DOI: https://doi.org/10.30525/2256-0742/2025-11-2-35-46

INVESTIGATING MULTICOLLINEARITY BETWEEN COUNTRY'S LEVEL OF DIGITAL COMPETITIVENESS AND INFLUENCING VARIABLES*

Kateryna Kraus[1], Nataliia Kraus[2], Bohdan Semenovych[3]

Abstract. The *purpose* of scientific research is to identify and argue the connection between the level of digital competitiveness of countries and variable factors, and to propose solutions for its improvement. The *object* of the research is the level of digital competitiveness of countries in 2023 and the variables that affect it (GDP per capita, population in the country, Digital Quality of Life Index). The subject of the study is the digital capabilities and innovative solutions of countries to strengthen their competitive position in the world in the context of globalisation. *Methodology.* The study is based on the method of multicollinearity according to the Farrar-Glauber algorithm, which makes it possible to understand the dependence of the level of digital competitiveness on three variable factors (GDP per capita, the number of people in the country and the Digital Quality of Life Index). The method of generalisation made it possible, on the basis of a multicollinear study, to provide recommendations for strengthening the country's digital competitiveness in the international arena, taking into account the potential of human resources, the degree of technological progress and the level of economic development. *Results.* The research revealed an insignificant relationship between the level of a country's digital competitiveness and GDP per capita. However, it was found that the more economically strong the state, the faster and larger the implementation of digital technologies. It has been posited that there exists a negligible relationship between a nation's digital competitiveness and its population size. Nevertheless, it is evident that as a nation's population increases, there is a concomitant rise in the number of individuals engaged in the production and implementation of innovative solutions and digital technologies. The multicollinearity study demonstrated that there is no multicollinear relationship between the level of the country's digital competitiveness and variable factors. However, it was determined that a country can acquire competitive advantages under the condition of contributing to the increase of the economic well-being of the nation and its accessibility to digital goods and services. *Practical implications.* The value of the publication is determined by the breadth of the author's recommendations for enhancing the Digital Quality of Life Index of the population, which, in the long term, will ensure the country's competitive position in the digital era and contribute to sustainable economic development. *Value/Originality.* The contribution of the article to the scientific value consists in the study of multicollinearity using the Farrar-Glauber algorithm to assess the impact on the level of digital competitiveness of such variable factors as GDP per capita (a macroeconomic indicator that indicates the well-being of the nation), the number of inhabitants of the country (an indicator that determines the intellectual potential of the country) and the Digital Quality of Life Index (characterises the accessibility and penetration of digital technologies in the life of society).

Keywords: digital competitiveness, economic growth, human resources, country's gross domestic product, digital quality of life.

JEL Classification: C19, F29, O33, O40

* This article is published in terms of scientific research work "Development models of the wartime and postwar economy of Ukraine based on digital entrepreneurship and virtual business mobility" (State registration number 0124U000066).

[1] Bohdan Khmelnytskyi National University of Cherkasy, Ukraine *(corresponding author)*
E-mail: k23k@ukr.net
ORCID: https://orcid.org/0000-0003-4910-8330
ResearcherID: ABC-9170-2020
[2] Bohdan Khmelnytskyi National University of Cherkasy, Ukraine
E-mail: k2205n@ukr.net
ORCID: https://orcid.org/0000-0001-8610-3980
ResearcherID: AAJ-9413-2020
[3] Yuriy Fedkovych Chernivtsi National University, Ukraine
E-mail: semenovych.bohdan@chnu.edu.ua
ORCID: https://orcid.org/0009-0000-8779-5966

1. Introduction

The current global economic development is characterised by divergence and increasing threats to stability, as well as rapid recession in many countries, threatening future economic prosperity. This has been caused by the COVID-19 pandemic and its consequences for humanity, geopolitical crisis, military confrontations between countries and regions, increasing social inequality and economic turbulence, deterioration in a number of macroeconomic indicators, a slowdown in the pace of technical and technological development, an increase in the number and scale of cyber-attacks, and the disruption of global value and supply chains. All this is changing the format of relationships, both between people and between organisations and companies, government institutions and countries. Relationships are becoming impersonal and digital. This determines the relevance of research, because the need for the development of digital technologies, the need to strengthen the country's technical and technological potential, scientific capacity, innovativeness and the development of human capital should be further argued.

The available scientific resources cover issues related to the need for the development of intellectual production and the introduction of digital technologies in business for the economic transformation of the country, as well as the destabilising impact of digital transformation on global competition. However, the relationship between the level of digital competitiveness (DC) and the country's population size and GDP per capita hasn't been sufficiently substantiated. It is imperative that practical recommendations for economists, businessmen and government officials are supported by scientific justification if they are to improve both the Digital Quality of Life (DQL) of the population in the country and ensure the growth of its DC.

2. Literature Review

The country's DC in today's globalised world is indicative not only of its improved socio-economic development, but also of its ability to overcome digital security risks and the challenges posed by the digital world, digital and social inequality. Consequently, the study of the prerequisites for the formation of the competitive strength of countries in the world, as well as the features of the digital transformation of the economy, has become a subject of interest to scientists.

In the contemporary digital economic era, the development of an internationally competitive industry that utilises intelligent production methods represents a pivotal strategy for the transformation of the nation into a manufacturing-oriented state, thereby facilitating the attainment of high-quality economic development (Zhang, 2023). It is imperative to acknowledge that DC should be regarded as a catalyst for competitive advantage at both the business and national economic levels. The effectiveness of the digital economy is contingent upon national strategies for achieving economic growth and socio-economic development (Laitsou, 2020). The nation's digital currency is founded on economic prosperity and advancement, a prospect contingent upon the implementation of methodical and unwavering digital transformations across diverse economic aggregation levels.

The influx of digital technologies has changed the business landscape, especially after COVID-19, when firms began to master new methods to achieve sustainability and competitiveness. There is a close relationship between digitalisation, sustainability and competitiveness: digitalisation contributes to the sustainability of the company; digitalisation contributes to the competitiveness of the company; sustainability contributes to the competitiveness of the company (Liu, 2023). Digital transformation is one of the tasks of the development of the digital economy and a step in deepening structural transformations to promote high-quality economic and social development (Sun, 2022[b]). The driving forces of the digital transformation of the national economy are new technological enterprises, which make a significant contribution to the creation of innovative products (Balcerzak, 2023).

