MAKÜ | Journal of Mehmet Akif Ersoy University
Economics and Administrative Sciences Faculty

1e-ISSN: 2149-1658
Volume: 12 / Issue: 1
March, 2025
pp.: 306-328

Building a Technological Change Index for Developed and Developing Countries: A New Multidimensional Measure *

Kadir GÖÇERİ[1], Selçuk KOÇ[2]

1. Dr., Independent Researcher,
kadirgoceri92@gmail.com,
https://orcid.org/0000-0003-1183-9074

2. Prof. Dr., Kocaeli University,
selcukkoc@kocaeli.edu.tr,
https://orcid.org/0000-0001-7451-2699

* This article is a revised and expanded version of a chapter from the PhD. thesis titled "The Effect of Technological Change, Job Polarization and Education on Income Distribution" submitted by the first author to the Institute of Social Sciences at Kocaeli University in 2023, under the supervision of the second author.

https://doi.org/10.30798/makuiibf.1532315

Abstract

In the economics literature, many indicators are used as proxy variables for technological change. However, most of these indicators generally overlook the complex and multidimensional nature of technological change. In this context, we develop a new composite indicator by applying multivariate statistical methods to determine the level of technological development. This new index, called the Technological Change Index (TCI), reflects various dimensions of technology, including infrastructure, access and use, innovation, and impact. It has been calculated using 13 normalized indicators. Each indicator belonging to these dimensions was weighted using Principal Component Analysis (PCA), and the leading factors contributing to technological change were identified. The main purpose of building this index is to determine the level of technological change in countries and, thus, to reveal the gaps in technological development across the world. The scores of the TCI, which cover a total of 46 developed and developing countries, provide useful insights for researchers and policymakers focusing on development issues.

Keywords: Technological Change, Economic Development, Principal Component Analysis.

Article Type	Application Date	Admission Date
Research Article	August 13, 2024	March 25, 2025

To cite this article: Göçeri, K., and Koç, S. (2025). Building a technological change index for developed and developing countries: A new multidimensional measure. *Journal of Mehmet Akif Ersoy University Economics and Administrative Sciences Faculty, 12*(1), 306-328. https://doi.org/10.30798/makuiibf.1532315

1. INTRODUCTION

Technological change has significantly progressed over the past two decades while gaining importance in modern macroeconomics literature. Consequently, the analysis of technological change has become a fundamental part of both national economic policies and international competition.

When the economics literature is examined, the role of technological change in growth and development has been analyzed from various perspectives. Solow (1956), one of the neo-classical economists, defined technological development as a determinant of long-term growth and considered it as an exogenous variable. In Romer's (1990) Endogenous Growth Theory, similar to Neoclassical economics, technological change is at the heart of economic growth. According to this theory, where technology is assumed to be an endogenous variable, technological change and innovation both stimulate capital accumulation and increase the productivity of the factors of production. One of the most important economists of the Austrian School, Schumpeter (1980), argued that development is dependent on innovations and the technological changes that emerge from these innovations. Kondratyev (1935), on the other hand, accepted innovation and related technological change as a driving force of long-term growth cycles. Kuznets (1966), who made significant contributions to development, refers to the role of technological change in the stages of industrialization and development. Relatively recent studies by Grossman and Helpman (1991), Aghion and Howitt (1992) and Barro and Sala-i Martin (2004) have also emphasized that research and development (R&D) is a driving force for growth and development. As a result of a series of empirical studies carried out, technology that helps increase in productivity is accepted as a driving force of economic growth and development nowadays (e.g. Ayres, 1988; Steinmueller, 2002; Mcguckin, et al., 2006; Acemoglu, 2023).

Innovative trends offer enormous economic potential for a country that can seize the opportunities offered by new technologies. For others, which largely include developing and least developed countries (LDCs), the rapid pace of overall technological change may pose a threat (Dahlman, 1989). Current trends between developed countries and the rest of the world show an increasing polarisation in competition between those that can successfully adapt to technological change and those that cannot. Research in this field shows that the innovation gap significantly affects differences in per capita income and levels of development among countries (Nepelski & Prato, 2020).

The success of technology policy at the country level can be determined by considering a realistic assessment of the current status of technological progress (Desai et al., 2002). In this context, it is important to measure technological change at the national level, and additionally to monitor the tendencies of technological change. To this end, drawing inspiration from existing studies in the literature, we have developed a new index to monitor technological change and more effectively demonstrate its multidimensional nature. The index differs from the methods in previous or existing studies because of its specific characteristics.

A detailed examination of the applied economics literature reveals that various proxy variables have been used to measure technological change. Although technology is multidimensional, studies in this field typically focus on only one dimension, relying on proxy variables such as infrastructure, R&D, innovation, or productivity indicators (e.g. Carlaw & Lipsey, 2003; Coccia, 2014; Pece et al., 2015). Upon reviewing the literature on measuring technological change, we found that weighting schemes for indicators are often either determined subjectively or lack sufficient observations to enable robust long-term empirical analysis. To fill this gap, we assign weights to 13 indicators reflecting various dimensions of technology by applying Exploratory Factor Analysis (EFA) based on Principal Component Analysis (PCA).

Our main motivations for using PCA are: (i) to reduce the complexity involved in representing technology-related indicators, (ii) to conduct a general evaluation of technological change, and (iii) to base analysis on a single composite measure rather than multiple different variables. Within this framework, this study presents a weighted composite index that reflects the various dimensions of technology as a whole. The index has several advantages: the most notable being its weighted composite structure and its ability to multidimensionally reflect technological change. Another advantage is that it provides a significantly larger number of observations compared to similar indices or indicators in the literature. Additionally, it generates annual scores for each of the 46 countries for the period 1991–2019. Thus, we can analyze the technological change trends of each country over approximately 30 years. We define this index as the Technological Change Index (TCI).

In this study, the TCI is designed to achieve three main objectives. Firstly, TCI measures technological progress at the country level, enabling the identification of technological gaps across countries. Secondly, the index scores indicate the trend of technological change at the country level. Thirdly, it provides a dataset suitable for econometric modeling due to the sufficient number of observations for empirical analysis. Thanks to these three key characteristics, technological gap can be identified, and empirical results relevant to policymakers can be obtained. TCI serves as a foundation for conducting a comprehensive evaluation of changes in technology, innovation, and science at the country level through distinctive variables.

The main purpose of this study is to measure the level of technological progress and examine trends in technological change in selected developed, and developing countries including the LDCs[1]. This study consists of five remaining sections. The second section provides a brief summary of the literature on measuring technological change and explains how this study differs from previous research. The third section introduces the data used and provides general information about the sample. The fourth

---

[1] In this study, the term 'developing countries' includes both developing economies and least developed countries, as classified by United Nations Conference on Trade and Development (UNCTAD, 2023).

section describes the methods used in the calculation and presents the statistical findings, while the fifth section presents the index scores and empirical findings. The final section offers a general evaluation of the study's findings along with policy recommendations.

2. LITERATURE REVIEW

Technological change is considered an integral part of development because it enhances the economic and social structure of society. More specifically, technological change contributes to the economic growth and development of countries by reducing costs, increasing prosperity, and creating new markets and products. Historically, technological change has been the most decisive factor in the differences in development between countries. It is observed that countries which rapidly adapted to technological changes and fostered innovations over the last half century have achieved the status of industrialized and developed countries.

In the literature review, we categorize studies into two groups. The first group includes studies related to the impact of technology on growth and development. When analyzing empirical studies, Ulku (2004) found a positive relationship between innovation (measured by patent stock) and per capita income in a study on Organization for Economic Co- Operation and Development (OECD) and non-OECD countries. Mudronja et al. (2019) conducted an empirical analysis on the European Union (EU)-28 and found that R&D expenditures accelerate growth. Choi and Yi (2009) used panel data from 207 countries and provided empirical evidence that internet usage positively affects economic growth. Koutroumpis (2009) analyzed the economic impact of broadband in 22 OECD countries and provided evidence of a strong causality between broadband infrastructure and growth. Ghosh (2017) obtained similar findings for 15 Middle East and North Africa (MENA) countries. Dutta (2020) examined the impact of Information and Communication Technology (ICT) goods exports on Gross Domestic Product (GDP) using panel data from BRICS countries and concluded that ICT goods exports have a positive effect.

