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DIGITAL TRANSFORMATION AND ECONOMIC DEINDUSTRIALISATION: IMPACT ON STATE FINANCIAL SECURITY

ABSTRACT

In the context of global challenges, digital transformation acts as a catalyst for emerging threats and heightened systemic risks, including those associated with premature economic deindustrialisation. Therefore, this study of the interrelationship and dual impact of accelerated digital transformation and economic deindustrialisation on state financial security is unequivocally relevant in the context of the comprehensive digitalisation of socio-economic relations. Through quantitative data analysis using Ukraine's economy as a case study, the study examines the correlation between information technology sector growth and declining industrial production, using energy consumption patterns as a key indicator. The key findings demonstrate a strong negative correlation between digital sector expansion and traditional industrial output. The analysis indicates that rapid digital economic development is leading to changes in sectoral proportions, primarily through the expansion of the digital sector, while simultaneously facilitating deindustrialisation processes. Furthermore, the study identifies critical vulnerabilities in state financial security arising from this economic restructuring, including reduced tax revenues from traditional industries, increased economic instability, and growing dependence on digital infrastructure. The study concludes that while digital transformation stimulates innovation and creates new economic opportunities, it simultaneously generates additional threats to state financial security through accelerated deindustrialisation. This study contributes to the understanding of contemporary economic transitions and their implications for national financial resilience, suggesting that the modern paradigm of ensuring financial security should be based on minimising the risks associated with rapid digital transformation while leveraging its benefits for sustainable economic development.

Keywords: digitalisation, national economy, digital economy, socio-economic restructuring, threats, industrial decline, financial security

JEL Classification: C25, G17, E66, H56

INTRODUCTION

As an object of economic security studies, the digital transformation of the national economy is characterised by the potential for self-development, globality, polysystemicity, supranationality, low efficiency of direct interventions and dialectic. However, deterministic digitalisation does not create new threats; it only transforms the national economic system and financial and market models, with all its existing disadvantages and advantages. Instead, the flexibility, mobility, financial efficiency, promptness, speed of managerial decisions, network anonymity of actors and substantive transformation of economic elements shape the trends of new threats and contribute to the development of security solutions.

The dialectical nature of digitalisation is reflected in the combination of deterrent and incentive components. Deterrence, denial or any other regulatory restrictions on digitalisation are ineffective and destructive, as they fail to achieve the goal and harm the competitiveness of the economy, the development of technology and science, and the transition to the digital services economy. On the contrary, excessive incentives, opti-

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mism, and a barrier-free environment for digitalisation will contribute to the rapid development of technologies and solutions at the cost of their shallow study and lack of a security framework. This process will create significant turbulence, the negative impact of which will spread rapidly.

The development of the digital economy is inextricably linked to the energy and digital infrastructure that enable its existence and significantly affect the structure of the national economy. The study of sectoral changes in the economy under the influence of digitalisation and their impact on the economic and financial security of the state requires increased attention from state protection and regulatory mechanisms in the context of the global digitalisation of socio-economic processes.

LITERATURE REVIEW

The analysis of the level of scientific interest in digitalisation on a global scale, conducted using Google Trends (Figure 1), showed that scientists are paying increased attention to digital transformation problems.

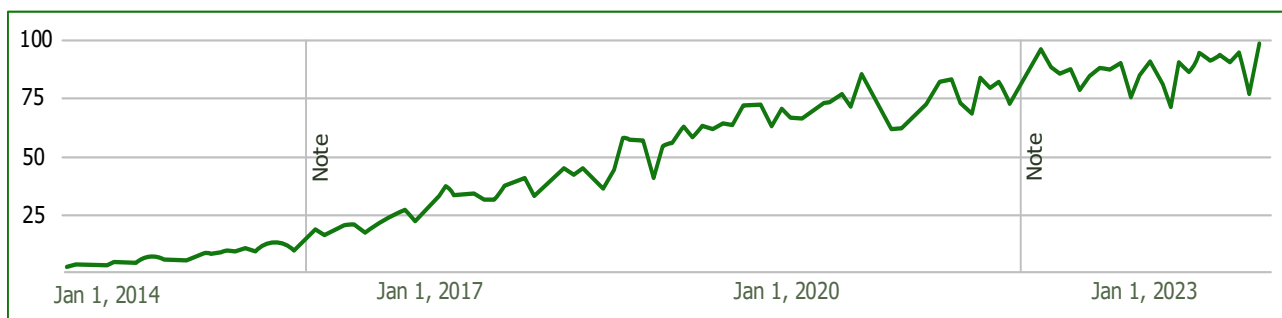


Figure 1. The dynamics of the popularity of the search term "digital transformation" from 01.01.2014 to 01.09.2024 worldwide, built using Google Trends tools.

The transformational processes associated with developing digital technologies in the context of the emergence of Industry 4.0 have brought to the forefront the research on the rapid digitalisation of economic activity. Studies in this area, such as Avi & Catherine (2019), focus on how digital technologies change economic activity and reduce economic costs. Baiyere et al. (2020) describe new management approaches to business process management in digital transformation. In this direction, Pappas et al. (2022) proposed the Digital Transformation and Sustainability (DTS) model and proved that significant data analytical ecosystems will drive digital transformation. Clark et al. (2016) and Elding & Morris (2018) noted the critical aspects for understanding technological optimism at the micro and nano levels.

Bezrukova et al. (2022) study the impact of digitalisation on the development of the global economy using the economies of European Union member states as an example. They prove that the transformation of economies using information and communication technologies not only strengthens countries' competitiveness but also helps to optimise and improve business processes in the international business environment. Zhang & Chen (2019) also argue that digital transformation has accelerated productivity growth with different effects on employment in different sectors.