"With the development of the digital economy, more and more companies are implementing digital transformation strategies to take advantage of opportunities and face various challenges. Accelerating the pace of digital transformation is crucial not only for countries, but also for enterprises to compete and survive" (Sun et al., 2022[a]). The digitalisation of the economy has been demonstrated to engender economic instability and to engender divergent outcomes across various markets, with some becoming more volatile and others demonstrating greater stability. It is evident that companies which incorporate big data as a fundamental component of their business model, capitalising on robust network effects, are poised to attain a sustainable and self-reinforcing competitive edge within the digital economy as the process of digitisation persists (Knudsen, 2021).

An integral part of a high level of DC is a high quality digital infrastructure, which is the foundation of an innovative economy and society. As "part of overall competitiveness, digital competitiveness ... covers various factors of the digital transformation process through the ability to learn and apply new technologies, technological factors that enable digital transformation, and digital readiness factors that assess the readiness of the economy and citizens for digital

transformation" (Stankovic, 2021). Researchers from Poland also see the creation of an effective digital economy infrastructure as one of the conditions for increasing the international competitiveness of middle-income countries. They are convinced that "from a national point of view, investing in the digital economy can be a tool that supports sustainable development and increases the speed of the convergence process at the regional level" (Balcerzak & Pietrzak, 2017).

Today's digital transformation is the result of increasing advancement, adoption of digital technologies and development of business dynamics, so "organisations struggle to define the digital capabilities they have or need in relation to their desired digital transformation goals. This struggle stems from a lack of knowledge and practical guidance on how to assess an organisation's digital capabilities against the digital transformation goals they seek" (Baiyere, 2024). Representatives of the scientific community from Latin American countries have proposed a model to explain the impact of digital capabilities on firm performance and analysed the mediating role of technological capabilities and the human development index (HDI) in explaining firm performance (Herediaa, 2022). "Technological capabilities have a mediating effect on digital capabilities and firm performance; in low HDI countries, the impact of digital skills on technological capabilities is more significant than in high HDI countries." (Herediaa, 2022)

Digital capabilities have been demonstrated to play a strategic role in supporting top management to exercise two-way leadership in an organisation during times of change, as well as indirectly influencing firm performance. It is evident that business flexibility and two-way leadership assume an intermediary role in the creation of new digital opportunities and the augmentation of firm productivity (Saputra, 2022). Digitisation contributes to the development of SMEs by enabling them to develop their internal capabilities to meet external challenges, according to M.-T. Bui and H.-L. Le (2023). Their research contributes to the theory of capabilities for the development of digital capabilities and the productivity and differentiation strategies of SMEs in dealing with external challenges. The researchers make recommendations on "overcoming obstacles, expanding digital and creative opportunities, engaging digital platforms, and benefiting from international marketing, international retail" (Bui & Le, 2023). The digital transformation of SMEs poses significant challenges due to their limited financial resources and employees' digital literacy levels, which differ from those of their larger competitors (Civelek, 2023).

This finding serves to substantiate the assertion that 'digital transformation is one of the most significant changes in business, which in turn contributes to changes in society, changing old models of human activity, behaviour, communication, and everyday life. Such changes are frequently substantial in nature, given that they involve the transformation of existing business structures and strategies with a view to achieving competitive advantage in new circumstances (Slavkovic, 2023). It is important not only to analyse the role of digital transformations in the economy and society, but also to evaluate them objectively. D. Lixandroiu's research is based on the analysis of the Digital Economy and Society Index (DESI), which measures digital productivity and tracks the development of EU Member States in terms of DC. The DESI index includes five parameters: Internet connectivity, human capital, use of Internet services, integration of digital technologies and digital public services. Another index, the International Digital Economy and Society Index (I-DESI), extends the DESI index and helps to analyse trends and compare digital indicators in 45 countries (28 EU Member States plus Australia, Brazil, Canada, Chile, China, Iceland, Israel, Japan, Mexico, New Zealand, Norway, Russia, Serbia, South Korea, Switzerland, Turkey and the US) (Lixandroiu, 2018).

Researcher I. Mlynarzewska-Borowiec uses the ICT Development Index (IDI) to assess DC and the Digital Competitiveness Index (ODCI) to measure actual competitiveness. She proves "the hypothesis that DC gap between the EU and the US is widening, especially in terms of ICT patent activity, the impact of ICT on new business and organizational models, the intensity of high technology trade and the importance of the ICT sector in creating added value" (Mlynarzewska-Borowiec, 2022). The United Nations E-Government Development Index (EGDI) is also used to assess the level of development co-operation, which is designed to measure the development of national e-government potential by taking into account three indices – online services, telecommunications and human resources. The Organisation for Economic Co-operation and Development (OECD), an intergovernmental organisation established in 1961 and covering 36 countries, aims to clarify, disseminate and evaluate the implementation of public policies to ensure sustainable economic growth and social stability, and has recently begun to monitor digital government activities. The Human Capital Index (HCI) has been developed for the purpose of evaluating human capital (its quantity and structure) and quantifying human potential for future generations (capital value, new challenges, opportunities, and risks, education level, place of residence, etc.) (Lixandroiu, 2018).

For a deeper understanding of what determines the level of DC, it is worth studying multicollinearity, which "occurs when two or more independent variables in a regression model are correlated. Multicollinearity sometimes causes big problems, but when it's moderate or high, it's a problem that needs to be solved" (Daoud, 2017). The diagnostics of

multicollinearity and the exclusion of multicollinear explanatory variables facilitate the formulation of a reliable multiple linear regression model (Jong Hae Kim, 2019). Multicollinearity is characterised by substantial changes in the estimated coefficients when a variable is added or removed, and when a data point is changed or removed, there are significant changes in the coefficients (Daoud, 2017).

In previous scientific works, an attempt was made to outline the prerequisites for accelerating the digitisation of the economy at the micro and macro levels. The formation of Industry 5.0 was also considered through the prism of innovations and technologies in the management of industry and business. This is considered a real condition for strengthening the country's competitive capabilities in the international arena (Kraus, 2021; Kraus, 2023). The authors consider it appropriate to continue scientific research on issues of digital transformation of the economy and society in the direction of assessing the impact of factors on the level of the country's DC by establishing multicollinearity according to the Farrar-Glauber algorithm.

