which may distort long-term structural patterns.
4) The study does not differentiate between types of exports (goods vs. services), despite the fact that 4IR disproportionately accelerates the growth of digital services.

These limitations highlight promising directions for future research, particularly in expanding the analysis through econometric modelling, sectoral decomposition, and firm-level datasets.

6 CONCLUSIONS

The results of the study allow for several key conclusions.

1) The term import substitution is widely used in the academic literature, as evidenced by a substantial body of research in economic theory and international economic relations. Although conceptually well-established, its macroeconomic measurement remains methodologically challenging.
2) The findings confirm the hypothesis that GDP growth rates depend on structural changes in the shares of exports and imports. The analysis demonstrates that GDP dynamics follow different trajectories depending on the direction and magnitude of these structural trade shifts. High-income countries are characterised by simultaneous increases in both export and import shares within the GDP structure, reflecting their integration into global value chains.
3) The study compares GDP growth patterns during the emergence of the Fourth Industrial Revolution with those observed during the period dominated by Industry 3.0. The comparison reveals important structural differences in how economies respond to changes in trade composition.
4) The results show that structural substitution of imports by exports is associated with more dynamic GDP growth relative to long-term averages. The Fourth Industrial Revolution affects GDP growth not only by accelerating technological transformation but also by increasing volatility. This is reflected in a more than twofold rise in the coefficient of variation (from 1.39 to 3.03 percentage points), indicating greater sensitivity of GDP growth to structural trade adjustments.

Future research will extend this work by examining the impact of artificial intelligence technologies on economic growth across countries with different income levels and technological trajectories.

REFERENCES

[1] O. Vyshnevskyi, V. Liashenko, and O. Amosha, "The impact of Industry 4.0 and AI on economic growth," Sci. Pap. Silesian Univ. Technol. Organ. Manag. Ser., vol. 9, pp. 391–400, 2019, doi: 10.29119/1641-3466.2019.140.32.

[2] O. Vyshnevskyi et al., "Economic growth in the conditions of digitalization in the EU countries," Estud. Econ. Apl., vol. 38, no. 4, pp. 1–15, 2020, doi: 10.25115/eea.v38i4.4041.

[3] A. Kuzior, O. Vyshnevskyi, and N. Trushkina, "Assessment of the impact of digitalization on greenhouse gas emissions on the example of EU member states," Prod. Eng. Arch., vol. 28, no. 4, pp. 407–419, 2022, doi: 10.30657/pea.2022.28.50.

[4] N. Trushkina, "The relationship between artificial intelligence and critical infrastructure development: Bibliometric analysis," in Proc. Int. Conf. Applied Innovation in Information Technology (ICAIIT), vol. 13, no. 1, pp. 231–241, 2025, doi: 10.25673/119238.

[5] World Bank, "Exports of goods and services (% of GDP), 1970–2021," 2021. [Online]. Available: https://data.worldbank.org/indicator/NE.EXP.GNFS.ZS.

[6] World Bank, "Imports of goods and services (% of GDP), 1970–2021," 2021. [Online]. Available: https://data.worldbank.org/indicator/NE.IMP.GNFS.ZS.

[7] World Trade Organization, World Trade Statistical Review 2021. Geneva, Switzerland, 2021. [Online]. Available: https://www.wto.org/english/res_e/statis_e/wts2021_e/wts2021_e.pdf.

[8] E. Brynjolfsson and B. Kahin, Understanding the Digital Economy: Data, Tools, and Research. Cambridge, MA, USA: MIT Press, 2000.

[9] C. Dahlman, S. Mealy, and M. Wermelinger, "Harnessing the digital economy for developing countries," OECD, Paris, France, 2016. [Online]. Available: http://www.oecd-ilibrary.org.

[10] H. Dzwigol et al., "Manager competency assessment model in the conditions of Industry 4.0," Entrepreneurship Sustain. Issues, vol. 7, no. 4, pp. 2630–2644, 2020, doi: 10.9770/jesi.2020.7.4(5).

[11] T. Elmasry et al., "Digital Middle East: Transforming the region into a leading digital economy," McKinsey & Company, New York, NY, USA, 2016. [Online]. Available: http://www.mckinsey.com.

[12] A. Kwilinski, "Implementation of blockchain technology in accounting sphere," Acad. Account. Financ. Stud. J., vol. 23, no. SI2, pp. 1–6, 2019.

[13] A. Kwilinski, H. Dzwigol, and V. Dementyev, "Model of entrepreneurship financial activity of the transnational company based on intellectual technology," Int. J. Entrep., vol. 24, pp. 1–5, 2020.

[14] F. Machlup, Knowledge: Its Creation, Distribution and Economic Significance, Vol. I: Knowledge and Knowledge Production. Princeton, NJ, USA: Princeton Univ. Press, 2014.

[15] R. Miśkiewicz, "Challenges facing management practice in the light of Industry 4.0: The example of Poland," Virtual Econ., vol. 2, no. 2, pp. 37–47, 2019, doi: 10.34021/ve.2019.02.02(2).

[16] A. Tugui, "Meta-digital accounting in the context of cloud computing," in Encyclopedia of Information Science and Technology, 3rd ed., IGI Global, USA, 2015, pp. 20–32.

[17] M. Carlberg et al., "Industry 4.0," European Parliament, 2016, doi: 10.2861/947880.