The second group of studies in the literature review focuses on the measurement of technological change. The literature review reveals numerous studies on the measurement and evolution of technological change. We observed that the index-type technology indicators have become relatively widespread over the last decade. In this context, Wagner et al. (2001) developed the Science and Technology (S&T) Capacity Index, which aims to measure national-level development in science and technology. Their study found that out of the 150 countries examined, 22—including the United States (US), Japan, Germany, Canada, and Taiwan—were scientifically advanced. Furthermore, when analyzing the methodology of the study, we observed that the indicators within the index were assigned specific weights based on the relative importance of each factor. Similar to the S&T Capacity Index, Desai et al. (2002) contributed to the literature on technological change by conducting a national-level analysis and developing the Technology Achievement Index (TAI), which assigned equal weight to its indicators. Changes in technological achievement for both 1998 and 1999 were calculated for over 70 countries, yielding fairly consistent findings. According to their study, developed countries such as Finland, the US, Sweden, Japan, South Korea, the Netherlands, the United Kingdom (UK), and Singapore were classified as part of the 'leaders' group in both years.

The United Nations Industrial Development Organization (UNIDO, 2002) developed the Competitive Industrial Performance (CIP) Index to assess countries' ability to produce and export in the global economy. In the calculation of the CIP, four key indicators were taken into account without weighting. It was observed that the scores vary significantly across countries. In this context, the CIP rankings, from highest to lowest, were as follows: Singapore, Ireland, Japan, Switzerland, and Sweden.

The ArCo Technology Index is a well-known indicator for measuring technological capabilities. Developed by Archibugi and Coco (2004), the index was calculated only for the years 1990 and 2000 using a total of eight indicators, considering three dimensions of technology: creation, infrastructure, and human skills. In their analysis, Archibugi and Coco (2004) included both developed and developing countries. The results indicated that Nordic European countries performed exceptionally well in technological capability, with Sweden ranking first, Finland second, and Norway seventh.

In a recent paper, Khayyat and Lee (2015) studied technological change in developing countries between 2003 and 2008. The index, called TC, estimated technological levels for 61 countries around the world to analyze their innovation performance. PCA was used as a method for calculating the index. The findings of the study revealed that China, Estonia, and Malaysia had the highest level of innovation among developing countries. However, findings for other countries were not available, as the study focused exclusively on developing countries. Additionally, analyzing a six-year period limited making inferences that are long-term and more technical in nature.

Since its first publication in 2009, the ICT Development Index has been calculated annually by the International Telecommunication Union (2017) to measure the level of development in information and communication technology. It is a composite index that combines three groups (access, use and skills) and a total of 11 indicators. In the ITU's 2017 report, the index scores ranked Iceland, Korea, Switzerland, Denmark and the UK as the top-performing countries. In this sense, the report revealed that European countries demonstrated excellent performance in the field of ICT during the 2010s.

The Global Innovation Index, prepared in cooperation with the World Intellectual Property Organization (WIPO), INSEAD, and Cornell University, ranks economies based on their innovation capabilities. This annually published index is based on approximately 80 grouped indicators related to technology and innovation. According to the 2023 Report published by the World Intellectual Property Organization (2023), three of the five most innovative countries were from Europe (Switzerland, Sweden and the UK) while the others were the US and Singapore.

The Network Readiness Index (NRI), developed by researchers at Portulans Institute (2020) and published annually by the World Economic Forum (WEF), measures the degree of readiness of countries to take advantage of the opportunities offered by ICT. The NRI includes sub-indices related to technology, people, governance, and impact. According to the NRI scores in 2020, the top-ranked countries in terms of ICT readiness were Sweden, Denmark, Singapore, the Netherlands, and Switzerland.

The European Innovation Scoreboard (EIS), published annually by the European Commission (2023), measures the research and innovation performance of European Union (EU) member states and 11 non-EU European countries. Its purpose is to provide a relative assessment of national innovation systems in European countries and to identify their strengths and weaknesses. The index consists of four dimensions: framework conditions, investments, innovation activities, and impacts, which comprises a total of 32 indicators. In the index methodology, each dimension includes an equal number of indicators, all of which are weighted equally, similar to how the previously mentioned indicators are weighted. According to the 2023 report, Belgium, Denmark, Finland, the Netherlands, and Sweden performed above the EU average, ranking as 'Innovation Leaders.' Additionally, it has been observed that most EU member states have significantly improved their innovation performance over the past decade.

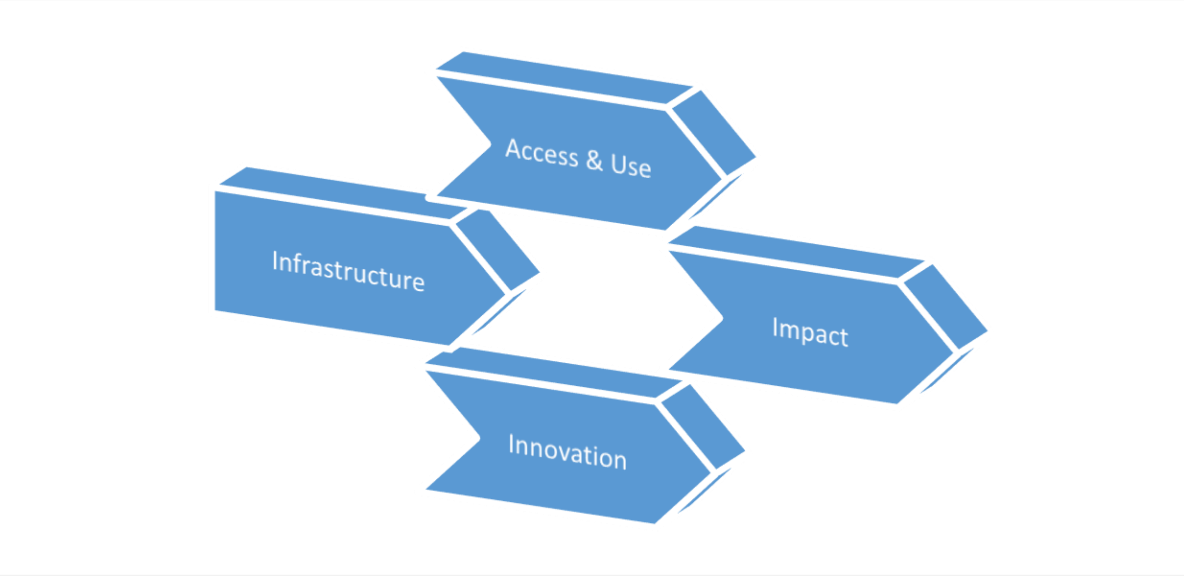
Another index published by the European Commission (EC) is the Digital Economy and Society Index (DESI), which is calculated exclusively for EU member states (European Commission, 2022). The purpose of DESI is to measure Europe's overall digitalization performance and assess the digital competitiveness of its member countries. DESI comprises four dimensions and ten sub-dimensions and is calculated using a total of 32 indicators. Similar to the EIS, each dimension in the index carries equal weight (25%), and the indicators within each dimension are also weighted equally. According to the latest report based on 2021 data, EU member states experienced significant progress in digitalization during the COVID-19 pandemic. However, they have yet to reach the desired level in terms of Small and Medium-Sized Enterprises (SMEs') digital performance and the widespread deployment of 5G networks. In country profile analyses, Scandinavian countries such as Finland, Denmark, and Sweden have demonstrated outstanding digitalization performance, with index scores well above the EU average.

To summarize, the literature review shows that research on the measurement of technological change has largely been conducted using index-type approaches. Technology-related indicators were subjectively weighted; and as a result, each indicator was either assumed to have the same degree of importance or lacked sufficient observations to enable long-term empirical analysis. In other words, most of these studies have not been adequate in capturing technological trends. To address this gap, we have developed a multi-dimensional, composite, and weighted index called TCI. Thanks to the scores calculated for this index, we can analyze the trend of technological change worldwide, covering both developed and developing countries (including LDCs) and highlighting differences in technological change between nations. An additional advantage is that index scores can be calculated for a large number of countries at different levels of development.

3. DATA AND VARIABLES

Technology is a complex concept that is difficult to define. For this reason, it is regarded a broad concept in the literature (Acemoglu et al., 2022). On the other hand, technological change is a more specific concept that encompasses a general process. The first step in constructing the level of technological change is to determine its dimensions and process. In this context, the dimensions of technological change are illustrated in Figure 1 below:

Figure 1. The Process and Dimensions of Technological Change



The index aims to capture a country's technological change across four dimensions. As seen in Figure 1, the dimensions of technological change, as determined by our study, are infrastructure, access and use, innovation, and impact. When compared with the Schumpeterian triad (invention-innovation-diffusion) proposed by Schumpeter (1980), these dimensions are found to be consistent. Each dimension essentially represents the components of technological change and contributes to a more effective analysis of technological progress. The second step is to assign proxy variables to these dimensions. The TCI has been developed using available and accessible data. In this regard, proxy variables were used for each dimension in our methodology. It is worth noting that almost all of the indicators used are proxy variables commonly employed in the literature to represent technology. Except for international bandwidth, all data for our index were obtained from the World Development Indicators (World Bank, 2023), which provide measures of social progress, economic development, physical infrastructure, and other related factors. The indicators listed in Table 1 offer more detailed information about the selected variables for each dimension.