The *purpose of the article* is to identify and justify the dependence of the level of digital competitiveness of countries on variable factors (GDP per capita, the number of people in countries, DQL Index) and to develop practical solutions for its improvement.

The article sets the following tasks: to identify and characterize the prerequisites for strengthening the DC of the countries of the world in the conditions of globalization and intensification of innovation processes; to provide a graphical representation and explain the dependence of the level of the DC of the country on the GDP per capita, the number of inhabitants in these countries and the DQL index; to carry out a scientific assessment of the influence of variable factors on the level of the DC of the country by studying multicollinearity.

3. Research Methodology

The present article aims to investigate the existence of a multicollinear relationship between the level of a country's DC and variable factors (GDP per capita, population, and DQL Index). The materials of the IMD World Digital Competitiveness (WDC) Ranking of 2023 were used to collect the initial information, which allowed for the analysis of the degree of implementation of digital technologies by countries and the resultant transformation of government practices, business models, and society. The study's sample comprised 25 countries that were identified as leaders in the 2023 DC rating. The WDC rating methodology employs a multifaceted approach to determine DC, with each factor – knowledge, technology, and future readiness – subdivided into three sub-factors and encompassing a total of 54 distinct criteria. The criteria consist of both hard (actual) and soft (survey materials, observations) data, with a 2:1 ratio of each, respectively (IMD World Competitiveness Center, 2024).

The initial factor selected for the study of multicollinearity is the GDP per capita indicator, which is a measure of a nation's economic strength. It is calculated by dividing the total value of final goods and services produced within a specified period by the average population during the same period. The research utilised data from 25 countries worldwide (ranked TOP-25 according to the IMD WDC Ranking 2023), presented by the International Monetary Fund and primarily based on the UNESCO classification and World Economic Outlook databases (International Monetary Fund, 2024).

The second factor presented in the article is the population of 25 countries worldwide in 2023 (leading countries according to the IMD WDC Ranking 2023), provided by the World Population Review. This provides an indication of the available human resources (World Population Review, 2024). The third factor employed in the multicollinearity study is DQL Index 2023 (fifth edition), which delineates digital well-being in 121 countries (representing 92% of the global population) and indexes each of them by five factors (Internet affordability, Internet quality, electronic infrastructure, electronic security, and electronic government). The DQL Index is an independent study conducted by Surfshark, a Dutch cybersecurity company, that provides information on 14 factors that affect a country's digital well-being and areas that are prioritized for future improvement (Surfshark, 2024).

In order to study multicollinearity using the Farrar-Glauber algorithm, raw data were taken for 10 countries in the world (TOP 10 according to the IMD WDC Ranking 2023) with the highest rating of DC, making it possible to reveal the relationship between it and three variable factors.

During the review of the literature on the researched issue and the identification of scientific gaps and unsolved problems, the basis was taken from scientific publications from the Scopus and WoS databases, which are marked by relevance, accessibility, openness, depth of scientific development, a wide range of represented countries (China, Norway, Greece, Malaysia, Romania, Serbia, Poland, Canada, Finland, Indonesia, the Czech Republic, Latin American countries). This can be regarded as a study's strength, as it serves to substantiate the methodological accuracy employed. The utilisation of articles primarily from journals indexed in the Scopus and WoS databases may be subject to certain limitations. These limitations may be associated with potential biases in the content of publications, and a lack of representation of specific areas of scientific research and subject

disciplines. However, this does not have a substantial impact on the overall bibliographic analysis, and the geographical space remains highly comparable.

The article puts forward hypotheses, the substantiation of which has significant scientific results and practical value. The first hypothesis (H1) suggests that there is an insignificant relationship between the level of a country's DC and GDP per capita. The second hypothesis (H2) suggests that there is an insignificant relationship between the level of a country's DC and the number of its population. The third hypothesis (H3) suggests that there is no multicollinear relationship between the level of a country's DC and variable factors (GDP per capita, number of population, DQL Index).

A variety of methods were used for the research, confirming methodological accuracy. The analytical method helped to process the information available in the scientific literature on the understanding of DC and the factors influencing it. The method of abstraction was used to try to isolate the influence of variable factors, except for three selected ones (GDP per capita, number of inhabitants of the country, DQL index) on the level of DC of the country. The methods of synthesis and generalisation were used to create the list of scientists' views on the characteristics of digital transformations in the economy and society. The utilisation of the Farrar-Glauber algorithm for the analysis of multicollinearity facilitated the evaluation of the impact of variable factors on the level of DC, thereby revealing that their influence exerts a synergistic effect. The utilisation of a graphic method contributed to the visualisation of the dependence of the level of the country's DC on GDP per capita and population size. The tabular method was employed to present the initial and resulting data of the assessment of the influence of factors on the level of the country's DC in the study of multicollinearity. The utilisation of a comparative method was employed to accentuate the contentious aspects of the research and the authors' contributions.

4. Correlation Between the Nation's Welfare and the Level of Country's DC

In the current situation, the more fierce the competition, the greater the impact of the degree of digital transformation on reducing the cost of debt financing, and the more technological the areas of a company's operations, the greater the impact of the degree of digital transformation on reducing the cost of debt financing (Sun (Ed.), 2022[b]). Digital transformation turns data and networks into powerful competitive weapons that can become a source of dynamic opportunities in the future. "The bigger the network, the more data can be collected… the faster you can learn about customer preferences and sense changes in those preferences, leading to the ability to innovate faster and with a higher probability of success." (Knudsen, 2021)

The contemporary changes that are occurring are frequently of a negative nature. In the short term, this leads to a decrease in the GDP of countries, especially per capita, the appearance of obstacles in obtaining additional financing, credit resources, foreign investments, and the difficulty of access to high-tech equipment and components for it.

In the medium term, such changes will have the following consequences: a decrease in the number and intensity of co-operation between intergovernmental organizations, partners from different countries in the field of high-tech development and production; incompatibility of the existing infrastructure with the real needs of citizens and business representatives; continued outflow of young workers capable of creating innovations abroad; structural, sectoral transformations and reorientations in export-import operations; deepening of inflationary processes and reduction of purchasing power of citizens; emergence of a digital divide between cities, regions and countries; deterioration of the DQL of the population; social inequality.

The ramifications of contemporary events are such that they will ultimately serve to lay the foundation for the future economic reorientation of the nation towards new strategic partners, new high-tech areas of production, the deepening of interstate competition in highly profitable areas, the formation of a society with a new format of thinking, the displacement of AI people from many areas of economic activity, and an increase in the differentiation of the country's DC on the world map. The latter of these factors requires a deeper study in the digital age.

The level of DC is influenced by the level of R&D, with various opportunities for obtaining higher education in specialties in demand on the market with strong digital skills being supported. Furthermore, mobile, adaptive and innovative business that actively implements modern ICT is encouraged, as is the promotion of the development, dissemination and application of advanced digital technologies in various spheres of economic activity. Finally, the development of digital ecosystems based on powerful autonomous digital platforms is supported.

There is an insignificant relationship between the level of country's DC and its GDP per capita (Hypothesis 1).

The global economic recession caused by the Covid-19 pandemic and its aftermath, as well as military and political confrontations in various regions of the world, led to a decline in world GDP that was one of the most significant since the Second World War. Figure 1 shows the GDP per capita indicator in 25 countries of the world in 2023, where the global economic crisis has had a negative impact on the

well-being of citizens of certain countries that are particularly dependent on foreign trade (Taiwan, China, Republic of Korea) and tourism (Denmark, Estonia, Czech Republic).

As illustrated in Figure 1, a clear correlation exists between the assessment of DC and GDP per capita, thereby underscoring the significance of this relationship. From the sample of 25 countries worldwide, it is evident that there is a significant correlation between GDP per capita and the assessment of DC, with this correlation being observed only in Norway and Switzerland. In order to ensure the effective functioning of the country's DC, it is imperative to implement a systematic and methodical approach to its enhancement. The following would be appropriate: high-tech production and development of the knowledge economy; stimulation of development of inclusive and digital entrepreneurship; support of proactive, creative and highly educated youth in implementation of innovative business projects, creation of innovations, new technologies; maximum use of the country's internal potential and own resources (natural, human, material, financial) in production processes, reduction of dependence on imported raw materials, materials, resources, technologies; active implementation of advanced technologies in production in order to follow market needs, meet modern trends and respond to challenges in a timely manner; strengthening the export orientation of technological production and reducing dependence on imports; expanding innovative production of in-demand goods, developing serial production of new goods; ecological orientation of business and production in order to achieve harmony with the environment, follow the principles of sustainable economic development and preserve human life on the planet; implementation of automated systems of management, production, exchange, sale and promotion of goods and services.

5. The Role of Human Capital in Sustainable Economic Development

Economic imbalances, a dynamic and large-scale reduction in production, an increase in the level of uncertainty and instability, a decrease in the level of employment of human resources, as a result, reduce the quantity and quality of human capital, leading to its accumulation and degradation. As a result, there is an outflow of investment, a decrease in the rate of economic growth and a long-term decrease in the productivity of human labour.

Increasing DC is seen in the context of the digital divide, and "areas where such policies are necessary include education and improving digital skills. Human capital is an important factor in digital competitiveness, while digital literacy can contribute to more productive use of the Internet" (Laitsou, 2020).

There is an insignificant relationship between the level of country's DC and the number of its population (Hypothesis 2).

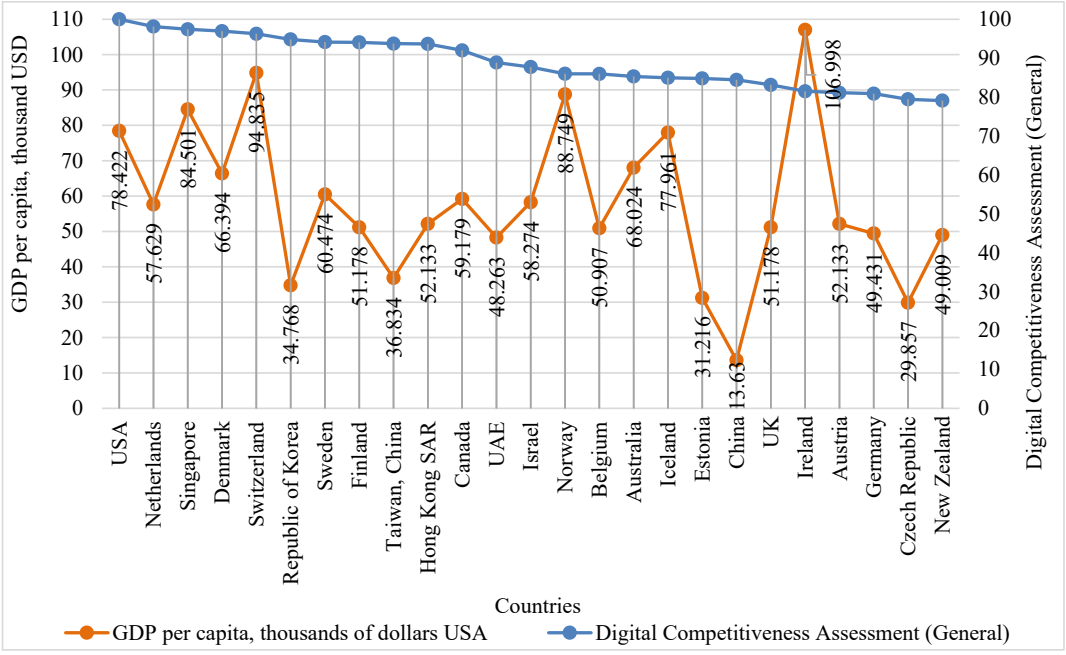

Figure 1. Visualisation of the relationship between the DC score of some countries (TOP 25 according to the IMD WDC Ranking 2023) and GDP per capita in 2023

Source: built on the basis of sources (IMD World Competitiveness Center, 2024; International Monetary Fund, 2024)

As illustrated in Figure 2, the population of 25 countries worldwide, which, in 2023, according to the IMD WDC Ranking, had the highest DC rating, is presented. The objective of this study is to ascertain whether there is a correlation between the level of a country's DC and its population size.

It is evident in Figure 2 that China, with a population exceeding 1.425 million, exhibits a lack of sufficient DC. It is imperative to acknowledge that China was the origin and epicentre of the global spread of the novel coronavirus, thereby becoming one of the first countries to experience the adverse consequences of the pandemic. These consequences included the loss of human capital due to increased mortality and the inability to access timely medical care, a decline in labour force participation as individuals sought alternative employment opportunities to maintain their economic well-being, and a decrease in the accumulation of qualified human capital due to deteriorating educational standards. With regard to the other countries presented in Figure 2, it is evident that a relationship exists between the level of DC and the number of the population; however, this relationship is non-significant.

It is therefore vital to emphasise the significance of a robust intellectual human capital component in the enhancement of the nation's DC. This is predicated on the premise that a high level and quality of education and science in the country, a robust social sphere and well-being, a high level of DQL, a developed labour market and infrastructure, the presence of a balanced institutional provision, rational use of the existing economic potential and the formation of an economically conscious society are prerequisites for the strengthening of the country's DC. The development of human capital is a pivotal factor in this regard, given its capacity to ensure sustainable economic growth, accelerate digital transformation and innovation, address contemporary challenges, and expeditiously capitalise on emerging opportunities.

6. Assessment of the Influence of Variable Factors on Level of Country's DC

In order to confirm (or refute) the hypothesis that there is a relationship between the assessment of DC of some countries in the world and GDP per capita and the number of people in these countries, a multicollinearity study will be conducted using the Farrar-Glauber algorithm. The employment of this algorithm will facilitate the quantification of the impact on DC of variables such as GDP per capita, population, and DQL Index. In the event of such an influence being present and it being proximate, the estimates of the model parameters may be subject to bias, and such a relationship between the variables is known as multicollinearity (the presence of a linear relationship between two or more factor (independent) variables in the regression model) (Jong Hae Kim, 2019, p. 558).

There is no multicollinear relationship between the level of country's DC and variable factors (GDP per capita, population, DQL Index) (Hypothesis 3).

The calculation will be based on the data presented in Table 1.

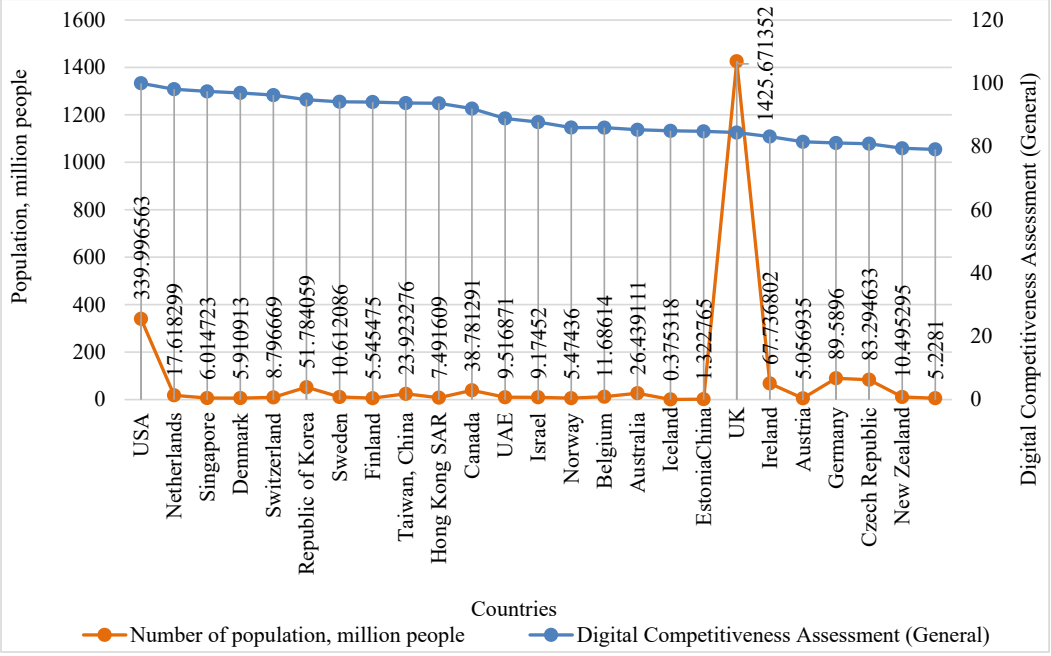

Figure 2. Visualisation of the relationship between the DC score of some countries (TOP 25 according to the IMD WDC Ranking 2023) and the population in these countries as of 2023

Source: built on the basis of sources (IMD World Competitiveness Center, 2024; World Population Review, 2024)

Table 1
Output data for assessing the impact of variable factors on the level of the country's DC in the study of multicollinearity using the Farrar-Glauber algorithm

Countries of the world from the digital competitiveness ranking of 2023	Digital Competitiveness Assessment (General)	GDP per capita, thousand USD	Population, million people	DQL Index 2023
	Y	x_1	x_2	x_3
USA	100.00	78.422	339.996563	0.6559
Netherlands	98.10	57.629	17.618299	0.7063
Singapore	97.40	84.501	6.014723	0.7096
Denmark	96.93	66.394	5.910913	0.7377
Switzerland	96.24	94.835	8.796669	0.7106
Republic of Korea	94.80	34.768	51.784059	0.6559
Sweden	94.12	60.474	10.612086	0.7079
Finland	94.05	51.178	5.545475	0.7483
Canada	91.98	59.179	38.781291	0.6527
UAE	88.86	48.263	9.516871	0.5821

Source: compiled based on sources (IMD World Competitiveness Center, 2024; International Monetary Fund, 2024; Surfshark, 2024; World Population Review, 2024) and own calculations)

The explanatory variables (GDP per capita, population, DQL Index) are then normalized, for which the mean and standard deviation are calculated (see Table 2).