[18] K. Schwab, The Fourth Industrial Revolution. Geneva, Switzerland: World Economic Forum, 2016.

[19] T. Philbeck and N. Davis, "The Fourth Industrial Revolution," J. Int. Aff., vol. 72, no. 1, pp. 17–22, 2018. [Online]. Available: https://www.jstor.org/stable/26588339.

[20] CompaniesMarketCap, "Largest companies by market cap," 2024. [Online]. Available: https://companiesmarketcap.com.

[21] L. W. Mihardjo, Sasmoko, F. Alamsyah, and Elidjena, "Boosting the firm transformation in Industry 5.0: Experience-agility innovation model," Int. J. Recent Technol. Eng., vol. 8, no. 2, pp. 735–742, 2019, doi: 10.35940/ijrte.B1154.0982S919.

[22] S. Nahavandi, "Industry 5.0 – a human-centric solution," Sustainability, vol. 11, no. 16, pp. 4371–4384, 2019, doi: 10.3390/su11164371.

[23] L. Świątek, "From Industry 4.0 to Nature 4.0 – Sustainable infrastructure evolution by design," in Advances in Intelligent Systems and Computing, vol. 788, Cham, Switzerland: Springer, 2019, pp. 438–447, doi: 10.1007/978-3-319-94199-8_42.

[24] V. Roblek, M. Meško, and I. Podbregar, "Mapping of the emergence of Society 5.0: A bibliometric analysis," Organizacija, vol. 54, no. 4, pp. 293–305, 2021, doi: 10.2478/orga-2021-0020.

[25] A. Lewandowska, J. Berniak-Woźny, and N. Ahmad, "Competitiveness and innovation of SMEs under Industry 4.0 and 5.0 challenges," Equilibrium, vol. 18, no. 4, pp. 1045–1074, 2023, doi: 10.24136/eq.2023.033.

[26] L. Anantharaman and M. R. Sridharan, "Evolving an industrial digital ecosystem: A transformative case of the leather industry," in Studies in Big Data, vol. 38, Singapore: Springer, 2018, pp. 247–272, doi: 10.1007/978-981-10-7515-5_18.

[27] E. Øvrelid and B. Bygstad, "The role of discourse in transforming digital infrastructures," J. Inf. Technol., vol. 34, no. 3, pp. 221–242, 2019, doi: 10.1177/0268396219831994.

[28] B. Hinings et al., "Digital innovation and transformation: An institutional perspective," Inf. Organ., vol. 28, no. 1, pp. 52–61, 2018, doi: 10.1016/j.infoandorg.2018.02.004.

[29] M. Burri and T. Cottier, Trade Governance in the Digital Age: World Trade Forum. Cambridge, UK: Cambridge Univ. Press, 2012, doi: 10.1017/CBO9781139136716.002.

[30] C. M. T. Johnston and J. Buongiorno, "Impact of Brexit on the forest products industry," Forestry, vol. 90, no. 1, pp. 47–57, 2017, doi: 10.1093/forestry/cpw062.

[31] Y. Sun et al., "Global supply chains amplify economic costs of future extreme heat risk," Nature, vol. 627, pp. 797–804, 2024, doi: 10.1038/s41586-024-07147-z.

[32] M. P. Abreu, S. A. Bevilacqua, and M. D. Pinho, "Import substitution and growth in Brazil, 1890s–1970s," Texto para Discussão, no. 366, 1996. [Online]. Available: https://www.econstor.eu.

[33] A. R. Adewale, "Import substitution industrialisation and economic growth: Evidence from BRICS," Future Bus. J., vol. 3, no. 2, pp. 138–158, 2017, doi: 10.1016/j.fbj.2017.06.001.

[34] J. A. Datas-Panero, "Import substitution," Finance Dev., vol. 8, no. 3, pp. 34–39, 1971. [Online]. Available: https://www.elibrary.imf.org.

[35] D. Irwin, "Import substitution is making an unwelcome comeback," Peterson Institute for International Economics, 2020. [Online]. Available: https://www.piie.com.

[36] D. Irwin, "The rise and fall of import substitution," World Dev., vol. 139, Art. no. 105306, 2021, doi: 10.1016/j.worlddev.2020.105306.

[37] A. Mendes, M. Bertella, and R. Teixeira, "Industrialization in Sub-Saharan Africa and import substitution policy," Braz. J. Polit. Econ., vol. 34, no. 1, pp. 120–138, 2014, doi: 10.1590/S0101-31572014000100008.

[38] B. Sudarmawan, "The correlation of international trade and growth in Indonesia," J. Econ. Dev., vol. 30, no. 1, pp. 31–46, 2022, doi: 10.14203/JEP.30.1.2022.31-46.

[39] C. Sapelli, "The political economics of import substitution industrialization," Documentos de Trabajo, no. 257, 2003. [Online]. Available: https://ideas.repec.org.

[40] J. Okwori, "Import substitution strategy and industrial sector performance in Nigeria," J. Econ. Policy Anal., vol. 3, no. 3, pp. 47–62, 2018. [Online]. Available: https://www.researchgate.net.

[41] O. Gbenga and O. Oghenebrorhie, "Globalization and industrialization in Nigeria," Soc. Manag. Sci., vol. 15, no. 1, pp. 12–24, 2023. [Online]. Available: https://www.researchgate.net.

World Bank, "GDP growth (annual %), 1970–2024," 2024. [Online]. Available: https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG.