sustainability

MDPI

Article

Global Analysis Regarding the Impact of Digital Transformation on Macroeconomic Outcomes

Mihaela Brindusa Tudose *, Amalia Georgescu and Silvia Avasilcăi

Faculty of Industrial Design and Business Management, Gheorghe Asachi Technical University of Iasi, Dimitrie Mangeron Boulevard, No. 29, 700050 Iasi, Romania

* Correspondence: mihaela-brindusa.tudose@academic.tuiasi.ro

Abstract: In the context of the development of information technologies, the concerns about assessing the effects of digital transformation have increased. Although it is intuitively accepted that digital transformation has a favourable impact on macroeconomic variables (based on the interdependencies between micro- and macroeconomic performance), there is little scientific research providing evidence of this. Building on this identified research problem, this study aims to bridge the gap between theory and practice. After assessing the extent to which the world's economies have responded to the need for digital transformation, an econometric analysis was conducted to quantify the impact of digital transformation on economic and social outcomes. To ensure the representativeness of the results, the econometric analysis was conducted on a sample of 46 countries selected according to the size of their gross national income per capita. The NRI (Network Readiness Index) and the sub-indices associated with the economic environment (future technologies, business, and economy) were used as independent variables. Gross domestic product (GDP) was used as a dependent variable. The results indicate that NRI has a positive and significant impact on GDP per capita. Analysis at the sub-indices level partially confirms this result and highlights that their contributions to the growth of macroeconomic performance may be different. The study results have practical utility as they provide clues on the structural efficiency of the benchmarks underpinning the digital transformation. To increase the positive impact on macroeconomic outcomes, policy-makers can propose and implement policies to facilitate access to those technologies that prove to be more effective.

Keywords: digital transformation; Network Readiness Index; GDP per capita; annual growth rate of GDP; America; Arab states; Asia; Pacific; Europe

Citation: Tudose, M.B.; Georgescu, A.; Avasilcăi, S. Global Analysis Regarding the Impact of Digital Transformation on Macroeconomic Outcomes. *Sustainability* **2023**, *15*, 4583. https://doi.org/10.3390/su15054583

Academic Editors: Maria Palazzo, Alessandra Micozzi and Dominique Lepore

Received: 7 February 2023
Revised: 28 February 2023
Accepted: 1 March 2023
Published: 3 March 2023

1. Introduction

Researchers' concerns about digitisation and digital transformation have been growing recently. The proof of this is the number of research articles identified on the Web of Science platform (as of 20 December 2022) on topics such as digitalisation (2792 articles), digital transformation (24,385 articles), digital transition (13,899 articles), digital innovation (18,847 articles), etc. Figure 1 shows the dynamics of this research, with a recent exponential increase.

Based on the review of a set of 39 relevant publications, Kraus et al. (2021) [1] highlighted two essential issues: technology is the driver of change induced by digital transformations; and digital transformations are occurring at all levels (companies, environment, society, and institutions). Reiterating that the use of new technologies is a requirement for ensuring the competitiveness of companies operating in a digital environment, Vial (2019) [2], in an extensive literature review, pointed out that digital transformation is both an endogenous phenomenon (in that it takes the form of a response by decision-makers to the opportunities offered by digital technologies) and an exogenous threat (requiring a response by companies to factors originating in the business environment).

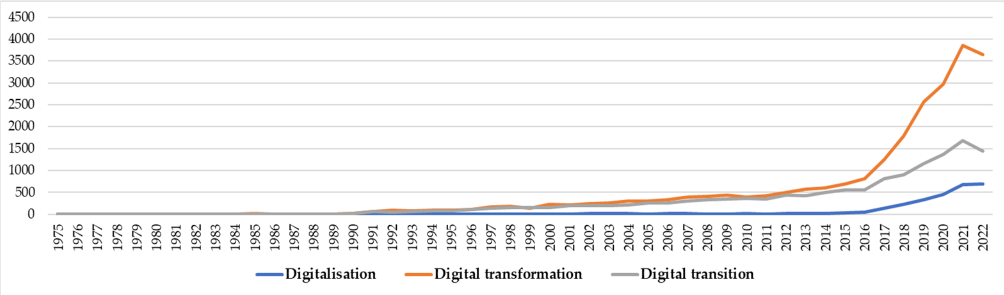

Figure 1. The dynamics of the annual number of publications. Source: Own processing based on data provided by the Web of Science.

Studies have shown that the most important determinants of digital transformation are associated with the external environment and organisational culture [3]. By the nature and magnitude of its impact, digital transformation based on the incorporation of digital technologies generates both opportunities (facilitating change) and threats for companies [4,5], ecosystems, industries, or economies [6].

Most research on the impact of transformations assesses the impact at the microeconomic level. Interactions between digital transformation and the value creation process, competitiveness, performance, sustainability, innovation, and business risks are considered. Zhang et al. (2023) [3] pointed out that digital transformation generates competitive advantages because it comes bundled with an innovation portfolio, which changes the value creation process. Thus, digital transformation generates new business models [5,7–10], stimulates innovation [11] and contributes to the creation of new products/services [3], achieves reconfigurations in customer preferences and behaviours [3,12,13], and contributes to increasing the performance of the economic environment [14].

Regarding the ubiquity of digital transformations, specialists affirm that not all companies need to be part of digital transformation processes, only those that can make creative and empirical simulations of business models that demonstrate the ability to implement digital transformations [15]. The same authors showed that, for these companies, digital transformation must respond to a 'planned digital shock'. In other words, the causes and effects of digital-transformation-induced change can be managed in a way that is good for business and good for the environment.

Through interactions at the microeconomic level, digitisation and digital transformation also create the conditions for increased macroeconomic performance. Of the more than 24,000 articles (in the above-mentioned database) that directly or indirectly address the causes and effects of digital transformation, only 0.2% integrate macroeconomic issues in the debate. As can be seen in Figure 1, after the 1990s, concerns about analysing the impact of digital transformations intensified. The researchers focused on ICT, a context in which evaluations were made regarding the effects of increasing access to information and increasing the speed of knowledge diffusion in different fields.

Taking the period 1970–1990 as a benchmark, Röller and Waverman (2001) showed that a third of the economic growth recorded in 21 countries was due to the development of telecommunications [16]. Vu (2011) carried out analysis for the period 1996–2005 and showed that ICT contributes to economic growth because it stimulates innovation and technology diffusion (at the level of industries and at the level of countries and regions) and improves the efficiency of resource allocations at the level of national economies [17]. The positive effect at the macroeconomic level derives from the positive effects recorded at the microeconomic level, which materialized in the reduction of production costs (because of easier and faster communication at the level of economic agents).

Comparing the two works written ten years apart, it is noticeable that there has been progress in the field of literature research. The impact of ICT is analysed by the country category (more developed and less developed) and the determinants are decomposed to highlight the structural changes in terms of economic growth. Simultaneously, a distinction is made between ICT penetration and the increase in its use. To provide more clarity on the contribution of ICT to economic growth, subsequent research has indicated that this contribution may differ depending on the type of technology examined.

For example, Toader et al. (2018) analysed the effects of accelerated ICT development and assessed the impact on GDP per capita for EU states for 18 years (2000–2017). They built impact measurement models based on four factors associated with ICT (fixed-broadband subscriptions, broadband Internet connection, level of internet usage, and mobile cellular subscriptions) and seven factors associated with macroeconomic variables. The authors showed that a 1% increase in the use of ICT infrastructure contributes to an increase in GDP per capita of between 0.0767% (fixed-broadband subscriptions) and 0.396% (mobile cellular subscriptions) [18]. Fernández-Portillo et al. (2019) analysed the impact of ICT globally but also from the perspective of five constructs (connectivity, human capital, Internet use, technological integration, and public services). Global analysis indicated that ICT was the most important contributor to GDP per capita. Conversely, the analysis at the level of the five constructs showed that the contribution to the growth of macroeconomic results is different [19].

Mayer et al. (2019) analysed the impact of broadband infrastructure investment on economic growth (as measured by GDP per capita). They showed that these networks speed up the transmission of information and knowledge; specifically, each 10% increase in speed produces about a 0.5% increase in GDP per capita [20]. Soava et al. (2022) retrospectively (2003–2020) and prospectively (2025) analysed the contribution of e-commerce to the formation and growth of the gross domestic product and indicated that the digital economy contributes to economic and social development, having the ability to multiply the growth effect of GDP [21].

Since the studies were conducted on different samples (more or less homogeneous), for different periods (of the order of a few years or decades), using different methodologies and different ICT components, the results regarding the positive impact of ICT on macroeconomic variables were heterogeneous. For this reason, some authors point out that the results cannot be generalized, especially since some studies either did not identify any relationship between the two variables (Fernández-Portillo et al., 2019) [19] or reported statistically insignificant results (Mayer et al., 2019) [20].

To ensure a convergence of results, some organizations have recently proposed the determination of aggregate indicators that allow the evaluation of digital transformations based on a unified methodology, applicable at the country or regional level. Thus, specific indicators were used in the profile research, such as the Networked Readiness Index (NRI), the Digital Economy and Society Index (DESI), the ICT Development Index, or sets of indicators developed by the OECD (Organisation for Economic Co-operation and Development) and the World Bank.

Studies using NRIs have shown that digital technologies shorten operating times at the economic level [22] and positively impact competitiveness and welfare [23], economic growth [24,25], industrial development, and employment [26], facilitating social progress [27].

DESI, as an index measuring the digital competitiveness of EU Member States, is used in various studies to highlight the dynamics of digital performance across EU countries [28], to assess the extent to which the gap between rich and poor countries in the EU can be narrowed through rapid and intensive digital transformation [29], or to assess the digital convergence of markets in the EU [26].

Research that has used aggregate indicators to measure digital transformations (such as that previously presented) has provided results that cannot be generalized. This is because the analyses were conducted for different samples and periods and used different methodologies. At the same time, the increase in the use of ICT, in the conditions of a dynamic economic environment, forces periodic reassessments regarding the impact of digital transformations on macroeconomic variables. For this reason, this study has a double objective: to assess the extent to which the world's economies have responded to the need for digital transformation and to assess the impact of digital transformations on macroeconomic outcomes. To ensure the originality and representativeness of the results, the empirical research was carried out on a sample of 46 states from different areas of the globe, selected according to gross national income per capita. The research strategy was based on the hypothesis of the positive impact of digital transformations on economic growth. The results of the analyses carried out both at the sample level and at the level of groups of countries confirmed the assumed hypothesis and highlighted that (for the selected sample) GDP per capita is the indicator that best captures the impact of digital transformations (measured by an aggregate indicator, as well as through sub-initials associated with the economic environment). To our knowledge, the evaluation of the impact of the selected sub-indices (future technologies, business, and economy) has not been the subject of previous analyses. Therefore, the present study opens up new research directions and signals that the degree of access to future technologies, financial support for R&D, and the network economy may have different impacts on macroeconomic outcomes.

To achieve this objective, the paper was structured as follows. Section 2 summarizes the results of the literature research on digital transformation and the measures used to assess its macroeconomic impact. Section 3 presents the methodology of the empirical research. The results of the research and discussion of the findings are summarised in Section 4. The last section presents the main conclusions, research limitations, and future research directions.

2. Literature Review

The literature review aims to identify the concepts describing digital transformation and the indicators used to assess the degree of digitisation of economies (such as NRI). We also gathered evidence on the impact of digital transformation on macroeconomic performance, according to the latest research available in this field. The three subsections provide detailed and relevant references regarding the scientific findings of the studies performed lately.

2.1. Digital Transformation—Concept, Causes and Effects

Most of the debates regarding the digital transformation are relatively recent. As a field that has not yet reached maturity in terms of conceptual foundations, early attempts to define the concept of digital transformation have lacked convergence. Thus, digital transformation has been associated with the use of new digital technologies capable of generating improvements (such as process efficiencies), facilitating adaptability, and supporting increased performance of businesses, industries, ecosystems, or even economies as a whole [8,30]. Other authors have defined the digital transformation in terms of the causes and effects it produces. For example, Hinings et al. (2018) [6] interpreted digital transformation through the lens of the combined effects of the implementation of digital innovations. Bondar et al. (2017) [31] interpreted digital transformation through the adaptive capacity of different economic or institutional actors to the new circumstances of the digital era.

To shed light on the scope and complexity of digital transformation, Vial (2019) [2] proposed four benchmarks: the target entity (which can be represented by companies, institutions, ecosystems, national economies, etc.), the scope (micro- or macroeconomic), the source of change (the technologies generating change) and the expected outcome (which can be positive or negative). Based on these benchmarks, Vial (2019) [2] has produced the most pertinent definition of digital transformation: 'a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies'.

At the microeconomic level, the digital transformation contributes to significant improvements in performance indicators (cost, quality, and service) [3] and facilitates innovation [11]. Additionally, under the impact of digital transformation, industrial competition becomes anabatic [32], consumer behaviour changes [12,13], corporate risk-taking capacity increases [33], resource and process management efficiency enhances [34], companies become more open to the information environment [35,36], the overall structure of the economy changes [37], and ecosystem conditions changes [38]. The effects of digital transformations take the form of new organisational structures, new business structures and models, new actors (and new forms of association such as associative businesses), new practices and beliefs (for both producers and consumers), new perceptions of value, etc. On the other side, new corporate strategies are formulated in the areas of innovation (process-rebuilding innovation and product-renewal innovation) [3], marketing [5,13], digital business [2] and sustainability [39].

More recent literature points to new directions of approach. For example, Okorie et al. (2023) [39] showed that digital transformation needs to be linked to business sustainability (to ensure decarbonisation of the industrial sector and facilitate the adoption of a circular economy). This correlation is possible as long as there are several scenarios for adopting digital technologies, differentiated according to stakeholder interests and options available to companies. Some authors [39] propose a resource-based approach (tangible and intangible) so that the potential for competitive advantage is correlated with corporate sustainability; companies can achieve lasting competitive advantages by carefully pooling and managing their resources and capabilities. Other authors [32] showed that digital transformation helps alleviate corporate financial constraints and improve corporate governance, thus removing barriers to corporate innovation.

These research directions indicate that researchers' attention is no longer limited to the corporate environment, but also includes environmental and business sustainability issues. Thus, the scope of the debate extends beyond the concern of aligning business with information and communication technology (ICT) trends [40]. Digital transformation is no longer limited to present technological changes [41], driven by different contexts, but forces anticipation of change and planning activities that strengthen business agility. To be sustainable, transformations at the microeconomic level must also produce changes at the level of industries and fields of activity, aiming at the macroeconomic level and longer time horizons. Micro-level transformations generate added value (by improving productivity, reducing costs, facilitating innovation, and increasing performance), contributing not only to improved outcomes at the level of industries and economies, but also to societal development [1].

2.2. NRI—A Tool for Measuring the Amplitude of Digital Transformations

Current research [25] presents three classes of indicators used to assess the degree of digitisation of economies: the ICT Development Index, which monitored and compared ICT developments at the country and period level until 2017 (the index was subsequently discontinued); Market Capitalization, designed to measure the performance of firms in the digital economy—as it only reflects digital transformations only for listed companies, this indicator has limited applicability; and the Network Readiness Index (NRI). To these indicators, we can also add: (a) the Digital Economy and Society Index (DESI), which monitors overall digital performance and measures the progress of EU countries in terms of digital competitiveness [42]; (b) the set of indicators developed by the OECD in order to measure the impact of digital technologies on companies, economies, and society [43]; and (c) the set of indicators developed by the World Bank to assess digital readiness [44].

Since the sample of countries on which empirical research was conducted in the present study includes countries from different continents, NRI was the best option. The Network Readiness Index (NRI) was developed by the World Economic Forum (WEF) to facilitate the assessment of the impact of ICT on the competitiveness of national economies. With a range from 1 to 100, the index highlights the extent to which countries are exploiting the opportunities offered by information and communication technology. As of 2019, the NRI is managed by the Portulas Institute, which has redesigned the methodology of determination precisely to reflect the ubiquitous nature of digital technologies [45].

The NRI is based on four pillars: technology (access, content, and future technologies), people (individuals, businesses, and governments), governance (trust, regulation, and inclusion) and impact (economy, quality of life, and contribution to sustainable development goals). Three of the four pillars (technology, people, and impact) have a sub-indicator that deals exclusively with the economic environment: future technologies, business, and economy. Each of these sub-indicators is broken down into six or seven explanatory variables. The indicator is calculated annually for 131 countries, grouped into six classes (Africa—31, Arab States—12, Asia and Pacific—21, Commonwealth of Independent States—6, Europe—41, America—20) [46].

2.3. Evidence on the Impact of Digital Transformation on Macroeconomic Performance

Some researchers [47] analysed digital transformation at the micro and macro level and showed that changes at the level of companies also enhance the development frameworks of all sectors of the economy. Other authors [21,30] showed that digital technologies are the driving force behind the current industrial revolution. They assessed the potential for digital transformation on a sample of 19 EU and OECD countries using the Digital Transformation Potential Index (DTPI) for the period 2008–2018. They showed that the potential for digital transformation is affected by economic cycles (it decreases in times of crisis and increases along with the economy's growth). At the same time, they showed that the benefits of digital technologies are more visible in economically weaker countries. Similar results were reached by Matthess and Kunkel (2020) [48], who reported that digital technologies can bridge gaps between countries, helping developing country economies move towards prosperity. Humenna et al. (2021) [49] showed that, under the impact of macroeconomic crises and imbalances, a country's macroeconomic stability depends to a large extent on the degree of digitisation of the economy.

Conducting research on a pilot sample (V4 countries), Georgescu et al. (2022) [25] assessed the interdependencies between the degree of digitisation of the economy and the dynamics of macroeconomic outcomes during the pandemic crisis (2019–2021) and showed that digital transformations have favourable economic and social impacts. Applying multiple linear regression, the authors used real GDP per capita as the dependent variable and NRI and *technology* sub-indices as independent variables. The statistically significant results indicated as follows: a one-unit increase in the NRI index increases real GDP per capita by 0.04 units. In the increase of real GDP per capita, technology has an important contribution.

By using the NRI and ICT Development Index as proxies for assessing digital transformation, Afonasova et al. (2019) [22] conducted a comparative analysis (multiple case study) on six economies (Russia, Finland, Germany, Norway, the Netherlands, and Switzerland). Their study revealed significant differences in the dynamics of selected variables and provided evidence on the conditions underlying the transition to the digital economy. The authors reiterated that a crisis can open up opportunities for growth. If these opportunities are not seized, progress towards the digital economy is slowed down.

Under the pretext of recognizing the interdependence between NRI on the one hand and a nation's competitiveness and well-being on the other, Sitnicki and Netreba (2020) [23] conducted empirical research on a group of eight Eastern European countries (Ukraine, Bulgaria, the Czech Republic, Estonia, Latvia, Lithuania, Poland, and Romania). Using exploratory factor analysis (for the period 2013–2016), the authors assessed the interdependencies between 4 sub-indices (Environment, Readiness, Usage and Impact) and tested the representativeness of the NRI from a macroeconomic perspective. The authors showed that the identified interdependencies allow for estimating global economic and social trends (the authors estimated that, in just a few months of the pandemic period, information technology use could increase by as much as three times).

Agustina and Pramana (2019) [24] analysed the dynamics of NRI and concluded that the improved competitiveness of Indonesian firms was made possible by the adoption of ICT. They conducted regression analyses (fixed effects model) and showed that 99.83% of the variation in provincial economic growth rates in Indonesia is driven by the ICT development index and local government ICT spending. Interpretation of the regression equation coefficients indicated that a one-unit increase in the ICT Index results in a 0.089 percent improvement in the economic growth rate. Analysis at the provincial level indicated that the impact of the ICT may differ, as provinces have advanced more in the area of digital transformation. As the ICT development index and public spending on ICT increase, the prospects for economic growth also increase.

Before the pandemic period (which forced the digital transformation), Stanley et al. (2018) [50] sought to explain whether the pace of growth of national economies depends on the extent of use of digital technologies. To find the answer to this question, the authors conducted analyses for both developed and developing countries. Based on a systematic literature review meta-analysis, they show that researchers' views converge, assuming that there is a positive relationship between ICT and economic growth (as measured by GDP growth or GDP per capita dynamics or productivity indicators). Specifically, the authors show that, in developed countries, all ICT-integrated media contribute to economic growth except the Internet. The exclusion of the Internet from the list of factors influencing economic growth was considered as a mistake (related either to sampling or to the meta-analysis tools used), and the authors recommend a more careful analysis of the channels through which the ICT effect on growth is transmitted (especially as the impact is quantified as relatively modest). The situation is different for developing countries, for which strong evidence has been identified on the positive impact of ICT (including the Internet) on economic growth.

Based on empirical research conducted on a sample of 145 countries, De la Hoz-Rosales et al. (2019) [27] sought to identify evidence of the interdependencies between ICT use and human development and social progress. Breaking down the analysis by groups of countries and entities (individuals, businesses, and governments) and using the NRI as an independent variable, they showed that the use of ICT to increase competitiveness and well-being is statistically significant. Specifically, for a one-unit increase in NRI, the social progress index increases by 0.93. The authors also showed that the use of ICT (at the individual and business level) has a positive impact on human development, regardless of the level of development of countries. In contrast, ICT use by governments was found to have a positive impact on human development only in developed countries. As for ICT use at the business level, the authors confirmed the positive impact on human development only at the global level (with the remark that the results were found to be statistically significant only for developing countries).

3. Materials and Methods

In the digital transition, the volume and flow of data online generates both added value (for governments, businesses and people) and inequality (for individuals, businesses and governments). At the same time, it changes the nature of work processes and leverages new factors of production at a higher level, such as digital skills, innovation, information, time, and online space.

In view of the above, this empirical research has a twofold objective. First, it aims to assess the extent to which the world's economies have responded to the need for digital transformation. Secondly, it is aimed at assessing the impact of digital transformation on economic and social outcomes. To achieve the objectives, data for the period 2018–2021 provided by Portulans Institute on the Network Readiness Index (NRI) and sub-indices, as well as data provided by the World Bank, were analysed.

3.1. The Sample

The sample was selected according to the following criteria: the rank of each country in the Portulans Institute's ranking and the income of each country [51]. According to the NRI methodology, countries were grouped according to gross national income per capita, based on data provided by the World Bank. Of the 131 countries included in the NRI report, only countries in the high-income category were selected. Out of the total of 49 countries identified, 46 countries are in the top 55 positions of the NRI ranking (according to ref. [51]).

The other three countries (Kuwait, Panama and Trinidad and Tobago) are significantly lower in the NRI ranking. To minimize discrepancies, these countries were removed from the sample. The final sample consisted of 46 countries, of which 30 are European countries, 7 are Asian and Pacific countries, 5 are Arab countries and 4 are American countries (Table 1).

Table 1. Sample.

Regions	Countries
Americas States	United States (1), Canada (11), Chile (43), Uruguay (47)
Arab States	United Arab Emirates (28), Saudi Arabia (35), Qatar (42), Oman (53), Bahrain (54)
Asia and Pacific	Singapore (2), Korea, Rep. (9), Japan (13), Australia (14), Israel (15), New Zealand (19), Hong Kong, China (30)
Europe	Sweden (3) Netherlands (4), Switzerland (5), Denmark (6), Finland (7), Germany (8), Norway (10), United Kingdom (12), France (16), Luxembourg (17), Austria (18), Ireland (20), Belgium (21), Estonia (22), Iceland (24), Czech Republic (25), Spain (26), Slovenia (27), Portugal (29), Malta (31), Italy (32), Lithuania (33), Poland (34), Slovakia (37), Cyprus (38), Latvia (39), Hungary (41), Croatia (45), Greece (49), Romania (52)

Source: Own processing. Note: The number in brackets represents the position of the countries in the NRI ranking, according to the report made by the Portulans Institute [51].

3.2. Variables Used and Research Hypotheses

The Network Readiness Index (NRI) was used to assess the level of digitisation. This index was originally developed by the Word Economic Forum (WEF) to highlight the extent to which countries are exploiting the opportunities offered by information and communication technology. As of 2019, the NRI is managed by the Portulans Institute, which has redesigned the methodology of determination precisely to better capture the dynamics of digital transformation related to 2018. For this reason, our analysis is limited only to the period for which the new NRI determination methodology was used (2018–2021).

The use of NRI in recent empirical research has shown the following: digital technology increases the speed of operation in the economy [22] and has a favourable impact not only on economic growth [24,25], but also on economic development, through favourable impacts on innovation, competitiveness, and welfare [23,52]. Differently from previous research (which focused either on one country or a small group of countries), in this study, we consider a broader sample, including 4 major regions of the globe.

The Network Readiness Index (NRI) is calculated on the basis of four pillars, each structured on three levels: technology (access, content, and future technologies); people (individuals, business, and governments); governance (trust, regulation, and inclusion); and impact (economy, quality of life, and contribution to the sustainable development goals). In our research, we give priority to sub-indices that are directly associated with the economic environment:

- future technologies (from the technology pillar), indicating the extent to which countries are prepared for the future of the network economy; specifically, variables such as artificial intelligence (AI), the Internet of things (IoT), and spending in emerging technologies are considered.
- business (from the people pillar), which indicates the extent to which businesses are leveraging ICT and are providing funding for R&D.
- economy (from the impact pillar), which reflects the economic impact of participation in the network economy.

Three sets of variables were used in the econometric analysis, based on panel data. The dependent variables were represented by two macroeconomic outcome measures (for which World Bank data were used): annual GDP growth rate (%) and real GDP per capita (current USD). These two indicators were considered the best options for assessing the economic impact of digital transformation. GDP per capita is used in the research literature both as a measure of economic activity and as a measure of living standards. The NRI and its sub-indices are independent variables. A control variable—the ease of doing business index (EDB)—was introduced for greater clarity at the level of the sample countries. This index is determined by the World Bank on the basis of quantitative indicators based on regulations that facilitate starting a business, obtaining permits (building and electricity connection), registering property, obtaining credit, protecting minority investors, paying taxes, trading across borders, enforcing contracts, resolving insolvency, employing workers, and contracting with the government. As this indicator is only available for the period 2018–2020, an estimate based on changes in previous years was made for 2021.

The econometric analysis (based on correlation and regression models) was carried out to test whether: (1) the increased use of digital technologies impacted increasing macroeconomic outcomes; and (2) the contribution of the selected sub-indices—future technologies (from the technology pillar), business (from people pillar), and economy (from impact pillar)—to increasing macroeconomic outcomes may be different.

3.3. Mathematical Modelling

Correlation and regression analyses were performed to identify interdependent relationships between the selected dependent and independent variables. SPSS software was used to perform the econometric analyses. Since the sample data consider several variables, for 46 countries over a 4-year period, we used the ordinary least square (OLS) method (model fitted to panel data). The following equation was constructed to examine the impact of digital transformation on selected macroeconomic variables:

$$Y_{it} = \beta_1 X_{it} + \beta_2 V_{it} + u_{it}, \quad (1)$$

where i represents the countries included in the analysis; t is the time (2018–2021); Y_{it} is the dependent variable (indicators of macroeconomic results); X_{it} represents the independent variables (NRI; respectively, future technology, business, and economy); V_{it} represents the control variable; β_1, β_2 represent the coefficient; and u_{it} is the error term.

If the sign of the β coefficients is positive, then we conclude that there is a positive impact of digital transformation on macroeconomic outcomes. On the other hand, if the coefficients are negative, an inverse relationship between both variables is predicted (provided this is statistically significant).

4. Results and Discussion

The first objective of the empirical research was to map the digital transformations over the 4 years (2018–2021). For this, data was collected from Portulans Institute annual reports [45,46,51,53]. According to the representations in Figure 2, the following conclusions can be drawn for the period 2018–2021:

- The number of countries with an NRI below 60 decreases from 10 (in 2018) to 8 (in 2019 and 2020); then, in 2021, as an effect of global crises (we take into account the crises associated with the pandemic period), the number of countries with an NRI below 60 increases to 11. Most countries in this NRI range (50–60) belong to the groups of American (2), Arab (3), and European (6) countries.
- The number of countries with an NRI between 60 and 70 increases from 14 (in 2018) to 15 (in 2019) and 16 (in 2020); in 2021, only 14 countries still fall within this NRI range (60–70).
- The number of countries with an NRI between 70 and 80 increases from 14 (in 2018) to 17 (in 2019); this increase is matched by a decrease to 15 (in 2020) and a rebound in 2021, when the number of countries increases to 20. This oscillating evolution highlights that some countries have experienced difficulties in the digital transition in the context of macroeconomic imbalances. The increase in the number of countries in

the 70–80 (NRI) range can be seen as evidence that the pandemic period has forced the economies of the world's countries to pay more attention to digital transformation.

- The number of countries with an NRI greater than 80 falls from 8 (in 2018) to 6 (in 2019); the two countries falling in the rankings are the United States and Norway. The year 2020 sees a slight recovery (the number of countries rises to 7, with the United States catching up, joining the countries with the highest NRI: Singapore, Sweden, Netherlands, Switzerland, Finland, and Norway); in 2021, only the United States is still in this gap (NRI > 80).

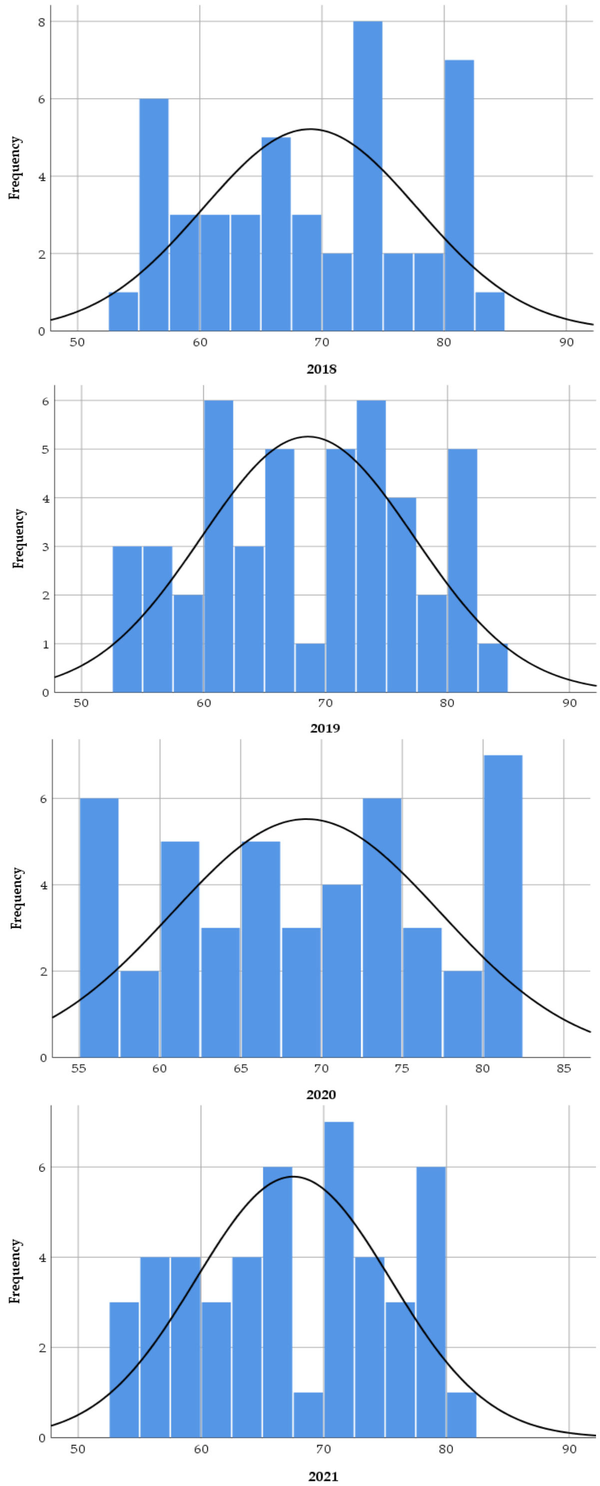

Figure 2. NRI—annual values. Source: Own processing.

The dynamic analysis, based on the previous year, revealed that the number of countries with a decrease in the NRI index decreased from 32 (in 2019) to 15 (in 2020), showing significant progress in the digital transition. In 2021, compared to 2020, 40 states marked a decrease in the NRI index. States that marked an increase in the NRI index (in 2021 compared to 2020) were Qatar (with an increase of only 0.04); Chile, Portugal, and Korea (with increases ranging from 0.30 to 0.43); Israel (with an increase of 0.69); Saudi Arabia (with an increase of 0.86); and the United Arab Emirates (with an increase of 1.72). These dynamics can also be captured in Figure 3, which shows the dynamics of the NRI index for the 46 countries in the sample. Figure 3 provides two important pieces of evidence on the decrease in the NRI index for most countries in the sample (the yellow line being lower than the lines corresponding to the previous years' values).

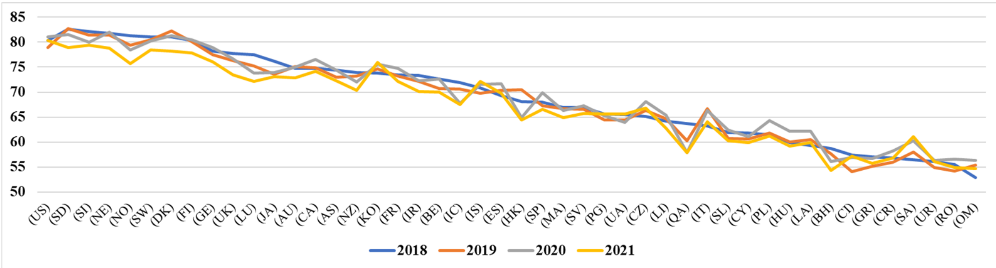

Figure 3. NRI dynamics—46 states (2018–2021). Source: Own processing.

The second objective of the empirical research was to assess the impact of digital transformation on the economic and social outcomes of the sample countries. The previously analysed database (on NRI dynamics) was complemented with information provided by World Bank on GDP growth rate (%), Real GDP per capita (current USD), and the ease of doing business. Descriptive statistics for the variables used in the econometric analysis are presented in Table 2.

Table 2. Descriptive statistics.

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
NRI	184	52.87	82.75	68.54	8.40	−0.07	−1.18
FTH	184	16.47	90.60	50.68	16.55	0.12	−0.81
BUS	184	26.98	88.39	60.19	13.64	−0.41	−0.31
ECN	184	15.53	84.71	47.32	14.31	0.12	−0.72
GDP	184	−10.82	13.48	1.57	4.33	−0.58	0.37
GDPc	184	12,398.98	135,682.79	41,215.83	23,247.89	1.18	1.74
L-GDPc	184	4.09	5.13	4.55	0.24	0.03	−0.92
EDB	184	61.03	87.02	76.95	5.76	−0.58	0.09

Source: Own processing. Legend: NRI—Network Readiness Index; FTH—future technologies; BUS—business; ECN—economy; GDP—gross domestic product growth rate (%); GDPc—gross domestic product per capita (US$); L-GDPc—logarithm of GDPc; EDB—ease of doing business.

Comparing the maximum (82.75, recorded in Sweden in 2019) and the minimum (52.87, recorded in Oman in 2018) for the NRI, it can be seen that the range of variation is statistically acceptable, with a standard deviation of 8.59. This is because the sampling ensured homogeneity of the values for the countries in the sample. In contrast, selected sub-indices (FTH, BUS, and ECN) show higher levels of variation. The lowest values were recorded for Croatia (FTH 16.47 in 2019), Oman (BUS 26.98 in 2018), and Uruguay (15.53 in 2018). The maximum values were recorded for the US (FTH 90.60 in 2020), Japan (BUS 88.39 in 2020), and Singapore (ECN 84.71 in 2020).

The evolution of GDP (%) is marked by a shift from negative values (the minimum being −10.82%, recorded in Spain in 2020) to positive values (the maximum being of 13.48%, recorded in Ireland in 2021). As for GDPc, the variation gap is represented by 12,398.98

(recorded in Romania in 2018) and 135,682.79 (recorded in Luxembourg in 2021). In order to normalize, the values were processed by the logarithm (L-GDPc).

Regarding the analysis of symmetry/asymmetry of the data, descriptive statistics indicate the following. The values of the NRI and the sub-indices analysed (FTH, BUS, ECN) show a roughly symmetric distribution, with Skewness taking values between (−1/2 and +1/2); the logarithmic variable (L-GDPc) has the same distribution. The values of GDP and EDB show a moderate distribution and those of GDPc show an asymmetric distribution (the value of asymmetry being greater than one). For all variables, there is a flattening of the curve reflecting the distribution of values, with Kurtosis showing values less than 3.

To examine the impact of digital transformations on selected macroeconomic variables, the following equations were formulated:

$$\text{GDP}_{it} = \beta_1\ \text{NRI}_{it} + \beta_2\ \text{EDB}_{it} + \text{u}_{it}, \quad (2)$$

$$\text{L-GDPc}_{it} = \beta_1\ \text{NRI}_{it} + \beta_2\ \text{EDB}_{it} + \text{u}_{it}, \quad (3)$$

$$\text{GDPc}_{it} = \beta_1\ \text{NRI}_{it} + \beta_2\ \text{EDB}_{it} + \text{u}_{it}, \quad (4)$$

$$\text{GDP}_{it} = \beta_1\ \text{FTH}_{it} + \beta_3\ \text{BUS}_{it} + \beta_3\ \text{ECN}_{it} + \beta_4\ \text{EDB}_{it} + \text{u}_{it}, \quad (5)$$

$$\text{L-GDPc}_{it} = \beta_1\ \text{FTH}_{it} + \beta_3\ \text{BUS}_{it} + \beta_3\ \text{ECN}_{it} + \beta_4\ \text{EDB}_{it} + \text{u}_{it}, \quad (6)$$

$$\text{GDPc}_{it} = \beta_1\ \text{FTH}_{it} + \beta_3\ \text{BUS}_{it} + \beta_3\ \text{ECN}_{it} + \beta_4\ \text{EDB}_{it} + \text{u}_{it}. \quad (7)$$

Correlation analysis showed a weak association between GDP and NRI (but not a statistically significant one) and a moderate association between NRI and GDPc (a positive, statistically significant association) (Table 3). The analysis showed a strong association between NRI and the logarithmic form of GDPc (L-GDPc). A weak association was found between the values of the control variable (EDB) and the other variables. As expected, there are strong associations between NRI and its sub-indices.

Table 3. Pearson correlations test.

	NRI	**FTH**	**BUS**	**ECN**	**GDP**	**GDPc**	**L-GDPc**	**EDB**
NRI	1	0.844 **	0.834 **	0.752 **	−0.038	0.694 **	0.795 **	0.635 **
FTH	0.844 **	1	0.690 **	0.741 **	−0.107	0.640 **	0.751 **	0.475 **
BUS	0.834 **	0.690 **	1	0.695 **	0.082	0.525 **	0.608 **	0.556 **
ECN	0.752 **	0.741 **	0.695 **	1	−0.127 *	0.504 **	0.592 **	0.459 **
GDP	−0.038	−0.107	0.082	−0.127 *	1	0.118	0.086	0.040
GDPc	0.694 **	0.640 **	0.525 **	0.504 **	0.118	1	0.954 **	0.292 **
L-GDPc	0.795 **	0.751 **	0.608 **	0.592 **	0.086	0.954 **	1	0.405 **
EDB	0.635 **	0.475 **	0.556 **	0.459 **	0.040	0.292 **	0.405 **	1

** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level. Source: Own processing.

To eliminate multi-collinearity, highly correlated variables were not included in the same regression model. Therefore, the equations that remain valid at this level of the analysis are (2), (4), (5), and (7).

As preliminary steps to the regression analysis, the significance of the relationship between variables was tested (Table 4). Assuming that the results of the regression analysis are statistically significant, the data in Table 4 indicate that 8% (i.e., 51.8%) of the variation in GDP (i.e., GDPc) can be explained by the variation in NRI and EDB for Equations (2) and (4). For Equations (5) and (7), 8.6% (respectively, 42.3%) of the variation in GDP (respectively, GDPc) can be explained by the variation in the variables included in the analysis (FTH, BUS, ECN, and IBD).

Table 4. The significance of the relationship between variables.

Equations	Multiple R	R Square	Adjusted R Square	Standard Error
(2)	0.092	0.008	−0.003	4.336
(4)	0.72	0.518	0.513	16,226.831
(5)	0.293	0.086	0.066	4.186
(7)	0.653	0.423	0.413	17,809.197

Source: Own processing.

To test the significance of the proposed statistical models, an ANOVA test was conducted. The results are presented in Table 5. Analysing the most significant coefficients (F and Sig.), it is observed that only in models (4), (5), and (7) do the F coefficients have an associated probability of less than 0.05, which rejects the null hypothesis and allows the assessment that only these prediction models are statistically significant.

Table 5. ANOVA test.

Results	Models				
	$GDP_{it} = \beta_1 NRI_{it} + \beta_2 EDB_{it} + u_{it}$ (2)				
ANOVA	Sum of Squares	df	Mean Square	F	Mr
Regression	28.966	2	14.483	0.770	0.464
Residual	3403.351	181	18.803		
Total	3432.317	183			
	$GDPc_{it} = \beta_1 NRI_{it} + \beta_2 EDB_{it} + u_{it}$ (4)				
ANOVA	Sum of Squares	df	Mean Square	F	Mr
Regression	5.1×10^{10}	2	2.5×10^{10}	97.311	0.000
Residual	4.7×10^{10}	181	2.6×10^{8}		
Total	9.9×10^{10}	183			
	$GDP_{it} = \beta_1 FTH_{it} + \beta_3 BUS_{it} + \beta_3 ECN_{it} + \beta_4 EDB_{it} + u_{it}$ (5)				
ANOVA	Sum of Squares	df	Mean Square	F	Mr
Regression	295.331	4	73.833	4.213	0.003
Residual	3136.986	179	17.525		
Total	3432.317	183			
	$L\text{-}GDPc_{it} = \beta_1 FTH_{it} + \beta_3 BUS_{it} + \beta_3 ECN_{it} + \beta_4 EDB_{it} + u_{it}$ (7)				
ANOVA	Sum of Squares	df	Mean Square	F	Mr
Regression	4.2×10^{10}	4	1.1×10^{10}	33.210	0.000
Residual	5.7×10^{10}	179	3.2×10^{10}		
Total	9.9×10^{10}	183			

Source: Own processing.

Given the results of the ANOVA test, regression analysis was applied only to models (4), (5), and (7), which were considered statistically significant. The results are presented in Table 6.

The coefficients of Equation (4) indicate that, for the period under analysis, NRI has a positive and significant impact on GDP per capita. For a one-unit change in NRI, GDP per capita increases by 2357.53. The analysis at the level of the NRI sub-indices (Equation (7)) shows that only FTH and BUS contributed to the increase in GDP per capita. In other words, the one-unit increase in the sub-index indicating the use of artificial intelligence (AI), Internet of things (IoT), and spending in emerging technologies increases GDP per capita by 755.275. With a more moderate (but statistically significant) contribution to GDP per capita growth is the BUS sub-index, which indicates the extent to which businesses are leveraging ICT and providing R&D funding. A one-unit increase in this sub-index contributes to a GDP per capita growth of 321.132.

Table 6. Coefficients of regression equations.

Equations/ Variables		Unstandardized Coefficients		Standardized	t	Sig.	Collinearity Statistics	
		B	Std. Error	Coefficients—Beta			Tolerance	VIF
(4) GDPc	(Constant)	−42,916.162	16,067.611		−2.671	0.008		
	NRI	2357.528	184.862	0.852	12.753	0.000	0.596	1.677
	EDB	−1006.584	269.502	−0.250	−3.735	0.000	0.596	1.677
(5) GDP	(Constant)	−1.832	4.337		−0.422	0.673		
	FTH	−0.048	0.030	−0.185	−1.611	0.109	0.387	2.582
	BUS	0.118	0.036	0.371	3.299	0.001	0.404	2.477
	ECN	−0.081	0.035	−0.269	−2.336	0.021	0.386	2.591
	EDB	0.034	0.065	0.045	0.519	0.604	0.673	1.485
(7) GDPc	(Constant)	5263.530	18,448.462		0.285	0.776		
	FTH	755.275	127.795	0.538	5.910	0.000	0.387	2.582
	BUS	321.132	151.941	0.188	2.114	0.036	0.404	2.477
	ECN	13.014	148.097	0.008	0.088	0.930	0.386	2.591
	EDB	−289.427	278.339	−0.072	−1.040	0.300	0.673	1.485

Source: Own processing.

Regarding the annual GDP growth rate (%), regression analysis indicated that BUS has a positive and statistically significant influence. A one-percent increase in the BUS sub-index increases the annual GDP growth rate by 0.118%. The results also indicate that the ECN has a negative, statistically significant influence on the GDP growth rate. A one-percent increase in the ECN sub-index decreases the annual GDP growth rate by 0.081%. This influence can be explained by the fact that, to increase the economic impact of participation in the network economy, expenditures are incurred which, in the short run, decrease GDP growth rates. Another possible explanation is that the positive externalities of the digital transition lag behind the timing of the commitment of resources to the digital transition. Therefore, present resource allocations generate effects on future macroeconomic outcomes.

Our results are in line with previous research findings that have tested the interdependence between the digital transformation at the aggregate level (assessed by NRI) and macroeconomic-level outcomes [24,25,27,47,50]. Regarding the positive impact of digital transformations (measured by variables other than NRI) on GDP per capita, our results converge with:

- Toader et al. (2018) [18], which showed that a 1% increase in the use of ICT infrastructure can contribute to an increase in GDP per capita; this contribution varies between 0.0767% and 0.396%, depending on the type of technology examined.
- Fernández-Portillo et al. (2019) [19], which showed that the sustainable economic development of nations is positively influenced by ICT (more precisely, connectivity, use of Internet and skills of human capital); their research results indicated that ICT explains 42.6% of the variance in GDP per capita.
- Mayer et al. (2019) [20], which showed that investment in broadband infrastructure accelerates the transmission of information and knowledge; specifically, each 10% increase in speed produces about a 0.5% increase in GDP per capita. These authors also indicated the causes associated with an overestimation of the economic impact.

As for the control variable EDB, the analyses indicated that its impact is statistically significant only in model (4). Increasing the EDB variable by one unit decreases GDP per capita. Similar results were also reported by Pal et al. (2022) [54], who analysed the link between GDP and the global competitiveness index, i.e., the EDB index. This can be explained by the fact that the ease of starting a business may have the effect that previous businesses are abandoned—so as to benefit from the facilities associated with new businesses. As entrepreneurs and investors prefer to engage in less ambiguous economic environments [55], the situation may generate an inconsistency in EDB dynamics. Recent research [56] has shown that business start-ups engage factors of production (human resources, land, and capital), which contributes to value-added goods. This can only increase GDP per capita under conditions of equitable distribution of national output. An inequitable distribution can therefore have the effect of reducing GDP per capita.

In all regression equations, the tolerance level is less than 0.7. The results are statistically robust because the collinearity test (VIF—Variation Inflation Factor) shows values less than 10. To test the results obtained, but also to identify possible differences, regression models were run at the level of sub-samples represented by the four groups of countries. The results are summarized in Table 7.

Table 7. Regression results (significance and variation coefficients)—by groups of countries.

	Americas States			**Arab States**			**Asia and Pacific**			**Europe**		
	Models			**Models**			**Models**			**Models**		
	(4)	**(5)**	**(7)**	**(4)**	**(5)**	**(7)**	**(4)**	**(5)**	**(7)**	**(4)**	**(5)**	**(7)**
NRI	**0.000 (+1966)**			**0.004 (+3038)**			**0.054 (+936)**			**0.000 (+2735)**		
EDB	0.714	0.968	0.249	0.114	0.976	0.222	0.283	0.984	0.502	**0.000 (−1609)**	0.942	0.104
FTH		0.875	**0.001 (+893)**		0.548	0.363		0.291	0.724		0.068	**0.002 (+687)**
BUS		0.399	0.159		0.621	**0.008 (−747)**		0.908	0.160		**0.001 (+0.237)**	**0.011 (+808)**
ECN		0.213	0.289		0.953	**0.000 (+1580)**		0.477	0.249		**0.004 (−0.146)**	0.783
Sig. (1)	**0.000**	0.541	**0.000**	**0.014**	0.944	**0.001**	0.066	0.876	0.371	**0.000**	**0.001**	**0.000**
R^2	0.954	0.229	0.961	0.394	0.046	0.673	0.195	0.049	0.163	0.541	0.114	0.470

Source: Own processing. Sig. (1)—model significance (ANOVA test). Significance level 95%. Statistically significant coefficients are marked in bold. Coefficients of variation are shown in brackets.

The data in Table 7 confirm the positive and significant impact of NRI on GDP per capita, for all four groups of countries (in model (4)). A one-unit increase in the NRI index increases GDPc by 1966 units in the Americas states, 3038 units in the Arab states, and 2735 units in Europe.

Model (5) was found to be valid only for European countries. In this model, (5), statistically significant (but with the opposite sign) are the influences of BUS and ECN on GDP (%). Model (7) is statistically valid only for three groups of countries. FTH contributes to GDPc growth only in American and European states. BUS has a negative influence on GDPc in Arab states and a positive influence in European states. ECN has a positive and significant contribution only in Arab states.

Judging by the R square, the intensity of the interdependence between these two indicators, the independent variables (NRI, FTH, BUS, ECN, and EBD) and the dependent ones (GDP) are stronger in the case of the Americas States group (where 95.4% of the variation in GDP per capita is explained because of NRI and EDB). In the case of European countries, the variation in GDP per capita is explained only to the extent of 54.1%. A weaker association between the variables is recorded in the Arab countries, as well as in the Asian countries and in the Pacific. Our results are confirmed by:

- Niebel (2019) [57] and David and Grobler (2020) [58], which showed that, in developed countries (compared to developing countries), the contribution of ICT to economic growth is greater.

- Mayer et al. (2019) [20], which showed that the speed and pace of broadband network penetration influence GDP per capita differently depending on the level of development of national economies.
- Chen and Ye (2021) [35], which showed that ICT effects are more consistent in developed areas (compared to less developed ones).

Regarding the annual growth rate of GDP (%) (model (5)), the tests confirmed the statistically significant impact of the BUS and ECN sub-indices only for the European group of countries. Tests performed on model (7), which evaluates the impact of selected NRI sub-indices on GDP per capita, confirmed the positive impact of FTH and BUS for three groups of countries (Europe, America, and Arab states). As a novelty, the tests also indicated that, in the case of Arab states, the ECN sub-index has a positive and significant influence on GDP per capita. The control variable (EDB) was found to have a negative and statistically significant impact on GDP per capita only for European countries in model (4), as predicted by the initial analyses performed at the level of the whole sample. Since the analysed period was marked by the pandemic crisis, it was considered necessary to evaluate the impact of digital transformations on macroeconomic results separately for two periods: the pre-pandemic period (2018–2019) and the pandemic period (2020–2021). The results of these analysis are summarized in Table 8.

Table 8. Regression results (significance and variation coefficients)—by periods.

	2018–2019			2020–2021		
	Models			Models		
	(4)	**(5)**	**(7)**	**(4)**	**(5)**	**(7)**
NRI	**0.000 (+2474)**			**0.000 (+2283)**		
EDB	**0.000 (−1233)**	0.111	0.370	0.064	0.575	0.707
FTH		**0.008 (−0.051)**	**0.002 (+614)**		0.104	**0.000 (+856)**
BUS		0.634	0.368		**0.002 (+0.217)**	**0.031 (+507)**
ECN		0.586	0.242		0.089	0.334
Sig. [(1)]	**0.000**	**0.013**	**0.000**	**0.000**	**0.015**	**0.000**
R^2	0.779	0.365	0.689	0.671	0.361	0.636
Tolerance	<2.0	<0.7	<0.7	<0.7	<0.8	<0.8
VIF	<0.6	<0.4	<4.0	<1.6	<2.4	<2.4

Source: Own processing. Sig. [(1)]—model significance (ANOVA test). Significance level 95%. Statistically significant coefficients are marked in bold. Coefficients of variation are shown in brackets.

The obtained results highlight the fact that the three models are valid for both periods. According to model (4), the contribution of digital transformations to GDPc growth was more consistent in the pre-pandemic period. However, judging by the size of the R square indicator, the results reveal that digital transformations (assessed by NRI) better explain the GDPc variation from the pre-pandemic period. The justification for this situation can be attributed to the fact that, during the pandemic period, several factors impacted GDPc (such as the suspension of some activities during the lockdown periods). The results of model (7) confirm the results of the previous regressions and reinforce the fact that FTH and BUS have a positive influence on GDPc, both in the period 2018–2019 and in the period 2020–2021. Model (7) also confirms that ECN has a statistically insignificant influence on GDPc.

The results related to model (5) confirm the results of the first regression analysis that highlighted the fact that FTH has a negative impact on GDP (%), specifying that, in the pre-pandemic period, this influence was statistically significant. A positive and statistically significant impact of BUS on GDP (%) was found during the pandemic period, which confirms the results of the first regression analysis—relevant for the entire sample and the entire period (with the specification that, in the regression run on groups of countries, this influence proved to be statistically significant only in the case of European states.

5. Conclusions

The study focuses on analysing the impact of digital transformation (assessed on the basis of the Network Readiness Index—NRI) on macroeconomic performance (assessed on the basis of GDP dynamics, expressed in both relative and absolute measures). The assessment of the current state of knowledge revealed gaps in the research topic, with most studies focusing on assessing the impact of digital transformation at the microeconomic level. Although there are a few studies that admit that the digital transformation contributes to increased performance at the macroeconomic level, empirical research results are not convergent. The lack of convergence can be attributed to the samples analysed, the methodologies applied and the indicators used, or the time periods over which the analyses were conducted.

To shed more light on these debates, empirical research was carried out on a sample of 46 countries, classified as *high income* by the World Bank. As the NRI has undergone changes in the determination methodology, only information for the period 2018–2021 was used, where the same determination methodology was applied.

As the debate on the impact of digital transformation is relatively recent, this study contributes to filling the research gap by providing robust evidence on the impact of NRI on the annual GDP growth rate (%) and GDP per capita (USD). These results confirm the findings of previous studies. Another original element of the research, which has not been found in previous debates, is the analysis of the impact of NRI sub-indices on the above-mentioned macroeconomic variables. Specifically, sub-indices assessing the extent to which countries are prepared for the future network economy were considered: future technologies (FTH—from the technology pillar); business (BUS—from the people pillar), and economy (ECN—from the impact pillar).

The econometric analysis tested and confirmed the assumptions made. Thus, evidence supporting the claim that the use of digital technologies impacts the growth of macroeconomic outcomes was provided, with NRI being positively correlated, statistically significantly, with GDPc—according to model (4). In terms of the contribution of sub-indices to the growth of GDP (%) and GDPc, it was shown that higher ICT leveraging and the provision of R&D funding contribute to the growth of GDP per capita, while artificial intelligence (AI), the Internet of things (IoT), and spending in emerging technologies have a positive impact on the growth rate of GDP (%) (according to Table 6).

To test the results obtained, we re-ran the regression analysis by groups of countries and by subperiods. The regression results for groups of countries mostly confirmed the results of the first regression (performed on the entire sample), but it highlighted some specific peculiarities for each of the four groups of analysed countries. The regression results on sub-periods—pre-pandemic (2018–2019) and pandemic (2020–2021)—support and increase the robustness of the results of previous regressions. Moreover, they provide a clearer picture of the impact of digital transformations on GDP, taking into account the particularities of each period.

The results of this study have important practical implications. By exploiting them, policy-makers can propose and implement policies to facilitate access to those technologies that prove the most effective. For example, policies to support the business environment—by facilitating access to ICT and stimulating (directly or indirectly, through tax incentives) R&D activities—can contribute both to increasing macroeconomic performance and to raising the level of economic and social development. This is evidenced by the favourable impact on GDP per capita.

The adoption of initiatives to support the development of the network economy (such as digital innovation hubs) would ensure access to new technologies (such as artificial intelligence and Internet of things) for small and medium-sized enterprises (considered the engine of many economies), thus helping ensure a sustained rate of annual economic growth. These Digital Innovation Hubs (DIHs) operate on the principle of associative business structures that help different organizations to test before investing in digital technologies.

DIHs facilitate the access of economic and public entities to digital technologies, to test various software and hardware programs, innovate new products or services with digital competence, initiate or evaluate various digital research and development programs, and support technological development in the region where these centres have impact. In this way, the fair access of the interested entities to various services and products is ensured, before they make major investments in projects or new development directions that may prove to be too expensive or unrealistic or will not be used to their true value, due to the lack of expertise or request on the market [59].

Furthermore, from a more general macroeconomic perspective, increased use of ITC may further increase the demand for human capital, which play a key role in modern economic growth [60–63].

Research limitations and future research directions. This study has some shortcomings that could be addressed in future studies. Due to the data used (cross-sectional data specific to different economies of the world), the generalizability of the results is limited to the sampled countries (selected by gross national income per capita). Secondly, the non-inclusion in the analysis of variables specific to the economies analysed runs the risk of incomplete representation of the results.

An important limitation of the research is given by the fact that—although it was considered to ensure the homogeneity of the sample—the selected countries present significant differences in terms of the analysed variables. Running individual regressions (with fixed effects) at the country level could highlight structural differences while testing regression functions at the year level could better control for the effect of time, especially in pandemic years. Last but not least, this study is limited to the exclusive use of NRI. Comparative analyses of the impact of other measures associated with digital transformation could add to the knowledge framework. All these limitations open up new research opportunities to be exploited in future studies.

Author Contributions: Conceptualization, M.B.T., A.G. and S.A.; methodology, M.B.T., A.G. and S.A.; software, M.B.T., A.G. and S.A.; validation, M.B.T., A.G. and S.A.; formal analysis, M.B.T., A.G. and S.A.; resources, M.B.T., A.G. and S.A.; data curation, M.B.T., A.G. and S.A.; writing—original draft preparation, M.B.T., A.G. and S.A.; writing—review and editing, M.B.T., A.G. and S.A.; visualization, M.B.T., A.G. and S.A.; supervision, M.B.T., A.G. and S.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kraus, S.; Jones, P.; Kailer, N.; Weinmann, A.; Chaparro-Banegas, N.; Roig-Tierno, N. Digital Transformation: An Overview of the Current State of the Art of Research. *SAGE Open* **2021**, *2021*, 1–15. [CrossRef]
2. Vial, G. Understanding digital transformation: A review and a research agenda. *J. Strateg. Inf. Syst.* **2019**, *28*, 118–144. [CrossRef]
3. Zhang, Z.; Jin, J.; Li, S.; Zhang, Y. Digital transformation of incumbent firms from the perspective of portfolios of innovation. *Technol. Soc.* **2023**, *72*, 102149. [CrossRef]
4. Sebastian, I.M.; Ross, J.W.; Beath, C.; Mocker, M.; Moloney, K.G.; Fonstad, N.O. How big old companies navigate digital transformation. *MIS Q. Exec.* **2017**, *16*, 197–213. [CrossRef]
5. Skare, M.; de las Mercedes de Obesso, M.; Ribeiro-Navarrete, S. Digital transformation and European small and medium enterprises (SMEs): A comparative study using digital economy and society index data. *Int. J. Inf. Manag.* **2023**, *68*, 102594. [CrossRef]

6. Hinings, B.; Gegenhuber, T.; Greenwood, R. Digital innovation and transformation: An institutional perspective. *Inf. Organ.* **2018**, *28*, 52–61. [CrossRef]
7. Berman, S.J. Digital transformation: Opportunities to create new business models. *Strategy Leadersh.* **2012**, *40*, 16–24. [CrossRef]
8. Liere-Netheler, K.; Packmohr, S.; Vogelsang, K. *Drivers of Digital Transformation in Manufacturing*; HICSS: Waikoloa Beach, HI, USA, 2018; pp. 3926–3935. Available online: http://hdl.handle.net/10125/50381 (accessed on 12 December 2022).
9. Aagaard, A.; Presser, M.; Andersen, T. Applying IoT as a leverage for business model innovation and digital transformation. In Proceedings of the 3rd Global IoT Summit (GIoTS), Aarhus, Denmark, 17–21 June 2019. [CrossRef]
10. Chesbrough, H. To recover faster from COVID-19, open up: Managerial implications from an open innovation perspective. *Ind. Mark. Manag.* **2020**, *88*, 410–413. [CrossRef]
11. Ciriello, R.F.; Richter, A.; Schwabe, G. Digital innovation. *Bus. Inf. Syst. Eng.* **2018**, *60*, 563–569. [CrossRef]
12. Sorescu, A.; Schreier, M. Innovation in the digital economy: A broader view of its scope, antecedents, and consequences. *J. Acad. Mark. Sci.* **2021**, *49*, 627–631. [CrossRef]
13. Verhoef, P.C.; Broekhuizen, T.; Bart, Y.; Bhattacharya, A.; Qi Dong, J.; Fabian, N.; Haenlein, M. Digital transformation: A multidisciplinary reflection and research agenda. *J. Bus. Res.* **2021**, *122*, 889–901. [CrossRef]
14. Roman, A.; Rusu, V.D. Digital technologies and the performance of small and medium enterprises. *Stud. Bus. Econ.* **2022**, *17*, 190. [CrossRef]
15. Andriole, S.J. Five myths about digital transformation. *MIT Sloan Manag. Rev.* **2017**, *58*, 20–22.
16. Röller, L.; Waverman, L. Telecommunications infrastructure and economic development: A simultaneous approach. *Am. Econ. Rev.* **2001**, *91*, 909–923. [CrossRef]
17. Vu, K.M. ICT as a source of economic growth in the information Age: Empirical evidence from the 1996–2005 period. *Telecommun. Policy* **2011**, *35*, 357–372. [CrossRef]
18. Toader, E.; Firtescu, B.N.; Roman, A.; Anton, S.G. Impact of Information and Communication Technology Infrastructure on Economic Growth: An Empirical Assessment for the EU Countries. *Sustainability* **2018**, *10*, 3750. [CrossRef]
19. Fernández-Portillo, A.; Almodóvar-González, M.; Coca-Pérez, J.L.; Jiménez-Naranjo, H.V. Is Sustainable Economic Development Possible Thanks to the Deployment of ICT? *Sustainability* **2019**, *11*, 6307. [CrossRef]
20. Mayer, W.; Madden, G.; Wu, C. Broadband and economic growth: A reassessment. *Inf. Technol. Dev.* **2019**, *26*, 128–145. [CrossRef]
21. Soava, G.; Mehedintu, A.; Sterpu, M. Analysis and Forecast of the Use of E-Commerce in Enterprises of the European Union States. *Sustainability* **2022**, *14*, 8943. [CrossRef]
22. Afonasova, M.A.; Panfilova, E.E.; Galichkina, M.A.; Slusarczyk, B. Digitalization in Economy and Innovation: The effect on social and economic processes. *Pol. J. Manag. Stud.* **2019**, *19*, 22–23. [CrossRef]
23. Sitnicki, M.; Netreba, I. Interdependence assessing for Networked Readiness Index economic and social informative factors. *Balt. J. Econ. Stud.* **2020**, *6*, 47–53. [CrossRef]
24. Agustina, N.; Pramasa, S. The Impact of Development and Government Expenditure for Information and Communication Technology on Indonesian Economic Growth. *Asian J. Bus. Environ.* **2019**, *9*, 5–13. [CrossRef]
25. Georgescu, A.; Tudose, M.B.; Avasilcăi, S. DIHs and the impact of digital technology on macroeconomic outcomes. *Rev. Manag. Econ. Eng.* **2022**, *21*, 248–260.
26. Borovskaya, M.A.; Masych, M.A.; Fedosova, T.V. The potential for labor productivity growth in the context of digital transformation. *Terra Econ.* **2020**, *18*, 47–66. [CrossRef]
27. De la Hoz-Rosales, B.; Camacho Ballesta, J.A.; Tamayo-Torres, I.; Buelvas-Ferreira, K. Effects of Information and Communication Technology Usage by Individuals, Businesses, and Government on Human Development: An International Analysis. *IEEE Access* **2019**, *7*, 129225–129243. [CrossRef]
28. Stavytskyy, A.; Kharlamova, G.; Stoica, E.A. The Analysis of the Digital Economy and Society Index in the EU. *TalTech J. Eur. Stud.* **2019**, *9*, 245–261. [CrossRef]
29. Olczyk, M.; Kuc-Czarnecka, M. Digital transformation and economic growth—DESI improvement and implementation. *Technol. Econ. Dev. Econ.* **2022**, *28*, 775–803. [CrossRef]
30. Corejova, T.; Chinoracky, R. Assessing the Potential for Digital Transformation. *Sustainability* **2021**, *13*, 11040. [CrossRef]
31. Bondar, S.; Hsu, J.C.; Pfouga, A.; Stjepandić, J. Agile digital transformation of system-of-systems architecture models using Zachman framework. *J. Ind. Inf. Integr.* **2017**, *7*, 33–43. [CrossRef]
32. Niu, Y.; Wen, W.; Wang, S.; Li, S. Breaking barriers to innovation: The power of digital transformation. *Financ. Res. Lett.* **2023**, *51*, 103457. [CrossRef]
33. Tian, G.; Li, B.; Cheng, Y. Does digital transformation matter for corporate risk-taking. *Financ. Res. Lett.* **2022**, *49*, 103107. [CrossRef]
34. Pagani, M.; Pardo, C. The impact of digital technology on relationships in a business network. *Ind. Mark. Manag.* **2017**, *67*, 185–192. [CrossRef]
35. Chen, W.; Zhang, L.; Jiang, P.; Meng, F.; Sun, Q. Can digital transformation improve the information environment of the capital market? Evidence from the analysts' prediction behaviuor. *Account. Financ.* **2021**, *62*, 2543–2578. [CrossRef]
36. Wu, K.; Fu, Y.; Kong, D. Does the digital transformation of enterprises affect stock price crash risk. *Financ. Res. Lett.* **2022**, *48*, 102888. [CrossRef]