The next step in the study of multicollinearity is to find the correlation matrix *r* using formula (1).

$$r = \begin{pmatrix} r_{x1x1} & r_{x1x2} & \dots r_{x1xn} \\ r_{x2x1} & r_{x2x2} & \dots r_{x2xn} \\ r_{xnx1} & r_{xnx2} & \dots r_{xnxn} \end{pmatrix} \quad (1)$$

In this case, it will have the form of a matrix of paired correlation coefficients:

$$r = \begin{pmatrix} 1 & 0.20622 & 0.32239 \\ 0.20622 & 1 & -0.27693 \\ 0.32239 & -0.27693 & 1 \end{pmatrix}$$

In this instance, the proposed model will assume the form of a matrix of paired correlation coefficients. In order to test the statistical hypothesis, the value of the Student's *t*-test (t_{table}) will be determined. It constitutes t_{table}=2.30600414. The multiple correlation coefficient can be determined by utilising formula (2), thereby yielding $r_{critical}$=0.63189686.

$$r_{critical} = \frac{t}{\sqrt{t^2 + n - 2}} \quad (2)$$

So, not all $r_{xixj} > r_{critical}$, which indicates a loose connection between all factors. In order to answer the question of whether this relationship is a consequence of multicollinearity or not, the χ_2 test is utilised (see Table 3, Part 1).

As $\chi_2 < \chi_{2table}$, then there is no multicollinearity in the array of explanatory variables. The matrix *C*

Table 2
Results of normalisation of explanatory variables for assessing the impact of factors on the level of the country's DC in the study of multicollinearity using the Farrar-Glauber algorithm

Countries of the world from the digital competitiveness ranking of 2023	Normalisation of explanatory variables		
	x_1	x_2	x_3
USA	0.8241	2.8129	-0.6185
Netherlands	-0.3292	-0.3083	0.3936
Singapore	1.1612	-0.4206	0.4599
Denmark	0.1569	-0.4216	1.0241
Switzerland	1.7344	-0.3937	0.4799
Republic of Korea	-1.5971	0.0225	-0.6185
Sweden	-0.1714	-0.3761	0.4257
Finland	-0.6870	-0.4251	1.2370
Canada	-0.2432	-0.1034	-0.6827
UAE	-0.8487	-0.3867	-2.1005
Average value	63.56	49.46	0.69
Standard deviation	18.03	103.29	0.05

Source: compiled on the basis of own calculations

Table 3

Results of intermediate calculations for assessing the impact of factors on the level of the country's DC in the study of multicollinearity using the Farrar-Glauber algorithm

Part 1. Determinant of matrix *r*	Part 2. Matrix *C*			Part 3. *F*-criterion
|r|=0.74002592	1.24767582	-0.399309132	-0.512821225	F_1=0.49535164
χ_2=-7.1344034	-0.39930913	1.210852831	0.464050267	F_2=0.42170566
χ_{2table}=7.8147279	-0.51282123	0.464050267	1.293837389	F_3=0.58767478

Source: compiled on the basis of own calculations

is also defined, and is the inverse of the matrix of paired correlation coefficients (see Table 3, Part 2). The value of the *F*-criterion will be calculated according to formula (3) for each explanatory variable, provided that F_{table}=4.75706266 (see Table 3, Part 3). As $F_1<F_{table}$, $F_2<F_{table}$, $F_3<F_{table}$, then this means that none of the explanatory variables is multicollinear with the others.

$$F_j = \left(c_{jj} - 1\right)\frac{n-m}{m-1} \quad (3)$$

The ensuing calculations will employ the partial coefficients of determination for each variable, utilising formula (4) (Table 4, Part 1).

The partial correlation coefficients will be determined according to formula (5), which indicates the closeness of the relationship between variables x_i and x_j, provided that all other variables do not affect this relationship (see Table 4, Part 2).

$$R_{xj}^2 = 1 - \frac{1}{c_{jj}} \quad (4)$$

$$r_{ij} = \frac{-c_{ij}}{\sqrt{c_{ii} \cdot c_{jj}}} \quad (5)$$

Following a comparison of the obtained correlation coefficients with the multiple correlation coefficient that was previously found, the following conclusions were drawn:

– As $r_{12}<r_{critical}$, then there is no close relationship between the variables x_1 (GDP per capita in the country) and x_2 (population in the country), if not to take into account the influence of DQL Index.

– As $r_{13}<r_{critical}$, then there is no close relationship between the variables x_1 (GDP per capita in the country) and x_3 (DQL Index), excluding the impact of the country's population.

– As $r_{23}<r_{critical}$, then there is no close relationship between variables x_2 (population in the country) and x_3 (DQL Index), excluding the impact of GDP per capita in the country.

It is the objective of this study to ascertain whether the factors x_1 and x_2, x_1 and x_3, and x_2 and x_3 are multicollinearly related, respectively, based on the results obtained. In order to accomplish this task, it is necessary to calculate the *t*-criteria using formula (6) (t_{table}=2.44691) (see Table 4, Part 3).

$$t_{ij} = \frac{r_{ij} \cdot \sqrt{n-m}}{\sqrt{1-r_{ij}^2}} \quad (6)$$

As $t_{12}<t_{table}$, then there's no multicollinear relationship between variables x_1 and x_2; as $t_{13}<t_{table}$, then there's also no multicollinear relationship between variables x_1 and x_3; as $t_{23}<t_{table}$, then there's no multicollinear relationship between variables x_2 and x_3.

Finally, the degree of influence of each of the studied factors on the resulting factor *Y* (general assessment of DC) will be determined. The following formula will be employed:

$$r_i^2 = \frac{t_i^2 \cdot R^2}{t_1^2 + t_2^2 + \ldots + t_n^2} \quad (7)$$

Therefore, DQL Index (factor x_3) has the greatest influence on the overall assessment of country's DC (*Y*) by 7.67%, followed by the number of country's population (factor x_2) by 7.72% and GDP per capita in country (factor x_1) – by 4.96%.

The DQL Index is recognised as a key component of sustainable development on a global scale, the importance of which depends on: the degree of

Table 4

Results of the final calculations for assessing the impact of factors on the level of the country's DC in the study of multicollinearity using the Farrar-Glauber algorithm

Part 1. Coefficients of determination	Part 2. Correlation coefficients	Part 3. *t*-criteria	Part 4. The degree of influence on the resulting factor *Y*
$R^2(X_1)$=0.19850975	r_{12}=0.3248723	t_{12}=0.84141	r^2_1=0.049629
$R^2(X_2)$=0.1741358	r_{13}=0.4036224	t_{13}=1.08060	r^2_2=0.071805
$R^2(X_3)$=0.22710535	r_{23}=-0.3707486	t_{23}=-0.97783	r^2_3=0.076681

Source: compiled on the basis of own calculations

introduction and penetration of innovations and advanced digital technologies in the everyday life of a person, his economic activity, business, production, governance; the level of labour productivity, which affects the growth of quality and durability of products, making positive changes in the social life of people; environmental, information and cyber security; the ability to quickly build smart cities and digital ecosystems; the ability to stimulate partnerships and network connections to achieve sustainable competitive advantages in the digital world based on IoS, big data, cloud technologies and AI technologies.