Despite the growing share of the service sector due to the development of the IT sector and the Internet of Things, Lautier (2024) argues that manufacturing continues to play a key role in economic development. Stemmler (2023) finds that digitalisation can contribute to "premature deindustrialisation" in emerging economies. As Callaghan (2021) proves, this has led to a slowdown in globalisation. Also, according to Liu & An (2023), deindustrialisation increases poverty in developing countries. Therefore, another crucial area of research on the chosen issue concerns the risks of digitalisation.

In this direction, Curran (2018) has explored how the innovative impetus of the digital economy creates risks and limits the scope of decision-making. The World Economic Forum (2024) monitors current global risks and threats on a systematic basis, among which digital risks are gaining priority. As Kanegaonkar (2024) proves, economic and security risks have been high for several decades and manifest themselves in economic crises and wars. Merrin (2018) explores the range of uses of digital technologies in modern wars and conflicts, while Merrin & Hoskins (2020) emphasise that digital technologies have created new opportunities for destructive activities in general and laid the foundation for information wars. Similar works by Zakeri et al. (2022) and Aviv & Ferri (2023) focus on the threats of energy and digital infrastructure involvement in hostilities and forceful influence on the economy and focus on individual components or technical and technological solutions. Onyshchenko V. et al. (2022, 2023) more comprehensively examine a wide range of digitalisation threats and focus on their primary impact on the state's financial security.

The methodological framework for identifying threats to the financial security of the state in Ukraine is defined by the Ministry of Economic Development and Trade of Ukraine (2013). However, given the changes in the national and global economy, the spread and penetration of digitalisation, the growing dependence of the economy on digital and energy infrastructure, and the deindustrialisation of the economy, there is a justified need to revise the system of indicators of the state's financial security, as noted by Onyshchenko S. et al. (2023), in particular, in terms of assessing the role of critical infrastructure and the degree of technology adoption at all levels of the social hierarchy. According to Biriuk et al. (2024), the constant transformation of the financial and credit system in rapid technological development requires adapting to change. Therefore, the problem of studying the impact of digitalisation and deindustrialisation on the state's financial security requires further in-depth research.

AIMS AND OBJECTIVES

The purpose of the study is to investigate the relationship between digital transformation and economic deindustrialisation, as well as their impact on the financial security of the state. Achieving this goal involves solving the tasks of studying the peculiarities of the development of the information technology sector in the structure of the national economy of Ukraine, studying the threat of deindustrialisation of the real sector of the national economy in the context of digitalisation, sectoral analysis of trends in the digital transformation of the Ukrainian economy; interpretation of the results obtained to assess the impact of the digital transformation of the economy in terms of deindustrialisation on the integral indicator of Ukraine's financial security using the method of correlation and regression analysis; determination of the conceptual framework for ensuring economic and financial security of Ukraine in the context of digital transformation of the economy.

METHODS

The study was conducted using general scientific and special economics methods. Using the methods of abstraction and concretisation, comparison, and generalisation, it investigated the peculiarities of the IT sector development in the structure of Ukraine's national economy based on the statistical data of the State Statistics Service of Ukraine [29] and the Ukrainian Association of Energy Auditors [31].

The threat of deindustrialisation of Ukraine's real sector is investigated using correlation, regression analysis, and modelling, using indicators of electricity production and the share of the IT sector in the country's GDP. The factors of further deindustrialisation of the national economy and threats of incomplete digitalisation were assessed using modelling and theoretical generalisation.

Statistical methods of time series analysis, linear and nonlinear regression with one variable, and graphical analysis were used to compare the gap in aggregate indicators of digital transformation penetration and spread between different economic sectors, estimate growth rates, and the ratio to certain parts of GDP, which allowed us to model the effects of energy and digital infrastructure on the pace of digitalisation.

The impact of the digital transformation of the economy in terms of deindustrialisation on the state's financial security was assessed using correlation and regression analysis. At the same time, in the absence of normatively approved methods for assessing digital transformation, using the developments of Lange, S. (2020), the author substantiates the feasibility of using the ratio of electricity production rates and the share of the IT sector in the country's GDP as a key indicator of deindustrialisation of the national economy due to digitalisation. This indicator reflects the loss of productivity and production volumes of the real analogue economy in favour of the digital one. To calculate the level of financial security of the state it was used the method of integral assessment was used in accordance with the Methodological Recommendations for Calculating the Level of Economic Security of Ukraine, approved by the Order of the Ministry of Economic Development and Trade of 29.10.2013 No. 1277 [19].

The study was conducted based on the official statistical indicators of the State Statistics Service of Ukraine [2] and the results of calculations of the Ministry of Economy of Ukraine, obtained in response to official requests No. ZI-647-24 of 27.05.2024 and No. ZI-952-23 of 05.10.2023 for public information on the indicators of the financial component of Ukraine's economic security [20, 21]. Significant limiting factors for the study are the lack of a significant amount of statistical information for 2022-2023 due to the inability to ensure data collection, analysis and dissemination under martial law and active hostilities in Ukraine.

RESULTS

The digital component of the economy is not self-sufficient and does not create material things; it only facilitates their production and related services, promotes the change of analogue processes to cyber ones, and requires only a limited number of physical infrastructure components. At the same time, it is incredibly dependent on uninterrupted energy supply, access to the Internet, and stable operation of providers and digital intermediaries, which make its activities possible or impossible.

The period of active development and formation of the Internet of Things and Ukraine's growing involvement in global digitalisation has created several positive effects, which have manifested themselves in increased labour efficiency, increased exports of digital services, higher living standards, a favourable foreign exchange balance, new jobs and others. Further macroeconomic effects of the digital transformation of the economy were also positive. For example, simplified access to financial services, increased transparency in economic relations, and reduced banking risks helped improve the investment and innovation climate. It prompted an increase in government support for digital industries. This process has led to increased digital exports and contributed to developing the image of engineering and technical professions.