37. Legner, C.; Eymann, T.; Hess, T.; Matt, C.; Böhmann, T.; Drews, P.; Mädche, A.; Urbach, N.; Ahlemann, F. Digitalization: Opportunity and challenge for the business and information systems engineering community. *Bus. Inf. Syst. Eng.* **2017**, *59*, 301–308. [CrossRef]
38. Subramaniam, M.; Iyer, B.; Venkatraman, V. Competing in Digital Ecosystems. *Bus. Horiz.* **2019**, *62*, 83–94. [CrossRef]
39. Okorie, O.; Russell, J.; Cherrington, R.; Fisher, O.; Charnley, F. Digital transformation and the circular economy: Creating a competitive advantage from the transition towards Net Zero Manufacturing. *Resour. Conserv. Recycl.* **2023**, *189*, 106756. [CrossRef]
40. Li, L.; Su, F.; Zhang, W.; Mao, J.Y. Digital transformation by SME entrepreneurs: A capability perspective. *Inf. Syst. J.* **2017**, *28*, 1129–1157. [CrossRef]
41. Bouncken, R.B.; Kraus, S.; Roig-Tierno, N. Knowledge- and innovation-based business models for future growth: Digitalized business models and portfolio considerations. *Rev. Manag. Sci.* **2021**, *15*, 1–14. [CrossRef]
42. European Commission. The Digital Economy and Society Index (DESI). 2022. Available online: https://digital-strategy.ec.europa.eu/en/policies/desi (accessed on 23 December 2022).
43. OECD. Toolkit for Measuring the Digital Economy G20 Report. 2018. Available online: https://www.oecd.org/g20/summits/buenos-aires/G20-Toolkit-for-measuring-digital-economy.pdf (accessed on 20 December 2022).
44. USAID. Digital Ecosystem Country Assessments. Available online: https://www.usaid.gov/digital-strategy/implementation-tracks/track1-adopt-ecosystem/digital-ecosystem-country-assessments (accessed on 12 January 2023).
45. Dutta, S.; Lanvin, B. *The Network Readiness Index 2019: Towards a Future-Ready Society*; Portulans Institute: Washington, DC, USA, 2019. Available online: https://www.insead.edu/sites/default/files/assets/dept/globalindices/docs/nri-2019.pdf (accessed on 20 November 2022).
46. Dutta, S.; Lanvin, B. *The Network Readiness Index 2021: Shaping the Global Recovery*; Portulans Institute: Washington, DC, USA, 2021. Available online: https://networkreadinessindex.org/wp-content/uploads/reports/nri_2021.pdf (accessed on 12 November 2022).
47. Stoianenko, I.; Kondratiuk, O.; Mostova, A.; Pikus, R.; Kachan, H.; Ilchenko, V. Digitization of the Economy Under the Influence of the COVID-19 Pandemic. *Postmod. Open* **2022**, *13*, 127–141. [CrossRef]
48. Matthess, M.; Kunkel, S. Structural change and digitalization in developing countries: Conceptually linking the two transformations. *Technol. Soc.* **2020**, *63*, 101428. [CrossRef]
49. Humenna, Y.G.; Tyutyunyk, I.V.; Tverezovska, O.I. The Effects of Digitalization on Macroeconomic Stability in the Context of the COVID-19 Pandemic: EU Practice. *J. V. N. Karazin Kharkiv Natl. Univ. Ser. Int. Relat. Econ. Ctry. Stud. Tour.* **2021**, *13*, 70–77. [CrossRef]
50. Stanley, T.; Doucouliagos, C.; Steel, P. Does ICT Generate Economic Growth? A Meta-Regression Analysis. *J. Econ. Surv.* **2018**, *32*, 705–726. [CrossRef]
51. Dutta, S.; Lanvin, B. The Network Readiness Index 2022. In *Stepping into the New Digital Era. How and Why Digital Natives Will Change the World*; Portulans Institute: Washington, DC, USA, 2022. Available online: https://networkreadinessindex.org/wp-content/uploads/reports/nri_2022.pdf (accessed on 28 October 2022).
52. Dogruel, M.; Firat, S.U. Prediction of Innovation Values of Countries Using Data Mining Decision Trees and a Comparative Application with Linear Regression Model. *Istanb. Bus. Res.* **2021**, *50*, 465–493. [CrossRef]
53. Dutta, S.; Lanvin, B. *The Network Readiness Index 2020: Accelerating Digital Transformation in a Post-COVID Global Economy*; Portulans Institute: Washington, DC, USA, 2020. Available online: https://networkreadinessindex.org/wp-content/uploads/2020/10/NRI-2020-Final-Report-October2020.pdf (accessed on 28 October 2022).
54. Pal, D.; Mitra, S.K.; Chatterjee, S. Does "investment climate" affect GDP? Panel data evidence using reduced-form and stochastic frontier analysis. *J. Bus. Res.* **2022**, *138*, 301–310. [CrossRef]
55. Kelsey, D.; le Roux, S. Strategic ambiguity and decision-making: An experimental study. *Theory Decis.* **2018**, *84*, 387–404. [CrossRef]
56. Asongu, S.; Odhiambo, N. Challenges of Doing Business in Africa: A Systematic Review. *J. Afr. Bus.* **2019**, *20*, 259–268. [CrossRef]
57. Niebel, T. ICT and economic growth—Comparing developing, emerging and developed countries. *World Dev.* **2018**, *104*, 197–211. [CrossRef]
58. David, O.O.; Grobler, W. Information and communication technology penetration level as an impetus for economic growth and development in Africa. *Econ. Res.-Ekon. Istraz.* **2020**, *33*, 1394–1418. [CrossRef]
59. Galor, O. From stagnation to growth: Unified growth theory. In *Handbook of Economic Growth*; Aghion, P., Durlauf, S.N., Eds.; Elsevier: Amsterdam, The Netherlands, 2005; Volume I, Part A; pp. 171–293.
60. Azarnert, L.V. Redistribution, fertility and growth: The effect of the opportunities abroad. *Eur. Econ. Rev.* **2004**, *48*, 785–795. [CrossRef]
61. Galor, O.; Mountford, A. Trading population for productivity: Theory and evidence. *Rev. Econ. Stud.* **2008**, *75*, 1143–1179. [CrossRef] [PubMed]

62. Azarnert, L.V. Free education, fertility and human capital accumulation. *J. Popul. Econ.* **2010**, *23*, 449–468. [CrossRef]
63. Georgescu, A.; Avasilcai, S.; Peter, M.K. Digital Innovation Hubs—The present future of collaborative research, business and marketing development opportunities. In *Marketing and Smart Technologies*; Rocha, Á., Reis, J., Peter, M., Bogdanović, Z., Eds.; Springer: Singapore, 2021; Volume 205, pp. 363–374. [CrossRef]