Increasing competitiveness in today's digital world "can be achieved through a systemic approach that allows for the creation and implementation of integrated national information systems at the state level, which include interconnected components that collect, process, store and disseminate information to facilitate the decision-making process and control" (Lixandroiu, 2018).

The study showed that development co-operation of the economically developed countries of the world should be strengthened by increasing scientific potential, technical and technological achievements, structural restructuring of the economy on the basis of digitalisation, modernisation of industry, balance of socio-economic and ecological development taking into account technological innovations, strengthening of institutional support and transparency of political decisions, ensuring information security, development of digital infrastructure, availability of digital labour market, active use of digital technologies.

7. Conclusions

The purpose of the study was to identify and substantiate the dependence of the level of a country's DC on variable factors (GDP per capita, population and DQL index) in order to develop practical recommendations for increasing the country's competitiveness in the digital era. The assessment of the influence of factors on the level of a country's DC in the course of the multicollinearity study made it possible to confirm that digital changes are global, dynamic and irreversible, and that digitalisation is part of long-term economic development. The hypotheses put forward proved that countries with a higher level of DC, diverse digital technologies and innovations have a better chance of sustainable economic development, welfare and prosperity, as well as new opportunities to strengthen their digital competitive advantages and harmonise the socio-economic situation.

Drawing upon the WDC ranking data provided by IMD, this study not only facilitates the analysis of a nation's DC level and the factors influencing it, but also enables the proposal of specific, practical actions for groups of countries, with due consideration for the paramount factor (DQL Index). Consequently, in order to enhance the level of DC by improving DQL, it is recommended that countries such as the UAE and the Republic of Korea further develop institutional support for sustainable economic development and strengthen the integration of various economic agents for digital transformation. It is imperative for countries such as the USA, Canada and the Netherlands, which exhibit an average level of DQL, to prioritise the pursuit of balanced development and the deepening of digitalisation. This strategic focus is crucial for the further enhancement of their DC, particularly in the context of the creation of digital technologies within the entrepreneurial, social and innovative domains. Moreover, the establishment of digital infrastructure at the institutional level is paramount for the advancement of these nations. Denmark, Finland and other countries with a high level of DQL are laying the foundation for further increasing their digital competitive advantages. In order to reduce socio-economic inequality and the digital gap between countries, it is advisable to continue to focus on achieving partnership advantages. In this process, less successful countries in digital development should be maintained by exporting digital technologies and strengthening integration.

The DC of countries enables the assessment of the effectiveness of various models of the modern digital economy, the tracking of the differences in the internal potential of countries, their strategic national priorities, methods and forms of management, features of innovative systems, and digital consciousness of the nation. The leaders in the development of e-commerce and the pace of digitalisation of business (USA, China), the variety of digital services (Great Britain, Ukraine), and the digitalisation of production processes (Germany) are singled out, but most countries are marked by an accelerated digital transformation. In order to increase the level of DC, in particular DQL, which is affected most significantly by the factors discussed above, the following steps are considered appropriate for implementation:

– To strengthen the institutional framework for the digital transformation of the economy by eliminating institutional imbalances, which will harmonise socio-economic, technical and technological development, and regulate business relations between business entities in various sectors of the economy.
– To stimulate the emergence of new digital professions, the demand for which in the market is caused by the change in economic development trends, the spread and active use of digital technologies, and the acquisition of digital skills and competencies by young specialists.
– To promote the creation and implementation of digital technologies and tools at the state level, which will help achieve large-scale automation of production

and business processes, increase productivity and speed of economic operations, and reduce the likelihood of errors and miscalculations.

– To develop new business models that are characterised by high mobility, maneuverability, adaptability to external challenges, innovation, rationality, inclusiveness, and social orientation and are a response to digital change.

– To expand public-private partnership in the field of scientific research, provision of educational services, conducting business activities, provision of public services, establishment of Industry 4.0, formation of network connections based on digital technologies in order to obtain a synergistic effect from equal co-operation, as well as strengthening social interaction of economic agents for the sake of obtaining better results of their joint work and interaction.

– To encourage the use of digital technologies in the energy sector in order to reduce harmful emissions into the environment, increase the energy efficiency of production, promote the preservation of natural biodiversity, and reduce the negative impact of industrialisation on people's lives and health.

A high level of DC of the country striving for economic prosperity and well-being of the nation should be its strategic reference point, which will allow the comprehensive achievement of the goals of sustainable development; at the institutional level, achieve a balance of economic and social growth, overcome social inequality and the digital divide in society; ensure the growth of DQL through the introduction of digital technologies; consistently and carefully carry out the digital transformation not only of the economy of individual countries, but also the world economy as a whole.

Future research should be devoted to finding effective tools to achieve sustainable digital competitive advantages of countries depending on their fixed income level (high, above average, below average or low). This is necessary in order to develop a far-sighted innovative "roadmap" with different variations of implementation depending on the financial capacity of the country, its import dependence and export orientation, its ability to implement digital technologies and to carry out innovative activities. This approach will help each specific country to choose "its own option and pace" for entering the world of numbers, which will correlate as much as possible with the state of the economy and society's readiness for dynamic change.