The information technology sector has grown significantly during the COVID-19 crisis, which has driven its rapid development. Thus, according to the National Bank of Ukraine (2024), 2021 saw the most significant growth in IT exports since 2014 - by 38.1% per year. Also, even at the beginning of Russia's full-scale invasion of Ukraine, the IT sector of the national economy continued to demonstrate stable exports and an increase in its share of the gross domestic product. However, in the context of the ongoing war and massive attacks on the energy infrastructure, the IT sector has become more vulnerable, firstly, due to its dependence on electricity consumption, which, according to the results of the study by Lange, S. et al. (2020), Baidya et al. (2021) and Singh et al. (2022), is growing significantly in the context of the digitalisation of the economy, and secondly, due to the uninterrupted power supply, which has become significantly more difficult due to the aggressor's systematic attacks on the energy sector of Ukraine (Ostashko, 2023). With limited access to sources of communication and specialists, as well as against the backdrop of a global downturn in this industry, the information technology segment of Ukraine's economy in 2023 experienced an 8.5% decline in exports for the first time in more than 20 years, according to the National Bank of Ukraine (2024).

In addition, as confirmed by Stemmler (2023) and Liu & An (2023), in the medium and long term, along with the undeniable benefits and additional opportunities, the development of the digital services economy poses a threat to the deindustrialisation of the real sector of the national economy due to the growth of digital services and intangible goods. In developing countries, this can cause structural distortions (Varnalii et al., 2022) and a decrease in the competitiveness of manufacturing, potentially more knowledge-intensive sectors of the economy.

The deindustrialisation and servitisation of the economy caused by the spread and deepening of global digitalisation pose a significant challenge to Ukraine's economic and financial security system, especially in a full-scale intensive war, as the digital consumption economy generates several wartime vulnerabilities. In particular, the destruction of the energy infrastructure during the war, which is critical for large industries and an integral part of the work of all digital infrastructure entities, creates significant obstacles to the further effective functioning of the national economy in the context of rapid digitalisation.

In the context of digitalisation, it can be assumed that there is a correlation between the development of the information technology sector and the corresponding decline of the real economy sector, as reflected in energy consumption, as specialists, technology, investment and government support flow into the digital segment.

An analysis of electricity generation and consumption by volume and major consumers allows us to assess the national economy's complex industrial processes and approximate structure. Thus, according to the Ukrainian Association of Energy Auditors (2024), electricity production in 2011-2022 steadily decreased by 1.5% annually. At the same time, the share of commercial and municipal electricity consumption in Ukraine's economy is about 75%, excluding the activities of private consumers and entrepreneurs. As of 2021, the share of energy consumption used by industry, construction and agriculture is 36%. At the same time, with a decrease in energy production, the share of IT in Ukraine's GDP in 2011-2022, according to the State Statistics Service of Ukraine (2024), is increasing (Table 1).

Table 1. Indicators of electricity production and the share of the IT sector in Ukraine's GDP for 2011-2022. (Source: compiled by the authors based on data from the State Statistics Service of Ukraine and the Ukrainian Association of Energy Auditors)

Indicator/Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Share of the IT sector in GDP, %.	3	3.1	3.1	3.5	3.7	3.8	4	3.8	4	4.9	4.9	4.9
Electricity generation, billion kWh	194	198	194	182	163	154	155	159	153	148	156	113

The identified trends can be explained not only by the growth of energy efficiency and rising electricity prices but also by the deindustrialisation of the real sector of Ukraine's economy. In this regard, it is advisable to mathematically determine and consider the dependence of the growth of the IT sector's share in GDP on the decline in electricity production in Ukraine. A sufficient level of correlation between these indicators will indicate the threat of digitalisation as a direct or indirect factor in the deindustrialisation of the real sector of the national economy.

The source of this correlation may be not only the destructive impact of the IT sector on the real economy but also hidden variables, such as general trends in global development or long-term structural changes in the national economy. It is also worth investigating the opposite hypothesis, that the decline of the real sector stimulates the development of the IT sector, contributing to the flow of personnel and changes in market supply.

Several hypotheses are used to determine the form of the regression relationship. Given the presence of one variable and the multiplicative specificity of the relationship, the paired nonlinear regression equation (1) is worth using.

$$y = b * x^a \tag{1}$$

where *a* and *b* – the parameters of the regression equation; *y* – electricity production, billion kWh; *x* – the share of IT in GDP, %

For the first hypothesis, let us define *x* as the share of the IT sector in Ukraine's GDP and *y* as the volume of electricity production.

For the calculation, the nonlinear regression $y=b*x^a$ needs to be transformed into a linear one and the logarithms of both sides of the equation need to be taken. We get $\ln(y)=\ln(bxa)$, $\ln(y)=\ln(b)+a*\ln(x)$. Denote $y_1=\ln(y)$, $x_1=\ln(x)$, $b_1=\ln(b)$, and $a_1=a$. We obtain the equation of the auxiliary regression line $Y_1=a_1x_1+b_1$. From the equations $b_1 =\ln(b)$ and $a_1 =a$, we have that $a=a_1$ and $b=\exp(b_1)$ (Table 2).

Table 2. Logarithmically transformed indicators for calculating the pairwise nonlinear regression of the dependence of energy generation on the share of the IT sector in the national economy for 2011-2022.

Y	X	Y ₁	X ₁	Y ₁ *X ₁	X ₁ ²	Y _{1P}	(Y ₁ -Y _{1P}) ²	Y _p	(Y-Y _p) ²	(Y-Y _c) ²	(X ₁ -X _{1c}) ²
194.95	3	5.27	1.10	5.79	1.21	5.257	0.000	191.86	9.535	651.58	0.050
198.88	3.1	5.29	1.13	5.99	1.28	5.238	0.003	188.23	113.292	867.72	0.036
194.38	3.1	5.27	1.13	5.96	1.28	5.238	0.001	188.23	37.735	622.81	0.036
182.82	3.5	5.21	1.25	6.52	1.57	5.167	0.002	175.40	54.936	179.40	0.005
163.68	3.7	5.10	1.31	6.67	1.71	5.135	0.001	169.82	37.719	32.94	0.000
154.82	3.8	5.04	1.34	6.73	1.78	5.119	0.006	167.21	153.569	213.27	0.000
155.42	4	5.05	1.39	7.00	1.92	5.089	0.002	162.29	47.316	196.17	0.004
159.35	3.8	5.07	1.34	6.77	1.78	5.119	0.002	167.21	61.753	101.40	0.000
153.96	4	5.04	1.39	6.98	1.92	5.089	0.003	162.29	69.400	238.95	0.004
148.81	4.9	5.00	1.59	7.95	2.53	4.971	0.001	144.22	21.046	424.85	0.071
156.58	4.9	5.05	1.59	8.03	2.53	4.971	0.007	144.22	152.636	164.99	0.071
1863.6	41	56.39	14.54	74.40	19.51	56.39	0.03	1861.0	758.93	3694.08	1863.63