Table 1. Selected Indicators of the Technological Change Index

Dimension	Abbreviation	Indicator	Unit of measure	Source
Infrastructure	RDE	Research and development	% of GDP	World Bank (2023)
	RES	Researchers in R&D	Per million people	World Bank (2023)
	SCH	School enrollment, tertiary	% gross	World Bank (2023)
	IBW	International Bandwidth	In Mbit/s	International Telecommunication Union (2023)
Access & Use	INT	Individuals using the Internet	% of population	World Bank (2023)
	FBS	Fixed broadband subscriptions	Per 100 people	World Bank (2023)
	MCS	Mobile cellular subscriptions	Per 100 people	World Bank (2023)
	ATM	Automated teller machines	Per 100.000 adults	World Bank (2023)
Innovation	PAT	Patent applications	Number of residents	World Bank (2023)
	STJ	Scientific and technical journal	Number	World Bank (2023)
Impact	GDP	GDP per person employed	Constant 2017 PPP$	World Bank (2023)
	ICT	ICT goods exports	% of total goods exports	World Bank (2023)
	MHT	Medium and high-tech manufacturing value added	% Manufacturing value added	World Bank (2023)

Infrastructure is crucial for accessing the opportunities provided by information and communication technologies. Additionally, it plays a key role in demonstrating human capital and supporting research and development efforts for the creation and adoption of technology. Infrastructure technologies enhance efficiency in technology-based economic activities and serve as leverage in the R&D, production, and market development stages of the process (Tassey, 1996). Here, we identify four key indicators of technological infrastructure: R&D expenditure, researchers in R&D, school enrollment (tertiary), and international bandwidth.

In the information society, the delivery and widespread sharing of technology have become a necessity in the modern world. Throughout history, access to technology and its effective use has enabled countries to achieve greater output with fewer resources. Therefore, the access and use dimensions play a major role in explaining technological change, which is considered the driving force of economic development. We selected four variables associated with access to and use of technology: individuals using the internet, fixed broadband subscriptions, mobile cellular subscriptions, and automated teller machines.

Innovation, defined as the improvement of existing technology in terms of commercial impact or social benefit, or the development of a completely new approach, lies at the heart of technological change (United Nations Conference on Trade and Development, 2019). We include patent applications and scientific and technical journal articles in the innovation dimension. Patent applications refer to filings made for developing new methods and generating novel solutions to existing problems. On the other hand, scientific and technical journal articles encompass research published in disciplines such as physics, chemistry, biomedicine, technology, earth sciences, and space sciences.

Ultimately, innovation serves as a means to enhance productivity and drive economic growth. Technological advancements are now widely recognized as the most significant drivers of economic progress, influencing productivity, industrial competitiveness, sustained improvements in living standards, and overall welfare (Gold, 1987). Therefore, the impact dimension of technology aims to explain its economic implications. In this dimension, we use three variables focusing on production, productivity, and exports: GDP per person employed, ICT goods exports, and medium- and high-tech manufacturing value added.

Table 2. Countries Included in the Index Calculation

Level of development	Countries	Classification by
Developed Countries (20)	Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, South Korea, Luxembourg, Netherlands, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, United Kingdom, United States	International Monetary Fund (2023)
Developing Countries (17)	Brazil, China, Colombia, Costa Rica, Dominican Republic, El Salvador, Honduras, India, Indonesia, Malaysia, Panama, Paraguay, Peru, Russian Federation, Thailand, Türkiye, Uruguay	International Monetary Fund (2023)
Least Developed Countries (9)	Angola, Bangladesh, Gambia, Madagascar, Malawi, Mali, Rwanda, Tanzania, Uganda	United Nations Conference on Trade and Development (2023)

In the final stage, we classify countries based on their level of development. Our goal is to include as many countries as possible without compromising the consistency of data and resources. The index score was calculated for a total of 46 countries, 20 are developed, 17 are developing, and 9 are least developed, as shown in Table 2. Although the aim was to calculate scores for all countries worldwide, the calculation was limited to 46 countries due to data unavailability. According to the World Bank (2023), the total population of the countries in this sample was approximately 5 billion in 2021. This figure accounts for about 63.6% of the global population. Additionally, the total GDP of the countries in the sample was approximately 76.5 trillion USD, representing 78.4% of global GDP. In the light of this information, it can be clearly stated that the sample represents the statistical population well. The countries in the sample are classified according to their level of development. The International

Monetary Fund (2023) classification was used for developed and developing countries, while the United Nations Conference on Trade and Development (2023) list was considered for least developed countries.

4. METHODOLOGY AND STATISTICAL FINDINGS

The TCI is a composite indicator that assesses the overall technological development of a country and enables cross-country comparisons. The following three procedures are applied sequentially in the calculating TCI scores:

- Normalization of Indicators
- Weighting of Indicators
- Calculating of the Index Score

Since the variables shown in Table 1 are expressed in different units, each indicator of the TCI is normalized to facilitate comparison and aggregation. Similar to the HDI proposed by United Nations Development Programme (UNDP, 2020), the indicators of the TCI are normalized between 0 and 1 using the following standard formula:

$$z_i = \frac{x_o - x_{min}}{x_{max} - x_{min}} \quad (1)$$

where x_o is the variable to be converted for country i, x_{min} is the minimum value for variables of all countries, x_{max} is maximum value for the variables of all countries and finally z_i is the normalized variable.

To overcome the differences in the power of variables to reflect technological change, we use exploratory factor analysis, which aims to discover a small number of conceptually significant variables by combining a large number of interrelated variables. In index creation, exploratory factor analysis has advantages such as ease of visualization and interpretation, as well as size reduction (Ferguson & Cox, 1993; Morrison, 2017).

Table 3. Correlation Matrix

	ATM	FBS	GDP	ICT	INT	IBW	MHT	MCS	PAT	RDE	RES	SCH	STJ
ATM	1.00	0.65	0.52	0.24	0.64	0.32	0.53	0.52	0.25	0.58	0.53	0.68	0.36
FBS	0.65	1.00	0.83	0.24	0.95	0.24	0.73	0.76	0.13	0.88	0.91	0.79	0.23
GDP	0.52	0.83	1.00	0.20	0.84	0.21	0.60	0.77	-0.01	0.68	0.80	0.62	0.15
ICT	0.24	0.24	0.20	1.00	0.34	0.29	0.58	0.33	0.40	0.34	0.30	0.36	0.26
INT	0.64	0.95	0.84	0.34	1.00	0.26	0.75	0.81	0.09	0.86	0.91	0.84	0.22
IBW	0.32	0.24	0.21	0.29	0.26	1.00	0.40	0.15	0.58	0.30	0.22	0.27	0.81
MHT	0.53	0.73	0.60	0.58	0.75	0.40	1.00	0.64	0.23	0.79	0.74	0.74	0.33
MCS	0.52	0.76	0.77	0.33	0.81	0.15	0.64	1.00	-0.04	0.64	0.73	0.75	0.05
PAT	0.25	0.13	-0.01	0.40	0.09	0.58	0.23	-0.04	1.00	0.27	0.07	0.11	0.85
RDE	0.58	0.88	0.68	0.34	0.86	0.30	0.79	0.64	0.27	1.00	0.91	0.75	0.36
RES	0.53	0.91	0.80	0.30	0.91	0.22	0.74	0.73	0.07	0.91	1.00	0.78	0.17
SCH	0.68	0.79	0.62	0.36	0.84	0.27	0.74	0.75	0.11	0.75	0.78	1.00	0.27
STJ	0.36	0.23	0.15	0.26	0.22	0.81	0.33	0.05	0.85	0.36	0.17	0.27	1.00

In the first step of exploratory factor analysis, the appropriateness of the factor model is evaluated. The correlation matrix is examined at this stage, and the existence of a strong relationship between the selected variables is revealed. Detailed results are shown in Table 3.

Table 4. Kaiser-Meyer-Olkin Measure of Sampling Adequacy

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.76
Bartlett's Test of Sphericity	Approx. Chi-Square	687.811
	df	78
	Sig.	0.00

As seen in Table 4, the KMO[2] and Bartlett's tests were applied to assess the suitability of the sample for factor analysis. The KMO measure of sampling adequacy is 0.76, which satisfies the KMO > 0.5 criterion, indicating that the factor analysis is appropriate for the selected data. The results of Bartlett's test, which tests whether the correlation matrix is an identity matrix, are rejected at the 99% confidence level, indicating significant correlations between variables, supporting the potential use of multivariate analysis methods. Accordingly, the condition implying that the data originate from a multivariate normal distribution has been satisfied.

Table 5. Principal Component Analysis

Compo-nent	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.418	57.063	57.063	7.418	57.063	57.063	6.887	52.978	52.978
2	2.461	18.934	75.997	2.461	18.934	75.997	2.992	23.019	75.997
3	0.916	7.049	83.046						
4	0.570	4.385	87.431						
5	0.485	3.733	91.164						
6	0.379	2.913	94.078						
7	0.276	2.123	96.201						
8	0.164	1.261	97.462						
9	0.127	0.976	98.438						
10	0.094	0.720	99.158						
11	0.063	0.487	99.644						
12	0.025	0.191	99.835						
13	0.021	0.165	100.000						

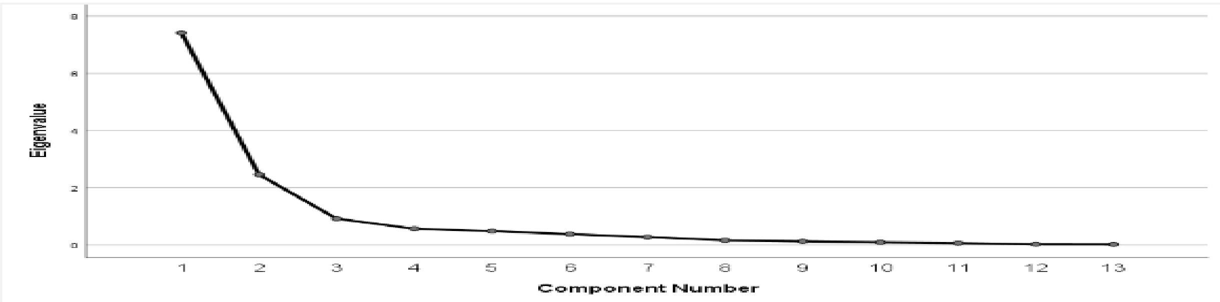
In the second step, the number of factors and the proportion of variance explained by the factors were determined by considering the results obtained from the Principal Component Analysis (PCA). Varimax rotation[3] was applied in the analysis, and the results of this rotation were taken into account.

[2] The Kaiser-Meyer-Olkin (KMO) test is essentially a statistical measure that determines how suitable the data are for exploratory factor analysis. More specifically, the test measures the sample adequacy for each variable and for the entire model. KMO values greater than 0.5 are considered sufficient, indicating that component or exploratory factor analysis would be useful for these variables.

[3] In exploratory factor analysis, rotation is performed to ensure clarity and meaningfulness in interpreting the factors. In other words, the purpose of rotation is to increase the interpretability of the retained factors. Through the rotation process, factors identify items that are highly related to themselves and become easier to interpret. The most commonly used rotation method is Varimax, which maximizes factor variances with fewer variables. Varimax rotation is the most widely used among orthogonal methods. This rotation method prioritizes the columns of the factor loading matrix to achieve simpler and more

In this analysis, components with eigenvalue greater than 1 are considered to explain a significant portion of the total variance in the dataset and are retained for analysis. Other components are excluded from the analysis. According to the results of the PCA in Table 5, two factors with eigenvalues greater than 1 have been identified ($\lambda_1 = 7.418\ and\ \lambda_2 = 2.461$). It was observed that these two factors explain approximately 75% of the total variance.

Figure 2. Scree Plot



The scree plot is a graph of the eigenvalues against all the factors. This plot is one of the graphs that provides insight into determining the number of factors in exploratory factor analysis. In this plot, the points where the curve flattens are counted, and the factors to be included in the solution are identified. In other words, the point of interest is where the curve starts to flatten. In addition to Table 5, the scree plot curve shown in Figure 2 clearly indicates that there are two factors with eigenvalues greater than 1.

Table 6. Rotated Component Matrix

Indicators	Component			
	F_1	$\Sigma F_1 = 1$	F_2	$\Sigma F_2 = 1$
INT	0.967	0.120		
FBS	0.945	0.117		
RES	0.936	0.116		
MCS	0.869	0.108		
GDP	0.865	0.107		
RDE	0.864	0.107		
SCH	0.864	0.107		
MHT	0.787	0.097	0.349	0.092
ATM	0.652	0.081	0.316	0.083
STJ			0.944	0.248
PAT			0.912	0.240
IBW			0.831	0.218
ICT	0.326	0.04	0.452	0.119

meaningful factors. We used the Varimax method during rotation to maximize factor variances with fewer variables and thus minimize the complexity of the factors.

In the third step, the factor loadings of the indicators are determined. After the rotation process, the rotated component matrix clearly reveals which variables belong to which factor. Examining the rotated component matrix in Table 6 reveals that the factor loadings of the indicators (F_1, F_2) are greater than the 0.30 threshold value[4]. Therefore, it has been concluded that the indicators are suitable for model analysis. To ensure that the index score takes a value between 0 and 1, the factor loadings have been revised so that their sum equals 1 ($\Sigma F_1 = 1$ and $\Sigma F_2 = 1$). To summarize, higher weights are assigned to factors that contribute more to the direction of common variation. Then, sub-indices are combined into higher indices using the same procedure.

Table 7. Weights of Indicators

Indicators	Weight Ratio (w_i)
MHT	0.0957
INT	0.0834
FBS	0.0816
ATM	0.0814
RES	0.0808
STJ	0.0751
MCS	0.0749
GDP	0.0746
RDE	0.0746
SCH	0.0745
PAT	0.0726
IBW	0.0661
ICT	0.0641
Σw_i	1.0000

Taking into account the variance explained by the factors and the factor loadings of the indicators, the weight of the selected indicators within the index is calculated and is shown in Table 7. It is important to note that the scores of the factors are not calculated individually in our study; instead, the TCI score is calculated by considering the variance explained by the two factors as well as the factor loadings. The Weighted TCI formula is:

$$TCI = \sum_{i=1}^{k} w_i X_{ij} \tag{2}$$

where i refers to each indicator of the index, and j refers to the country included in the analysis. Therefore, w_i represents the weight of the i indicator in the index, and X_{ij} represents the value of i indicator for the j country.

[4] Factor loadings indicate the relationship between a variable and a specific factor. A factor loading greater than 0.30 suggests that the variable is significantly associated with that factor and can be considered in explanatory factor analysis.

Table 8. Grading System of the Technological Change Index

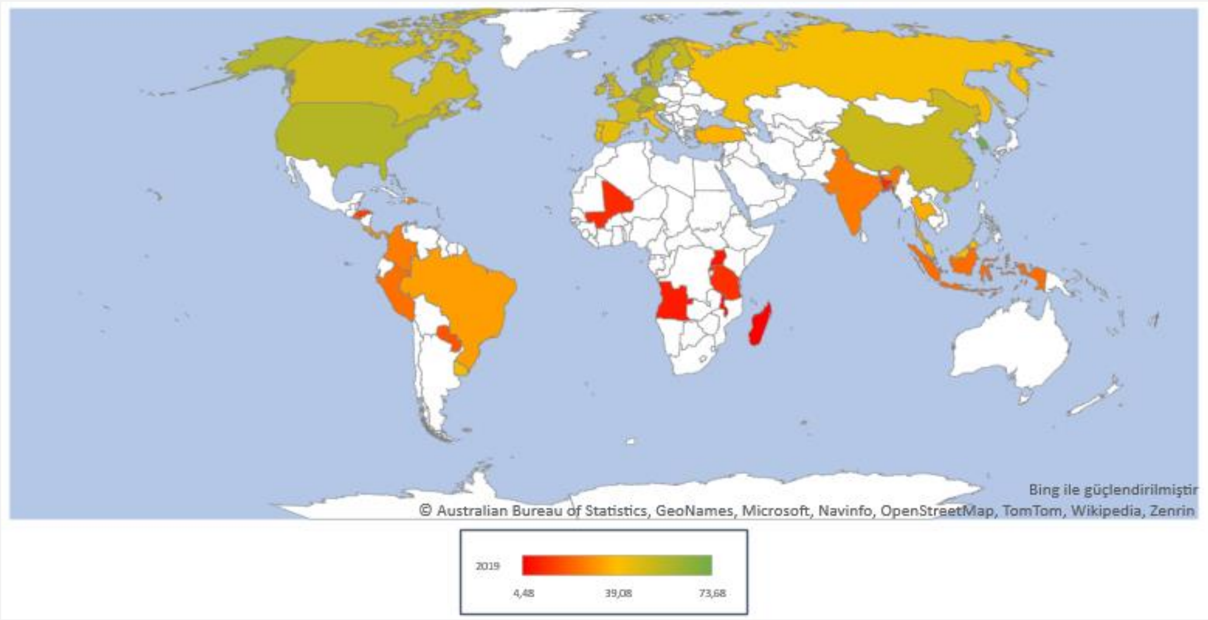
Score range	Score	Grade	Level
61-100	> 70	A+	Ultra-High
	65-70	A	
	61-65	A-	
46-60	56-60	B+	High
	51-55	B	
	46-50	B-	
31-45	41-45	C+	Upper Middle
	36-40	C	
	31-35	C-	
16-30	26-30	D+	Lower Middle
	21-25	D	
	16-20	D-	
Less than 15	11-15	F+	Poor
	6-10	F	
	0-5	F-	