References:

Baiyere, A., Salmela, H., Nieminen, H., & Kankainen, T. (2024). Assessing digital capabilities for digital transformation – the MIND framework. *Information Systems Journal,* 1–33. DOI: https://doi.org/10.1111/isj.12519

Balcerzak, A. P., Zinecker, M., Skalicky, R., Rogalska, E., & Doubravsky, K. (2023). Technology-oriented start-ups and valuation: A novel approach based on specific contract terms. *Technological Forecasting and Social Change,* vol. 197: 122876. DOI: https://doi.org/10.1016/j.techfore.2023.122876

Balcerzak, P. A., & Pietrzak, B. M. (2017). Digital economy in Visegrad countries. Multiple-criteria decision analysis at regional level in the years 2012 and 2015. *Journal of Competitiveness,* vol. 9, no. 2: 5–18. DOI: https://doi.org/10.7441/joc.2017.02.01

Bui, M.-T., & Le, H.-L. (2023). Digital capability and creative capability to boost firm performance and formulate differentiated CSR-based strategy. *Heliyon,* vol. 9, no. 3: e14241. DOI: https://doi.org/10.1016/j.heliyon.2023.e14241

Civelek, M., Krajcik, V., & Kljucnikov, A. (2023). The impacts of dynamic capabilities on SMEs' digital transformation process: the resource-based view perspective. *Oeconomia Copernicana,* vol. 14, no. 4: 1367–1392. DOI: https://doi.org/10.24136/oc.2023.019

Daoud, J. I. (2017). Multicollinearity and regression analysis. *ICMAE'17. IOP Conf. Series: Journal of Physics: Conf. Series,* vol. 949: 012009. DOI: https://doi.org/10.1088/1742-6596/949/1/012009

Digital Quality of Life Index 2023 (2024). *Surfshark.* Available at: https://surfshark.com/dql2023

GDP per capita 2023 (2024). *International Monetary Fund.* Available at: https://www.imf.org/external/datamapper/NGDPDPC@WEO/WEOWORLD

Herediaa, J., Castillo-Vergarab, M., Geldesc, C., Carbajal Gamarrad, F. M., Florese, A., & Heredia, W. (2022). How do digital capabilities affect firm performance? The mediating role of technological capabilities in the 'new normal'. *Journal of Innovation & Knowledge (JIK),* vol. 7, no. 2: 1–10. DOI: https://doi.org/10.1016/j.jik.2022.100171

Jong Hae Kim, M. D. (2019). Multicollinearity and misleading statistical results. *Korean Journal of Anesthesiology,* vol. 72, no. 6: 558–569. DOI: https://doi.org/10.4097/kja.19087

Knudsen, E. S., Lien, L. B., Timmermans, B., Belik, I., & Pandey, S. (2021). Stability in turbulent times? The effect of digitalization on the sustainability of competitive advantage. *Journal of Business Research,* vol. 128: 360–369. DOI: https://doi.org/10.1016/j.jbusres.2021.02.008

Kraus, K., Kraus, N., & Manzhura, O. (2021). Digitalization of business processes of enterprises of the ecosystem of Industry 4.0: virtual-real aspect of economic growth reserves. *WSEAS Transactions on Business and Economics,* vol. 18: 57, 569–580. DOI: https://doi.org/10.37394/23207.2021.18.57

Kraus, K., Kraus, N., Manzhura, O., Ishchenko, I., & Radzikhovska, Y. (2023). Digital transformation of business processes of enterprises on the way to becoming Industry 5.0 in the gig economy. *WSEAS Transactions on Business and Economics,* vol. 20: 93, 1008–1029. DOI: https://doi.org/10.37394/23207.2023.20.93

Laitsou, E., Kargas, A., & Varoutas, D. (2020). Digital competitiveness in the European Union era: the Greek case. *Economies,* vol. 8, no. 4: 85. DOI: https://doi.org/10.3390/economies8040085

Liu, S., Cai, H., & Cai, X. (2023). The paradox of digitalization, competitiveness, and sustainability: a firm-level study of natural resources exploitation in post Covid-19 for China. *Resources Policy,* vol. 85: Part A, 103773. DOI: https://doi.org/10.1016/j.resourpol.2023.103773

Lixandroiu, D. (2018). Digital competitiveness indicators and the e-government process in Romania. *Journal of smart economic growth,* vol. 3, no. 2: 107–122. Available at: https://jseg.ro/index.php/jseg/article/view/47/47

Mlynarzewska-Borowiec, I. (2022). Digital competitiveness gap between the US and EU member states in the 21st century. *European Resaerch Studies Journal,* vol. XXV, no. 4: 364–380. DOI: https://doi.org/10.35808/ersj/3087

Saputra, N., Sasanti, N., Alamsjah, F., & Sadeli, F. (2022). Strategic role of digital capability on business agility during COVID-19 era. *Procedia Computer Science,* vol. 197: 326–335. DOI: https://doi.org/10.1016/j.procs.2021.12.147

Slavkovic, M., Pavlovic, K., Mamula Nikolic, T., Vucenovic, T., & Bugarcic, M. (2023). Impact of digital capabilities on digital transformation: the mediating role of digital citizenship. *Systems,* vol. 11, no. 4: 172. DOI: https://doi.org/10.3390/systems11040172

Stankovic, J. J., Marjanovic, I., Drezgic, S., & Popovic, Z. (2021). The digital competitiveness of European Countries: a multiple-criteria approach. *Journal of Competitiveness,* vol. 13, no. 2: 117–134. DOI: https://doi.org/10.7441/joc.2021.02.07

Sun, C., Lin, Z., Vochozka, M., & Vincúrová, Z. (2022[a]). Digital transformation and corporate cash holdings in China's A-share listed companies. *Oeconomia Copernicana*, vol. 13, no. 4: 1081–1116. DOI: https://doi.org/10.24136/oc.2022.031

Sun, C., Zhang, Z., Vochozka, M., & Voznakova, I. (2022[b]). Enterprise digital transformation and debt financing cost in China?s A-share listed companies. *Oeconomia Copernicana*, vol. 13, no. 3: 783–829. DOI: https://doi.org/10.24136/oc.2022.023

Total Population by Country 2023 (2024). *World Population Review.* Available at: https://worldpopulationreview.com/countries

World Digital Competitiveness Ranking 2023 (2024). *IMD World Competitiveness Center.* Available at: https://www.imd.org/wp-content/uploads/2023/12/Digital_2023.pdf

Zhang, L., Qiu, P., & Cao, P. (2023). Does digital transformation enhance the core competitiveness? – Quasi-natural experimental evidence from Chinese traditional manufacturing. *PLOS ONE,* vol. 18, no. 11: e0289278. DOI: https://doi.org/10.1371/journal.pone.0289278

Received on: 16th of February, 2025
Accepted on: 27th of March, 2025
Published on: 30th of April, 2025