A system of normal equations (2) is required to determine the parameters *a*₁ and *b*₁ of the least-squares model.

$$\begin{cases} a_1 \sum_i x1_i^2 + b_1 \sum_i x1_i = \sum_i x1_i y1_i \quad (i = \overline{1, n}); \\ a_1 \sum_i x1_i + b_1 n = \sum_i y1_i \quad (i = \overline{1, n}); \end{cases} \quad (2)$$

where n – the number of study periods; y – electricity production, billion kWh; x – the share of IT in GDP, %.

The system of normal equations has the form $Z^*A=T$ in matrix form. The matrix solution of this equation will be performed using the least squares method (3-6) to determine the parameters a_1 and b_1 .

$$Z = \begin{pmatrix} \sum_i x1_i^2 & \sum_i x1_i \\ \sum_i x1_i & n \end{pmatrix} = \begin{pmatrix} 19,51 & 14,54 \\ 14,51 & 11 \end{pmatrix} \quad (3)$$

$$T = \begin{pmatrix} \sum_i x1_i y1_i \\ \sum_i y1_i \end{pmatrix} = \begin{pmatrix} 74,40 \\ 56,39 \end{pmatrix} \quad (4)$$

$$Z^{-1} = \begin{pmatrix} 3,58 & -4,74 \\ -4,74 & 6,36 \end{pmatrix} \quad (5)$$

$$A = T * Z^{-1} = \begin{pmatrix} a_1 \\ b_1 \end{pmatrix} = \begin{pmatrix} -0,58 \\ 5,895 \end{pmatrix} \quad (6)$$

where n – the number of study periods; Z – the matrix of system coefficients; T – the matrix of right-hand sides of the equation; Z^{-1} – the inverse matrix of system coefficients; A – the matrix of regression parameters.

Returning the indicators a_1 and b_1 into the linear dimension (7-8). It can be noted that the calculation of the paired nonlinear regression equation of the correlation of the real economy's decline by the development of the digital services economy is in the multiplicative form (9).

$$a = a_1 = -0,58 \quad (7)$$

$$b = \ln b_1 = \ln(5,895) = 363,5 \quad (8)$$

$$y = 363,5 * x^{-0,58} \quad (9)$$

where y – electricity generation, billion kWh; x – the share of IT in GDP, %.

In order to assess the adequacy of the chosen mathematical model to the experimental data, we will determine the assessment of the closeness and significance of the relationship between the variables in the regression model. The correlation coefficient (10) is 0.89, and the static significance, F-criterion (12) for a probability of 0.95, is 34.81 and is higher than the table value of 5.12, which means a strong correlation and adequacy of the model.

$$R = \sqrt{1 - \frac{\sum(y_i - y_{pi})^2}{\sum(y_i - \bar{y})^2}} \quad (10)$$

where R – the correlation coefficient; y_i – the electricity production for period i .

To assess the closeness of the relationship between the variables of the model, the coefficient of determination, calculated using the formula (5), needs to be calculated. The value is 0.79, which indicates a close relationship between the economic indicators of this function.

$$R^2 = 1 - \frac{\sum(y_i - y_{pi})^2}{\sum(y_i - \bar{y})^2} \quad (11)$$

$$F_{cal} = \frac{R^2}{1-R^2} * (n - 2) \quad (12)$$

where R^2 – the determination index; F_{cal} – the actual value of Fisher's criterion; n is the number of study periods.

Testing the second hypothesis of the inverse dependence of the share of the IT sector in Ukraine's GDP on electricity production, we obtain a correlation value of 0.85 (10), which is 0.04 less than the first hypothesis. Accordingly, the F-

criterion (12) of 23.06 is also less than the first hypothesis but more significant than the table value of 5.12; the second model remains adequate, which may also indicate a possible third correlator.

The possibility of an illusory correlation with a potential correlation – GDP growth rather than electrification – is insufficient, less than 0.5. The results confirm the assumption that the economy is being threatened by the deindustrialisation due to digital transformation.

Using the forecasting function of the estimated model and based on the electricity production values for 2023, the corresponding average share of energy-dependent components (including the IT industry) in the national economy can be calculated (13), which serves as a factor of further deindustrialisation.

$$x = \sqrt{\frac{a}{b}} = {}^{-0,51}\sqrt{\frac{104}{363,5}} = 11,63\% \quad (13)$$

where *a* and *b* – the parameters of the regression equation; *y* – electricity production, billion kWh; *x* – the share of IT in GDP, %.

This significant growth of the IT sector and the digitalisation of the economy both facilitates and requires the infrastructural transformation of the economy to minimise threats to the economic and financial security of the state. In addition, it is worth focusing on the different levels of digital transformation of economic entities, considering the professional qualities of staff, operating conditions and other factors that accelerate or slow down the digital transformation of business.

Considering the issue of incomplete digitalisation at the level of individual business entities and financial and economic institutions, three key obstacles are direct or indirect sources of threats to the security of the digital economy.

Firstly, the legislation needs to realise the potential of digital document management sufficiently, which forces double circulation and analogue storage of documents. Although the list of documents that are not available in digital form is constantly decreasing, incomplete or poor-quality digitalisation creates errors and inaccuracies, leads to parallel circulation of a large variety of documents, and increases the workload of staff. This operation risks in the context of extensive operational and information activities and strict reporting inherent in banking and insurance institutions.