In our method, a TCI score can be calculated annually for the period 1991-2019. Additionally, the index score can take a value between 0 and 100. If the score approaches 100, it indicates that technological change is at an advanced level, while a score closer to 0 indicates the opposite. A grade is then assigned to these scores to further communicate technological change in a manner easily understood by everyone. Grading system of the TCI is presented in Table 8. Each grade corresponds to a technological level: Ultra-High, High, Upper Middle, Lower Middle, and Poor, respectively. We assign a performance scale using “Ultra-High” for scores 61-100, “High” for 46-60, “Upper Middle” for 31-45, “Lower Middle” for 16-30, and “Poor” for scores less than 15.

5. SCORE AND RANKING

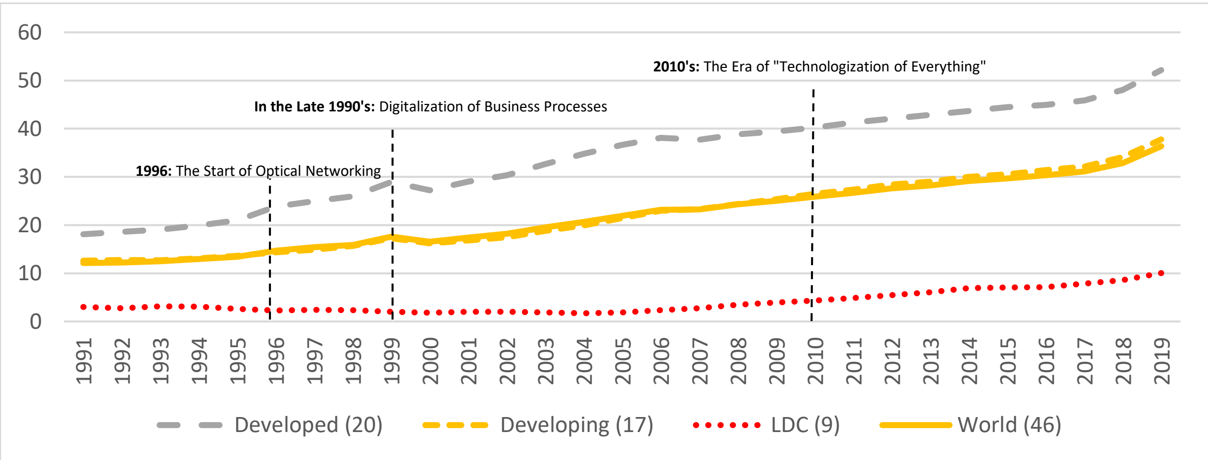
The TCI scores have been calculated for 46 countries for which data are available and of high-quality. Based on this calculation, the TCI heat map is presented in Figure 3. One of the most important benefits of constructing a heat map for technological change is that it allows us to see trends on a single map. The intensification of red or green colors in the heat map provides information on whether technological change is at an high or poor level, and also highlights the gap in technological progress both between regions and across countries. Consequently, the TCI score of a country with a near-green view is higher than that of one with a near-red view. The score could not be calculated for the countries in white on the map due to data unavailability.

Figure 3. Heatmap of the Technological Change Index, 2019



Examining the heat map, we find that technological progress varies significantly between the north and the south, especially in the Americas. Accordingly, TCI scores are relatively high in North America, Scandinavia, and the North Asia-Pacific region, where we can already observe quite a bit of green on the map. In contrast, in Latin America, Sub-Saharan Africa, and Asia-Pacific regions, we see that TCI scores are relatively low. Consequently, technological progress is also relatively low in these regions, which are characterized by a more intense reddish color.

Figure 4. Mean the Technological Change Index Scores by Level of Development



On the other hand, technological progress remained noticeably low in the least developed countries during the analyzed period (1991-2019), while the increase in developed and developing countries continued due to the acceleration of economic investment in ICT, especially broadband connectivity, education, digital literacy, and innovation. The mean scores of developed, developing, and least developed countries, shown in the time path graph in Figure 4, shed light on this inference.

As mentioned earlier, the TCI scores are classified and evaluated based on grades. Within this framework, the TCI scores calculated for the countries are shown in Figure 5, and the ranking is presented in Table 9. As can be seen in Figure 5, there are five grades for the countries, with TCI scores ranging from 73.67 for South Korea to 4.48 for Madagascar.

First, in our methodology, the "Ultra-High" level (Grade A) is considered the most advanced degree of technological change. We define countries that have reached the "Ultra-High" level as those that are able to create and successfully maintain innovation in technology. According to our findings, South Korea and Singapore, two of the Asian Tigers, occupy the top two in this ranking. South Korea and Singapore, which have attracted attention with their educational reforms and technological breakthroughs in the last 60 years, are considered among the world's largest economies at present. According to our grading system, South Korea, with an A+ ("Ultra-High") grade of technology, has also been the leader in the ranking over the past 10 years. Singapore's TCI score has shown a remarkable increase in recent years and is approaching the leader. Thus, these countries have managed to rank among the two countries at "Ultra-High" level in terms of technological progress.

Among the grades, the "High" level (Grade B) refers to a certain level of maturity in terms of technology access and use, infrastructure, and their economic impact. In our study, a country with a B+ rating is particularly considered a candidate for the "Ultra-High" level. According to our findings, the largest number of countries in this grade comes from the EU. The US and China, the two global economic heavyweights that together account for more than 40% of the world's GDP today, have a "High" level of technological development. The analysis shows that Denmark, the US, Switzerland, Germany, and Sweden are the most likely to transition to "Ultra-High" (Grade A) technological progress in the coming decades.

Figure 5. Grades by Country, in 2019

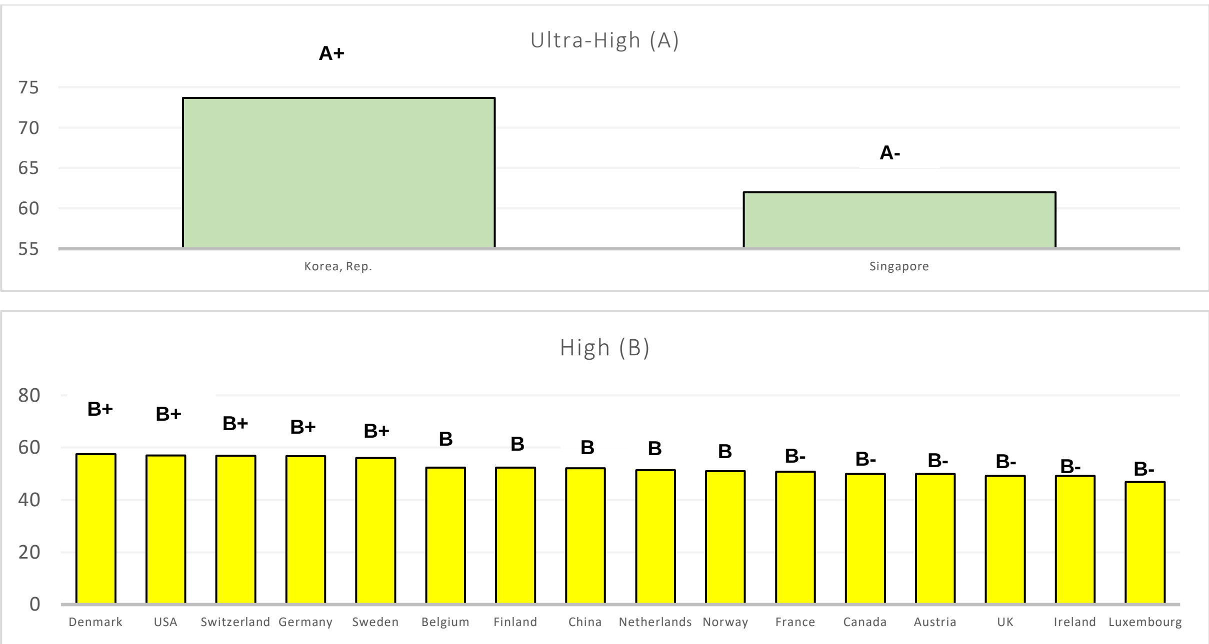


Figure 5 (cont.)

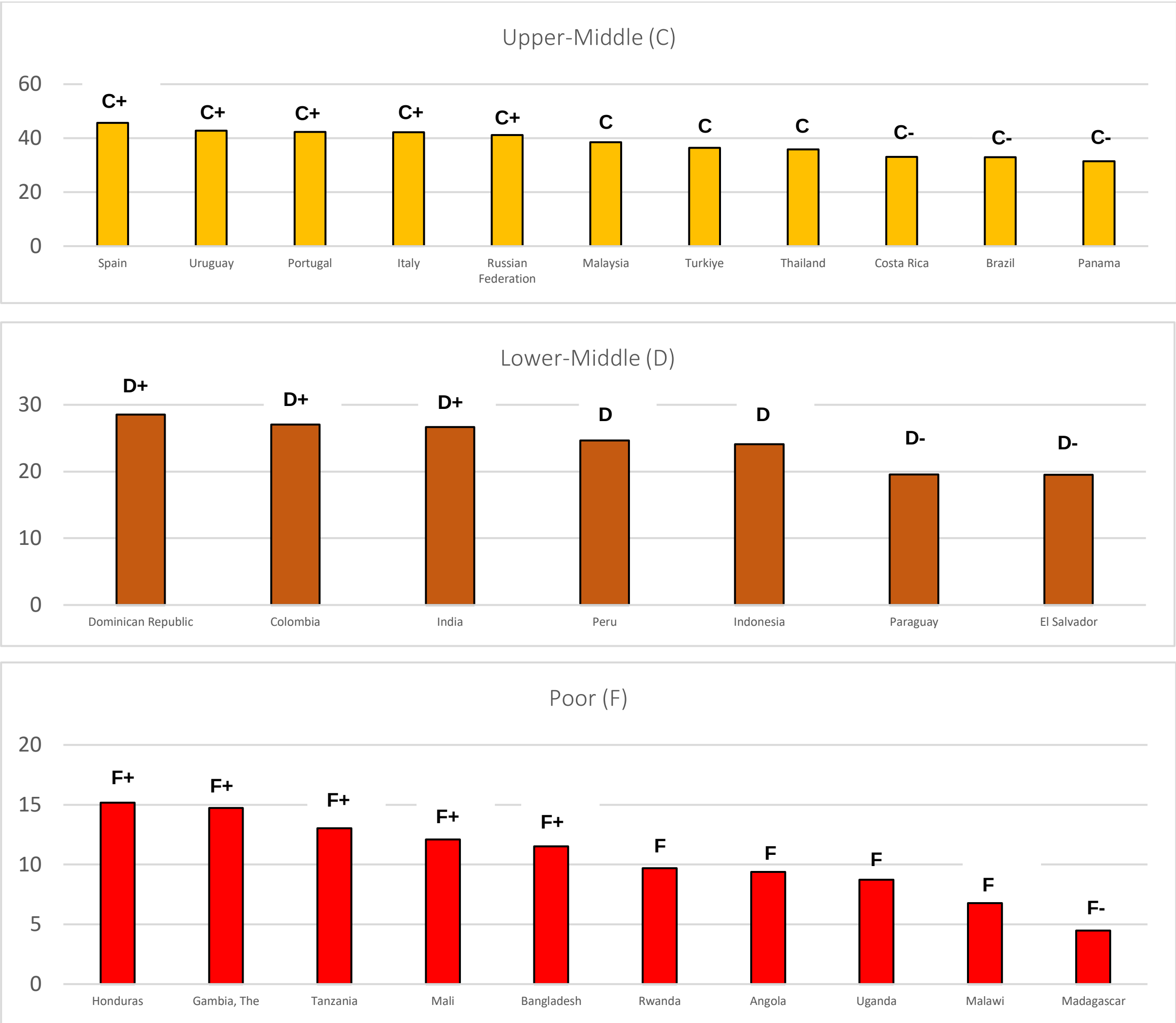


Table 9. Country Rankings

Country	2010			2015			2019		
	Score	Level	Rank	Score	Level	Rank	Score	Level	Rank
Korea, Rep.	54.39	High	1	60.19	High	1-	73.68	Ultra-High	1–
Singapore	47.81	High	4	50.66	High	3↑	61.99	Ultra-High	2↑
Denmark	45.46	Upper Middle	5	49.16	High	4↑	57.49	High	3↑
United States	48.66	High	2	57.79	High	2–	56.97	High	4↓
Switzerland	41.37	Upper Middle	10	47.92	High	6↑	56.93	High	5↑
Germany	43.60	Upper Middle	6	48.28	High	5↑	56.74	High	6↓
Sweden	43.39	Upper Middle	7	45.90	Upper Middle	8↓	56.08	High	7↑
Belgium	37.58	Upper Middle	16	43.31	Upper Middle	15↑	52.34	High	8↑
Finland	48.01	High	3	44.21	Upper Middle	12↓	52.31	High	9↑
China	27.36	Lower Middle	22	40.89	Upper Middle	17↑	52.16	High	10↑
Netherlands	41.02	Upper Middle	11	45.13	Upper Middle	10↑	51.34	High	11↓
Norway	42.75	Upper Middle	8	44.45	Upper Middle	11↓	51.07	High	12↓
France	40.10	Upper Middle	13	43.43	Upper Middle	14↓	50.72	High	13↑
Canada	40.58	Upper Middle	12	43.08	Upper Middle	16↓	49.95	High	14↑
Austria	36.01	Upper Middle	18	43.92	Upper Middle	13↑	49.95	High	15↓
U.K.	42.37	Upper Middle	9	47.40	High	7↑	49.22	High	16↓

Table 9 (cont.)

Country	2010			2015			2019		
	Score	Level	Rank	Score	Level	Rank	Score	Level	Rank
Ireland	39.98	Upper Middle	14	45.15	Upper Middle	9↑	49.14	High	17↓
Luxembourg	38.76	Upper Middle	15	40.79	Upper Middle	18↓	46.90	High	18–
Spain	35.72	Upper Middle	19	37.59	Upper Middle	19–	45.62	Upper Middle	19–
Uruguay	19.20	Lower Middle	28	26.05	Lower Middle	25↑	42.74	Upper Middle	20↑
Portugal	36.21	Upper Middle	17	35.44	Upper Middle	22↓	42.26	Upper Middle	21↑
Italy	34.63	Upper Middle	20	37.56	Upper Middle	20–	42.24	Upper Middle	22↓
Russian Fed.	25.04	Lower Middle	23	36.29	Upper Middle	21↑	41.11	Upper Middle	23↓
Malaysia	27.87	Lower Middle	21	32.62	Upper Middle	23↓	38.47	Upper Middle	24↓
Türkiye	19.39	Lower Middle	27	23.80	Lower Middle	27–	36.41	Upper Middle	25↑
Thailand	23.97	Lower Middle	24	25.48	Lower Middle	26↓	35.83	Upper Middle	26–
Costa Rica	16.34	Lower Middle	30	22.80	Lower Middle	28↑	33.07	Upper Middle	27↑
Brazil	21.86	Lower Middle	26	29.35	Lower Middle	24↑	32.94	Upper Middle	28↓
Panama	22.80	Lower Middle	25	21.85	Lower Middle	29↓	31.46	Upper Middle	29–
Dom. Rep.	16.00	Lower Middle	31	19.48	Lower Middle	31–	28.55	Lower Middle	30↑
Colombia	16.66	Lower Middle	29	20.72	Lower Middle	30↓	27.04	Lower Middle	31↓
India	11.78	Poor	36	15.18	Poor	35↑	26.67	Lower Middle	32↑
Peru	13.42	Poor	35	17.65	Lower Middle	33↑	24.66	Lower Middle	33–
Indonesia	13.94	Poor	33	19.07	Lower Middle	32↑	24.10	Lower Middle	34↓
Paraguay	13.49	Poor	34	15.49	Poor	34–	19.57	Lower Middle	35↓
El Salvador	14.12	Poor	32	14.86	Poor	36↓	19.52	Lower Middle	36–
Honduras	10.74	Poor	37	9.28	Poor	39↓	15.17	Poor	37↑
Gambia, The	6.28	Poor	38	10.73	Poor	37↑	14.72	Poor	38↓
Tanzania	4.69	Poor	41	7.46	Poor	42↓	13.02	Poor	39↑
Mali	4.47	Poor	43	9.46	Poor	38↑	12.09	Poor	40↓
Bangladesh	3.44	Poor	44	7.42	Poor	43↑	11.52	Poor	41↑
Rwanda	4.64	Poor	42	7.65	Poor	40↑	9.68	Poor	42↓
Angola	4.93	Poor	40	7.61	Poor	41↓	9.39	Poor	43↓
Uganda	5.19	Poor	39	5.34	Poor	44↓	8.74	Poor	44–
Malawi	2.89	Poor	45	4.27	Poor	45–	6.77	Poor	45–
Madagascar	2.45	Poor	46	3.40	Poor	46–	4.48	Poor	46–

The "Middle" level represents countries that are lagging behind in terms of technological development due to lack of education, infrastructure, and poor legislation. These countries need to focus on the infrastructure, use and access dimensions in their technology policies, aiming to bring them to a more advanced stage. According to the results, three of the five countries likely to transition from the "Upper-Middle" group to the "High" level in the near future are from Europe: Spain, Portugal, and Italy. Two others, Uruguay and the Russian Federation are also mentioned. The vast majority of countries in the middle level, both "Upper" and "Lower", are from Latin America.

Finally, the "Poor" level refers to the performance of countries that have limited access to technology and inadequate infrastructure to take advantage of new technologies. These countries have a long way to go in terms of the spread of technology and the establishment of their infrastructure. As can be seen in Figure 5, most of these countries are from the African continent, except for Bangladesh and Honduras. Among the African countries, Gambia, Tanzania, and Mali are better performers than the others. Madagascar ranks the lowest, 46th, with a TCI score of 4.48.

6. CONCLUSION

Technological change is considered one of the most important driving forces behind production efficiency. Technological change not only increases productivity but also spreads economic development to broader segments of society, thereby raising the welfare levels of communities.

The increasing focus on the technological development of countries has the potential to lead to more productive decision-making, whether at the policy level, in markets, or for the public as a whole. Building broader technological change indices could play a leading role in enabling the success of development policy and increasing growth and prosperity. Within this framework, a technological change index is constructed for developed and developing countries including least developed countries (LDCs), by considering the multidimensional nature of technology in this study. This new index is presented as a composite measure that includes the infrastructure, access and use, innovation, and impact dimensions of technology. We also use Principal Component Analysis, which has become increasingly popular in the applied economics literature in recent years, to weight the indicators of the index. TCI fills a significant gap, due to the absence of a weighted and multidimensional index in the literature that enables long-term technological development analysis for a large number of countries with varying levels of development.

According to the findings of this study, as expected, developed countries have received higher TCI scores. However, it has been observed that the TCI score is gradually decreasing in developing and least developed countries. The findings of the study support the argument in the literature that technology is the driving force of growth and development. In addition, the findings of this study lead to conclusions similar to those in the relevant literature. Indeed, the studies conducted by Ulku (2004), Mudronja et al. (2019), Choi and Yi (2009), Koutroumpis (2009), Ghosh (2017), and Dutta (2020) have demonstrated a strong relationship between various indicators representing technology and development indicators.

Technological change has accelerated around the world in the last three decades. When the TCI is analyzed at the national level, it has been revealed that South Korea and Singapore have the highest scores. These countries have achieved the most advanced level of technology, which we have defined as "Ultra High". The success of the Asian Tigers in technology allowed them to reach a significant level of economic strength during this period. In fact, the Asian Tigers experienced a successful development process at the end of the 20th century and the beginning of the third millennium, particularly due to their comprehensive technology policies and increased technological advancements during the late 20th century.

Examining the trend of TCI scores as a whole, it is seen that most countries have reached the “High” level of technology from 1991 to 2019. During this period, while productivity, growth, and welfare significantly increased in technologically advanced countries, the other side of the coin was the widening technological gap between these countries and others. As a matter of fact, while technological progress has been accelerating in developed countries during the 2000s and developing countries have experienced reasonable technological change, the least developed countries have made little to no progress. While the strong economies of South Korea, Singapore, the US, and the EU have gained momentum in technology, the gap with low-income countries has been widening. In other words, there has been a 'technological polarization' between the developed countries and LDCs. Nine LDCs analyzed in the study were still at the “Poor” level of technology in 2019.

Developed countries achieve higher efficiency in production processes by utilizing advanced technologies, whereas least developed countries remain dependent on low-tech production methods. This situation contributes to increasing welfare levels in developed countries by reducing production costs and enhancing value-added output, while in least developed countries, a lack of productivity constrains economic growth and results in relatively lower welfare levels. The estimates of Comin and Hobijn (2010) for 166 countries over the period 1820–2003 support this finding. According to their study, cross-country differences in technology adoption account for approximately 25% of the disparities in per capita income, which is one of the most significant indicators of welfare. Furthermore, access to technology is more readily available in developed countries due to well-established infrastructure and sufficient financial resources, whereas in least developed countries, infrastructure deficiencies and financial constraints significantly limit such access. This polarization in technological advancement deepens economic and social inequalities, reinforcing disparities in welfare levels and making them more persistent. This technological gap, particularly affecting the development process of LDCs, hinders the equal distribution of economic growth, productivity increase, and welfare levels on a global scale. Bridging this gap is crucial for global prosperity, and in this context, various policy measures are necessary.

The technological gap is gradually widening because developed countries are rapidly adopting frontier technologies in the third millennium, while less developed countries are failing to do so due to their distinctive structural problems. In this context, the least developed countries need partnerships to develop and strengthen their technologies. Current international norms on technology and innovation indicate that protectionism, rather than proliferation, is at the forefront. For this reason, a global partnership led by developed countries should contribute to the development of these regions by providing technology transfer to LDCs. A strengthened international partnership for least developed countries will play a key role in expanding productive capacity and promoting sustainable development in these countries. However, regardless of the level of development, policymakers should support their technology policies that prioritize increasing productivity and welfare, with education policies that focus on establishing human capital capable of quickly adapting to and meeting new technological developments.

The least developed countries (LDCs) face significant challenges in terms of technology access and infrastructure. In these countries, infrastructure deficiencies and difficulties in accessing technological resources are hindering the economic development process. In this context, technology transfer and infrastructure investments should be made by developed countries and international organizations. Through projects led by international organizations, strong infrastructure systems should be established in these regions, with a focus on areas such as broadband internet access and digital education. Without investment in infrastructure, reducing the existing technological divide and addressing increasing inequalities will not be possible. These policy recommendations will contribute to strengthening innovation and supporting industrialization, which help achieve Sustainable Development Goal 9 (SDG-9). Closing the technological divide will not only provide great opportunities for the least developed countries but also for more sustainable and inclusive economic growth and lasting increases in prosperity worldwide.

Future research can enhance the Technological Change Index (TCI) by integrating elements such as AI-driven innovations, digital transformation indicators, and big data analytics, thereby creating a more comprehensive framework. As technological change evolves rapidly in the Digital and Artificial Intelligence Era, traditional indicators may no longer fully capture the multidimensional nature of this transformation. In this context, with the availability of relevant data for countries, a TCI enriched with digitalization and artificial intelligence could provide future research with in-depth insights into how next-generation technologies shape socioeconomic transformation. Such an index would serve as a valuable reference for policymakers and scholars.

Ethics Committee approval was not required for this study.

The authors declare that the study was conducted in accordance with research and publication ethics.

The authors confirm that no part of the study was generated, either wholly or in part, using Artificial Intelligence (AI) tools.

The authors declare that there are no financial conflicts of interest involving any institution, organization, or individual associated with this article. Additionally, there are no conflicts of interest among the authors.

Contribution Rate Declaration: This paper is a revised version of selected parts of a PhD thesis, prepared by the first author and supervised by the second author.