Second, staff need to be provided with digital keys and signatures, trained in their use, and provided with the technical means. Such transformations are an obstacle to the broader involvement of market participants, without whom digital record-keeping is limited to internal processes. Software, staff training and hardware require additional investment, and pirated or free software can be compromised and pose a threat to internal infrastructure.

Thirdly, due to insufficient qualifications and support of contractors, intermediaries, and service users, the final forms of document flow are maintained, processed and stored in dual form. The combination of computer equipment for data processing and storage in the analogue form leads to threats of lack of legal support, conflict of digital methods of transferring analogue documents, and unbearable workload for staff to digitise.

Complete digitalisation of the financial and market environment and the economy, in general, is simultaneously unattainable for various reasons, including insufficient involvement of counterparties in the digital economy and regulatory insecurity. Creating a single digital document may require more time and effort than an analogue document, especially if the advantages of remote control and mobility are unimportant or unprincipled.

Due to the large number of software involved, errors can also occur due to the variability in the way documents are maintained, collected, and entered. In Ukraine, to address the threat of variability and conflict in the use of different software, a standardised exchange platform for Ptah has been created to ensure interoperability for digital document management.

A separate issue is the possibility of archival storage of these documents. Physical versions take up a lot of real space and are vulnerable to exogenous threats. On the other hand, digital documents must be stored in the cloud, making them a vulnerable target for hackers and technological espionage. In addition, some documents have long retention periods, and risks are associated with the durability of intermediaries. And storage on hard drives or USB sticks is also vulnerable to the external environment. Interruptions in power supply or Internet access by any entity make it impossible to access cloud services, which creates additional threats during urgent and crisis operations.

To estimate the gap in the levels of penetration and spread of digital transformation between different economic sectors that demonstrate leading positions in the use of information and communication technologies, as well as the largest sectors in terms of economic indicators, formulas (14-15) should be used.

$$GapTI = \frac{\overline{TI_T}}{\overline{TI_L}} \tag{14}$$

$$GapTI = \left(\frac{\frac{\sum_T(TIx)}{N_{Tx}}}{\frac{\sum_L(TIx)}{N_{Lx}}} + \frac{\frac{\sum_T(TIy)}{N_{Ty}}}{\frac{\sum_L(TIy)}{N_{Ly}}} + \dots \right) / N_{TI} \tag{15}$$

where *GapTI* – the gap between the leading digital transformation industries and the largest sectors of the economy; *TI_T* – the level of digital transformation of leading (top) industries; *TI_L* – the level of digital transformation of the largest industries; *TI_{x,y...}* – a separate transformation indicator defined and collected by the State Statistics Service; *NT/L* – the number of enterprises in the sample; *N_{TI}* – the number of transformation indicators in the sample.

The calculation was based on the following transformation indicators: the share of the number of enterprises that conducted e-commerce in the total number of enterprises; the share of the number of enterprises that sent invoices; the share of the number of enterprises that analysed big data; the share of the number of enterprises that conducted training in information and communication technology skills.

According to the State Statistics Service of Ukraine (2024), the food industry, metallurgy, and oil refining were studied as the largest industries in production and sales, and pharmaceuticals, computer programming, and telecommunications were identified as the leading industries in digital transformation.

The GapTI index, as calculated (Figure 2), shows an almost double gap between the leading (top) industries in digital transformation and the largest industries in sales. This gap is also growing with the growth of the digital economy, which underscores the main hypothesis of the economy's deindustrialisation in the context of digitalisation.

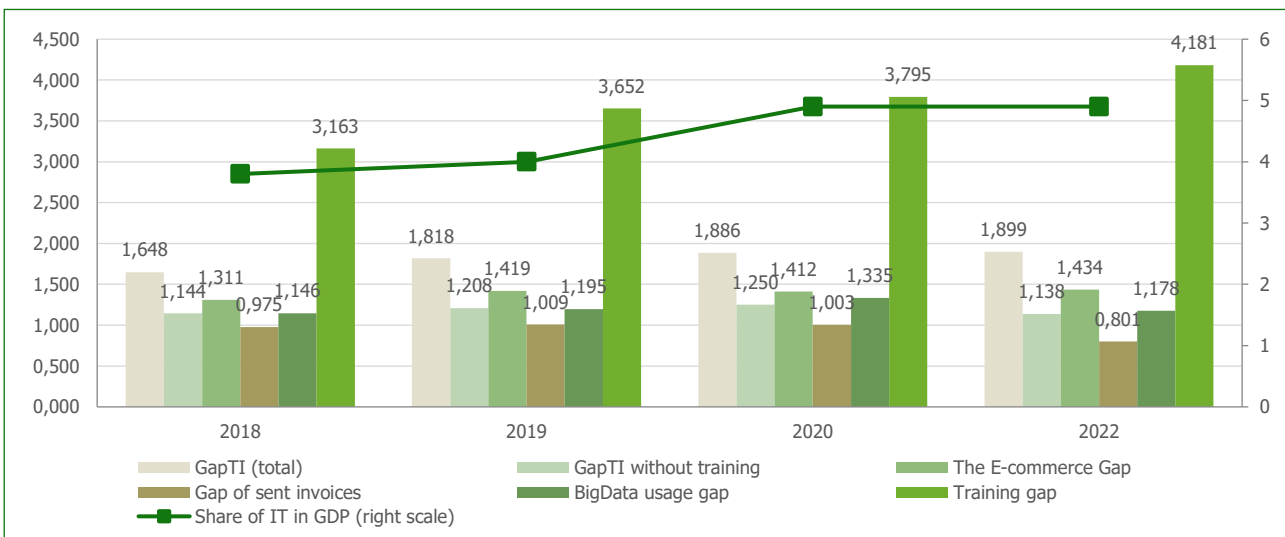


Figure 2. Results of calculating the gap between the leading digitalisation industries and the largest sectors of the economy in 2018-2022.

However, special attention is drawn to the use of digital financial elements for settlements, where the most prominent industries are, on the contrary, ahead of the leading ones in terms of the introduction of information and communication technologies, which highlights the duality and hybridity of processes between different market agents. This calculation indicates that the digital transformation of the Ukrainian economy is incomplete, inconsistent, and unbalanced.

In this context, it is useful to compare the enterprises that provided information and communication technology training services in 2020-2022 with the data of the European Investment Bank (2023) and the European Commission (2021) on the Digital Economy and Society Index (DESI) for 2021 for Ukraine and EU countries. Ukraine's overall score of 4.5% remained unchanged in both years while significantly lagging behind all EU countries, ranking among the laggards alongside Bulgaria (7%) and Romania (6%). An analysis of the economic sector shows that the share of the food industry is 4.8%, metallurgy 4.1%. In comparison, the leading sectors are telecommunications (23.7%) and pharmaceuticals (17.9%), comparable to the national figures for Ireland and Poland.

Thus, the active digital transformation of the economy under the influence of exogenous and endogenous factors causes inequality between the real and digital sectors of the economy. The short-term advantages of flexible medium and small

digital market players over large and less adaptive enterprises are created by technological optimism and wage differentials due to more excellent orientation towards easier access to the international market, leading to a decline in the competitiveness of the real economy.

The threat of deindustrialisation due to digital transformation can significantly impact the state's financial security, including budgetary stability, foreign exchange reserves, debt burden, and the banking system. Increased concentration of resources in the digital sector may contribute to increased financial risks. For example, dependence on cloud technologies or foreign software increases currency risks and dependence on foreign markets, which may affect the stability of the national currency and the state's currency security as part of the financial security. Suppose digitalisation processes are unevenly distributed among economic sectors. In that case, this may lead to an imbalance in the financial system, where the digital sector receives significant benefits while increasing threats to the economic security of the real sector of the national economy. This disbalance may lead to a reduction in state and local budget revenues, as the real sector of the economy provides a significant portion of tax revenues, a decline in employment in the real sector, which will increase public spending on social programs and unemployment and put additional pressure on the budget and debt components of financial security, and create new challenges for the banking system, in particular in the form of increased insolvency of enterprises in the real sector, which will affect the credit risks of banks.

In a traditional economy, GDP growth is often accompanied by increased energy consumption, as the primary electricity consumers are the real sectors (industry and agriculture). However, if GDP growth significantly exceeds the growth in electricity production, this may indicate a decrease in the role of energy-intensive industries in creating economic value added. Such a disproportion indicates deindustrialisation when the manufacturing sector is declining and the digital sector is growing, as it is much less energy-intensive. GDP growth without a proportional increase in electricity production may indicate the growing influence of the digital sector, which is characterised by high productivity with relatively low energy consumption. The IT sector, the services sector, and other sectors of the digital economy can generate high revenues and create value without putting a significant strain on energy resources. Therefore, the increase in electricity production according to GDP growth should be considered an indicator of the deindustrialisation of the economy due to digital transformation.

Analysing the relationship between the indicator of deindustrialisation of the economy as a result of digital transformation and the integral indicator of the state's financial security is extremely important for identifying the quantitative impact of the digital transformation of the economy on the state's financial security (Table 3). The advantage of this approach is also to avoid distortions from inflationary increases in nominal GDP.

Table 3. Growth rates of the indicator of deindustrialisation of the economy due to digital transformation and the level of financial security of Ukraine in 2012-2022. (Source: compiled by the authors based on the data of the State Statistics Service of Ukraine, the Ukrainian Association of Energy Auditors and the Ministry of Economy of Ukraine)

Indicator/Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Indicator of deindustrialisation of the economy due to digital transformation, %.	86.33	94.69	93.72	130.8	130.2	91.89	83.5	87.9	82.2	95.5	81.8	90.4
Increase in the integral indicator of the Financial Component of Ukraine's Economic Security, %.	111.90	100.00	106.38	80.00	87.50	108.57	105.26	112.50	93.33	95.24	100.00	77.50

To reflect the correlation between the indicator of deindustrialisation of the economy as a result of digital transformation and the growth of Ukraine's financial security, given one independent variable and the type of progression, we hypothesise a linear stochastic dependence, which should be reflected using a paired linear regression (16).

$$y = a * x + b \tag{16}$$

where y – the increase in the integral financial security indicator compared to the previous year, %; x – the indicator of deindustrialisation of the economy for the relevant period, %.

Table 4. Indicators for calculating the paired linear regression of financial security growth to the growth of economic deindustrialisation in 2011-2022. (Source: compiled by the authors)

Year	Y	X	Y*X	X ²	Y _p	(Y-Y _p) ²	(Y-Y _c) ²	(X-X _c) ²
2011	111.90	86.33	9661.05	7453.35	104.39	56.40	140.23	98.08
2012	100.00	94.69	9469.17	8966.52	100.74	0.55	0.00	2.39
2013	106.38	93.72	9970.48	8783.91	101.16	27.25	39.94	6.32
2014	80.00	130.8	10464.32	17109.70	84.94	24.45	402.53	1194.91
2015	87.50	130.2	11395.38	16960.62	85.19	5.32	157.83	1155.75
2016	108.57	91.89	9976.80	8444.07	101.96	43.67	72.39	18.88
2017	105.26	83.48	8787.75	6969.52	105.64	0.14	27.04	162.64
2018	112.50	87.89	9888.15	7725.48	103.71	77.24	154.68	69.59
2019	93.33	82.2	7672.02	6756.87	106.20	165.60	45.29	197.02
2020	95.24	95.53	9098.44	9126.67	100.37	26.34	23.28	0.49
2021	100.00	81.81	8181.44	6693.60	106.37	40.59	0.00	208.00
2022	1100.69	1144	104565.0	104990.3	1100.7	467.544	1063.212	3114.072

The calculation of the paired linear regression equation (Table 4) to reflect the correlation of the impact of deindustrialisation of the economy as a result of digital transformation on the dynamics of financial security is in linear form (17).

$$y = -0,44 * x + 142,15 \quad (17)$$

where y – the increase in the integral financial security indicator compared to the previous year, %; x – the indicator of deindustrialisation of the economy for the relevant period, %.