REFERENCES

Acemoglu, D. (2023). Distorted innovation: Does the market get the direction of technology right? *AEA Papers and Proceedings*, (113), 1-28. https://doi.org/10.3386/w30922

Acemoglu, D., Laibson, D., & List, J. (2022). *Macroeconomics, global edition*. Pearson Education Limited.

Aghion, P., & Howitt, P. (1992). A model of growth through creative destruction. *Econometrica, 60*(2), 323-351. https://doi.org/10.2307/2951599

Archibugi, D., & Coco, A. (2004). A new indicator of technological capabilities for Developed and Developing Countries (ArCo). *World Development, 32*(4), 629–654. https://doi.org/10.1016/j.worlddev.2003.10.008

Ayres, R. U. (1988). Technology: The wealth of nations. *Technological Forecasting and Social Change, 33*(3), 189-201. https://doi.org/10.1016/0040-1625(88)90013-3

Barro, R. J., & Sala-i-Martin, X. (2004). *Economic growth*. MIT Press.

Carlaw, K. I., & Lipsey, R. G. (2003). Productivity, technology and economic growth: What is the relationship? *Journal of Economic Surveys, 17*(3), 457-495. https://doi.org/10.1111/1467-6419.00201

Choi, C., & Yi, M. H. (2009). The effect of the internet on economic growth: Evidence from cross-country panel data. *Economics Letters*, *105*(1), 39-41. https://doi.org/10.1016/j.econlet.2009.03.028

Coccia, M. (2014). Driving forces of technological change: The relation between population growth and technological innovation: Analysis of the optimal interaction across countries. *Technological Forecasting and Social Change*, (82), 52-65. https://doi.org/10.1016/j.techfore.2013.06.001

Comin, D., & Hobijn, B. (2010). An exploration of technology diffusion. *American Economic Review, 100*(5), 2031-2059. https://doi.org/10.1257/aer.100.5.2031

Dahlman, C. J. (1989). Technological change in industry in Developing Countries. *Finance & Development, 26*(2), 13-15. https://doi.org/10.5089/9781451952445.022

Desai, M., Fukuda-Parr, S., Johansson, C., & Sagasti, F. (2002). Measuring the technology achievement of nations and the capacity to participate in the network age. *Journal of Human Development, 3*, 95-122. https://doi.org/10.1080/14649880120105399

Dutta, A. (2020). The impact of ICT exports on the economic growth of the BRICS countries. *International Journal of Recent Technology and Engineering (IJRTE), 9*(1), 1183-1185. https://doi.org/10.35940/ijrte.F9737.059120

European Commission. (2022). *Digital economy and society index (DESI) 2022*. https://digital-strategy.ec.europa.eu/en/library/digital-economy-and-society-index-desi-2022

European Commission. (2023). *European innovation scoreboard 2023 methodology report*. https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/european-innovation-scoreboard-2023_en#related-links

Ferguson, E., & Cox, T. (1993). Exploratory factor analysis: A users' guide. *International Journal of Selection and Assessment, 1*(2), 84-94. https://doi.org/10.1111/j.1468-2389.1993.tb00092.x

Ghosh, S. (2017). Broadband penetration and economic growth: Do policies matter? *Telematics and Informatics, 34*(5), 676-693. https://doi.org/10.1016/j.tele.2016.12.007

Gold, B. (1987). Technological innovation and economic performance. *Omega, 15*(5), 361-370. https://doi.org/10.1016/0305-0483(87)90036-3

Grossman, G. M., & Helpman, E. (1991). Trade, knowledge spillovers, and growth. *European Economic Review, 35*(2), 517-526. https://doi.org/10.1016/0014-2921(91)90153-A

International Monetary Fund. (2023). *Country composition of WEO groups*. https://www.imf.org/external/pubs/ft/weo/2022/01/weodata/groups.htm

International Telecommunication Union. (2017). *Measuring the information society report 2017: Volume 1 and 2*. http://handle.itu.int/11.1002/pub/80f52533-en

International Telecommunication Union. (2023). *Statistics*. https://www.itu.int/en/ITU-D/Statistics/Documents/statistics/2022/December/InternationalBandwidthMbits_2007-2021.xlsx

Khayyat, N. T., & Lee, J. D. (2015). A measure of technological capabilities for Developing Countries. *Technological Forecasting & Social Change, 1*(92), 210-223. https://doi.org/10.1016/j.techfore.2014.09.003

Kondratyev, N. D. (1935). The long waves in economic life. *The Review of Economics and Statistics, 17*(6), 105-115. https://doi.org/10.2307/1928486

Koutroumpis, P. (2009). The economic impact of broadband on growth: A simultaneous approach. *Telecommunications Policy, 33*(9), 471-485. https://doi.org/10.1016/j.telpol.2009.07.004

Kuznets, S. (1966). *Modern economic growth: Rate, structure, and spread*. Yale University Press.

Mcguckin, R. H., Streitwieser, M. L., & Doms, M. (2006). The effect of technology use on productivity growth. *Economics of Innovation and New Technology, 7*(1), 1-26. https://doi.org/10.1080/10438599800000026

Morrison, J. T. (2017). Factor analysis, exploratory. In C. D. J. Matthes, & R. Potter (Eds.), *The International Encyclopedia of Communication Research Methods* (pp. 21-56). Wiley-Blackwell. https://doi.org/10.1002/9781118901731.iecrm0102

Mudronja, G., Jugoviæ, A., & Škalamera-Aliloviæ, D. (2019). Research and development and economic growth: EU port regions. *Zbornik radova Ekonomskog Fakulteta u Rijeci, 37*(2), 587-602. https://doi.org/10.1016/0304-3932(89)90047-0

Nepelski, D., & Prato, G. D. (2020). Technological complexity and economic development. *Review of Development Economics, 24*(2), 448-470. https://doi.org/10.1111/rode.12650

Pece, A. M., Simona, O. E., & Salisteanu, F. (2015). Innovation and economic growth: An empirical analysis for CEE Countries. *Procedia Economics and Finance, 26*(3), 461-467. https://doi.org/10.1016/S2212-5671(15)00874-6

Portulans Institute. (2020). *The network readiness index 2020*. https://networkreadinessindex.org/wp-content/uploads/2020/10/NRI-2020-Final-Report-October2020.pdf

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy, 98*(5), 71-102. https://doi.org/10.1086/261725

Schumpeter, J. (1980). *Theory of economic development*. Routledge. https://doi.org/10.4324/9781315135564

Solow, R. M. (1956). A contribution to the theory of economic growth. *Quarterly Journal of Economics*, (70), 65-94. https://doi.org/10.2307/1884513

Steinmueller, W. E. (2002). Knowledge-based economies and information and communication technologies. *International Social Science Journal, 54*(171), 141 - 153. https://doi.org/10.1111/1468-2451.00365

Tassey, G. (1996). Infratechnologies and economic growth. In M. Teubal, D. Foray, M. Justman, & E. Zuscovitch (Eds), *Technological Infrastructure Policy: An International Perspective* (pp. 59-86). Springer. https://doi.org/10.1007/978-94-015-8739-6_3

Ulku, H. (2004). *R&D, innovation, and economic growth: An empirical analysis*. International Monetary Fund. https://doi.org/10.2139/ssrn.879010

United Nations Conference on Trade and Development. (2019). *Science, technology & innovation capacity development course*. https://unctad.org/system/files/official-document/dtlstictinf2019d1_en.pdf

United Nations Conference on Trade and Development. (2023). *UN list of Least Developed Countries*. https://unctad.org/topic/least-developed-countries/list

United Nations Development Programme. (2020). *Human development report 2020 technical notes*. https://hdr.undp.org/sites/default/files/data/2020/hdr2020_technical_notes.pdf

United Nations Industrial Development Organization. (2002). *Industrial development report 2002/2003*. https://doi.org/10.18356/94674506-en

Wagner, C. S., Brahmakulam, I., Jackson, B., Wong, A., & Yoda, T. (2001*). Science and technology collaboration: Building capacity in Developing Countries*. World Bank Science and Technology Policy Institute. https://www.rand.org/pubs/monograph_reports/MR1357z0.html

World Bank. (2023). *World development indicators*. https://databank.worldbank.org/source/world-development-indicators

World Intellectual Property Organization. (2023). *Global innovation index 2023: Innovation in the face of uncertainty*. WIPO. https://www.wipo.int/edocs/pubdocs/en/wipo-pub-2000-2023-en-main-report-global-innovation-index-2023-16th-edition.pdf