Similarly, to the first regression study, it is worthwhile to assess the adequacy of the model. The correlation coefficient (10) is 0.75, and the F-test (12) for a probability of 0.95 is 11.47, which is higher than the table value of 2.201. This calculation means the correlation is relatively high, and the model is adequate.

Thus, these indicators correlate, making it possible to model the financial system's security state in accordance with the dynamics of processes caused by digitalisation.

The opposite hypothesis was not considered since the financial security indicator is a derivative. The possibility of an illusory correlation with the real correlation - GDP growth, a partial component of both indicators - is not confirmed since the correlation in this case is insufficient, less than 0.5.

It should be noted that a full-scale invasion further worsens the state's financial security, and therefore, further forecasts require new calculations. However, deviations from the 2022 figures (18-20) can be calculated, thus modelling the impact of digitalisation in wartime on the state's financial security and determining the forecast for 2023 (21-22).

$$\Delta y = (y_{cal} - (t_{crit} * \sqrt{\frac{(y_i - \bar{y})^2}{n-m-1}} * \sqrt{\frac{1}{n} + \frac{(x_i - \bar{x})^2}{\sum(x_i - \bar{x})^2}})) - y_{act} \quad (18)$$

$$\Delta y = \left(104,8 - \left(2,201 * \sqrt{\frac{467}{11-2-1}} * \sqrt{\frac{1}{11} + \frac{117}{3114}} \right) \right) - 77,5 = 20\% \quad (19)$$

$$\Delta y_1 = -0,44 * 85,4 + 142,15 - 20 = 84,57\% \quad (20)$$

$$I_{f_{si}} = I_{f_{si-1}} * \Delta y_1 \quad (21)$$

$$I_{\phi_{62023}} = 31 * 0,8457 = 27 \quad (22)$$

where Δy is the adjusted value of the increase in y ; t_{crit} – two-sided inverse Student's t -distribution; y_{cal} – calculated value of y ; y_{act} – the actual value of y in the wartime period; n – the number of observations; m – the number of independent

variables; y_i – value of y for the i -th period; x_i – value of x for the i -th period; I_{fsj} – the forecast value of the indicator of the integrated assessment of the financial security of the state.

According to the results of the calculations, the forecast value of Ukraine's financial security indicator in the context of further digital transformation will have a negative downward trend and is 27% of the optimal value. This score indicates a dangerous situation, objectively caused by the general economic crisis, a significant state budget deficit, an increasing debt burden, and other challenges as a result of Russia's full-scale invasion of Ukraine. At the same time, however, the identified correlation indicates possible additional threats to Ukraine's financial security due to the deindustrialisation of the economy in the context of total digitalisation.

The dual nature of the threats caused by digitalisation is, firstly, the contradictory impact that causes the deindustrialisation of the real sector of the economy. Secondly, the incompleteness and heterogeneity of the penetration of the digital transformation process leads to the emergence of regulatory, legal, technical, and technological grey areas that create conflicts and generate additional threats. However, given the impossibility of the simultaneous widespread introduction of digital tools and technologies, the emergence of grey areas is an integral stage of digital transformation. Therefore, the emergence of threats to the state's financial security related to digitalisation is an objectively determined and inevitable process that requires a set of measures and a systematic approach to minimise their destructive impact.

Conceptually, the digitalisation of financial market participants involves the conversion of document flow into a digital format, the use of computer equipment for automated accounting, audit and resource control, the introduction of cash registers, cashless payments, online retail and feedback systems, and the fast processing of orders, data entered, information about counterparties, contractors and employees. The electronic signature records the time and place of signing, and documents contain metadata that tracks interventions, changes made, and their integrity. Thus, fully digitised financial market participants become more transparent, efficient, stable, fair and competitive, but also more vulnerable, as they depend not only on analogue infrastructure but also on digital infrastructure, which is mainly provided by intermediaries (ISPs, software developers, hosting services and others) and requires additional measures to ensure financial security at the macro level.

DISCUSSION

The calculations confirm the assumption that there is a threat of deindustrialisation caused by the spread of the digital services economy and its presence in the Ukrainian economy. This coincides with the findings of Stemmler (2023) on the possibility of "premature deindustrialisation" in emerging economies under the influence of digital transformation.

With a generally low digital divide in Ukraine compared to EU countries (Elding & Morris, 2018), it has significant innovation capabilities, but due to the accumulated institutional deformations described by Varnalii et al. (2022), there is a risk of making the wrong decisions. In addition, insufficient legal and regulatory support and a lack of skills and resources for such a transition are key obstacles to complete digitalisation. Although hybrid incomplete digitalisation has advantages, excessive and hasty implementation of digital technologies can lead to threats that outweigh the benefits, especially in the context of a lack of resources to sufficiently ensure the state's financial security during the digital transformation of the socio-economic system.

The forecasted share of the IT sector in the national economy shows that about a tenth of the Ukrainian economy is heavily dependent on digital infrastructure and uninterrupted energy supply. The threat of the economy's dependence on energy and digital infrastructure and related industries, especially against the backdrop of military operations, damage to critical servers, and power-generating substations, highlights the threat of the institutional, instrumental, technical, and technological fragility of the modern digital economic system, which is most acutely felt by the financial sector.

The calculated value of the GapTI index between the leading (top) and most significant industries in terms of digitalisation indicates unevenness and different capabilities of enterprises in implementation, the formation of new market barriers, loss of competitiveness in the market for skilled personnel, the deindustrialisation of the real sector of the economy, the threat of digital inequality, and an increase in the share of unreliable enterprises that can quickly leave the national market. This destructive impulse across the economy is most acutely felt in the financial sector. Socio-economic restructuring in the context of digitalisation creates a delayed adverse impact on financial security. These risks of digitalisation significantly complement the list of threats to the state's financial security compiled in previous studies (Onyshchenko, V. et al., 2023).

Under the dual influence of accumulated systemic threats and additional global challenges, including those related to total digitalisation, the calculated value of Ukraine's financial security indicator in 2023 is in a hazardous zone, only 27% of the optimal value. This estimate, based on the previous calculations of the Ministry of Economy of Ukraine (2022, 2023), is

realistic given the large-scale destruction, active hostilities, impossibility of uninterrupted operations of a significant part of business entities, crisis use of the budget and other destructive factors in the war.

Excessive stimulation of digital transformation at the state level leads to deindustrialisation of the economy and loss of competitiveness of the real sector in domestic and foreign markets. At the same time, slowing down or restraining this process contributes to financial security by reducing dependence on fragile digital infrastructure. However, this positive effect is offset by a decline in the skills and quality of digital security systems, as well as the emergence of "grey areas" of imbalances between different sectors of the economy.

CONCLUSIONS

There is an interdependence between the indicator of the economy's deindustrialisation as a result of digital transformation and the state's financial security. The loss of the real sector's position in favour of the development of the digital economy creates a cascading effect of destructive impact on the state's financial security.

The modern digital financial market is becoming vulnerable to covert, hybrid, and even more conventional attacks on digital and energy infrastructure, so reliance and optimism in digital technologies do not have sufficient objective grounds. The broad macroeconomic impact of deindustrialisation limits the tools and measures financial market actors can use to prevent threats.

This anomaly changes the logic of the process of ensuring the financial security of the state, as there is a need to manage processes, flows and significant trends, coordinate their development, and maintain an adequate balance between progressive digital industries and the real sector at the macroeconomic level, rather than just maintaining the stability of specific indicators of the financial component of economic security. This issue requires significant changes in legal and regulatory frameworks, alignment of digitalisation processes, and the creation of reliable and broad institutional mechanisms to counter threats from vulnerable critical digital and energy infrastructure.

Disproportionate measures aimed at stimulating the development of the digital economy, deterrence and restrictions, as well as inconsistency and lack of proper regulatory support for socio-economic restructuring in the context of digitalisation, are key factors in the emergence of threats to the financial security of the state as one of the most essential components of economic security, its foundation and material basis. Qualitative changes in market conditions and exogenous challenges require a corresponding system transformation to ensure the state's financial security. The indicators of deindustrialisation of the economy as a result of digital transformation proposed in this paper can serve as a supplement to the outdated base of the Methodological Recommendations for Assessing the Level of Economic Security of Ukraine, reflecting the impact of digital transformation of various sectors of the economy and the need for their systematic analysis to obtain an objective assessment of the economic security of the state in the current conditions of socio-economic restructuring.

Further research requires determining the strength of the correlation and excluding possible random correlates on a larger sample of data, which is currently challenging in the context of a full-scale Russian invasion. The five indicators are insufficient to fully assess the impact of digital transformation on the economic and financial security of the state, as they do not cover all aspects, including the use of cryptocurrencies, network coverage, and the circulation of digital goods. In addition, it is advisable to study the dual impact of digital transformation on the financial security of the state and the competitiveness of the largest sectors of the national economy in more depth.

ADDITIONAL INFORMATION

AUTHOR CONTRIBUTIONS

All authors have contributed equally.

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CONFLICT OF INTEREST

The Authors declare that there is no conflict of interest.

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ЦИФРОВА ТРАНСФОРМАЦІЯ ТА ЕКОНОМІЧНА ДЕІНДУСТРІАЛІЗАЦІЯ: ВПЛИВ НА ФІНАНСОВУ БЕЗПЕКУ ДЕРЖАВИ

Цифрова трансформація в умовах глобальних викликів є каталізатором нових загроз, посилення системних ризиків, у тому числі пов'язаних із передчасною деіндустріалізацією економіки. Тому проведене дослідження взаємозв'язку та дуального впливу прискореної цифрової трансформації та економічної деіндустріалізації на фінансову безпеку держави є беззаперечно актуальним в умовах тотальної цифровізації соціально-економічних відносин. За допомогою кількісного аналізу даних на прикладі економіки України досліджено кореляцію між зростанням сектора інформаційних технологій і падінням промислового виробництва з використанням моделі споживання енергії як ключового показника. Ключові результати демонструють сильну негативну кореляцію між розширенням цифрового сектора й традиційним промисловим виробництвом. Проведений аналіз показує, що стрімкий цифровий розвиток економіки призводить до зміни секторальних пропорцій у ній, першочергово через розширення цифрового сектора, а також сприяє процесам деіндустріалізації. Крім того, дослідження визначає критичні слабкі місця у фінансовій безпеці держави, що виникають унаслідок цієї економічної реструктуризації, включаючи зменшення податкових надходжень від традиційних галузей промисловості, підвищення економічної нестабільності й зростання залежності від цифрової інфраструктури. У дослідженні зроблено висновок, що хоча цифрова трансформація стимулює інновації й створює нові економічні можливості, вона водночас генерує додаткові загрози фінансовій безпеці держави через прискорену деіндустріалізацію. Проведене дослідження сприяє розумінню сучасних економічних змін і їх наслідків для національної фінансової стійкості, припускаючи, що сучасна парадигма забезпечення фінансової безпеки має базуватися на мінімізації ризиків, пов'язаних зі швидкою цифровою трансформацією, з одночасним використанням її переваг для сталого економічного розвитку.

Ключові слова: цифровізація, національна економіка, цифрова економіка, соціально-економічна реструктуризація, загрози, занепад промисловості, фінансова безпека

JEL Класифікація: C25, G17, E66, H56