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An Efficiency Measurement of E-Government Performance for Network Readiness: Non-Parametric Frontier Approach

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Abstract: Information and Communications Technology (ICT) network readiness competency improves service quality and provides efficient service in implementing successful e-governments. By confirming ICT network readiness of e-governments, it must be redesigned using limited resources effectively to achieve realistic goals. When ICT investment and economic performance are featured, e-government's network readiness competency improves potential demand, supply, and service maturity. It reflects information technology (IT) development competency on performance effectively. In this study, we propose the Data Envelope Analysis (DEA) method to present a method of improving ICT network readiness between countries. We derived the ICT network's readiness competency level and strategic plan by comparing each country for efficient ICT operation of e-governments. If we make rankings in a non-traditional and efficient manner, it will become a successful strategy for ICT in the future. This effort provides guidance for each government and a solution for the growth delay problem, which is required for advancement in ICT investment and productivity. It also guides each government to overcome marginal products.

Keywords: e-government; informatization; efficiency strategy; user-centric ICT innovation; ICT competitiveness; network readiness

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1. Introduction

E-government has used information technology in the field of the economy, breaking away from the traditional methods of government operation and bringing a paradigm of integrating functions between governments [1]. Currently, society demands innovative digital services and advanced Information and Communication Technologies (ICT) for e-governments in order to solve social problems and respond to changes in the political, economic, and social environment [2]. Information technology contributes to enhancing the efficiency of government functions. It also strengthens the government's capability of systemizing knowledge and information of the government organizations electronically and of managing government organizations efficiently [3]. In order to improve the capabilities of e-government, ICT investment and technology development have become the center of attention in making information technology develop and in enhancing national competitiveness [4].

ICT has the effect of facilitating technology spreading throughout our society, affecting economic activity in various ways and performing a significant role [5,6]. Jorgenson and Stiroh [7] and Oliner and Sichel [8] asserted that technological progress and innovations of ICT increase productivity and create added value, thereby bringing rapid economic growth forward. Innovation promotes national competitiveness and sustainable economic development. Countries with advanced development in ICT-driven innovation show better competency. This study demonstrates that ICT industry, infrastructure, and environment are important factors for innovation competency. Innovation reflects high-quality innovation performances, including R&D and patents of ICT industry in general [9]. It is essential to explore new strategies by sharing these efficient innovation performances. By utilizing shared resources, efforts must be made to efficiently decrease the uncertainty of investment into futuristic technology. In other words, "Open Innovation" is required to solve ICT-related problems and to search for sustainable ICT strategies.

The positive effects of ICT progress on industries and national economies have been proven empirically [10,11]. Fukugawa [12] indicates that the ICT environment is required to be preceded in creating economic added value, and Koh and Magee [13] perceived the significance of information technology progress by verifying that competitiveness and productivity are enhanced through information technology progress. Furthermore, the added value of the ICT industry announced by OECD would increase the growth of the related industry at a very high speed [14]. ICT in the fourth industrial revolution is being used as a significant indicator remarkably in evaluating national competitiveness because of its significance and ripple effect.

Many countries have been making great efforts on ICT progress through cooperative work in accordance with a rapidly changing environment of information-oriented generation based on ICT progress [15]. International organizations and civilian departments have been continuously discussing and understanding the degree of informatization by the country for its progress. This kind of discussion provides us with guidelines for analyzing the level of informatization objectively by country and proposes a conceptual model for measuring information society. International Telecommunication Union (ITU), as a representative of international comparison index, guides the ICT development index, e-government readiness index of United Nations (UN), and the online participation index. In addition, the World Economic Forum (WEF) announced the Network Readiness Index (NRI), which indicated the ICT environment and informatization development level that is used as a continuous index in terms of reinforcing competitive advantages [16,17].

Relative comparison applying the international comparison index is used as a key measure to understand the degree and change of informatization progress and competitiveness level in a globally competitive environment by analyzing the level of ICT informatization objectively [18–20]. This is effective in tracking comparison and changes, which does not establish absolute national rank or standard. Each country uses a multiplication about the index to inquire the availability and influence of ICT accessibility and technology. Again, it contributes to measuring various aspects of the information society and is reflected in the countries with ICT policies by understanding national ICT policies [21]. At the point when economic results are highlighted by ICT technology progress, research about the effect of ICT on various industrial fields has been constantly conducted [22–24]. On the other hand, research about the effective operational output of ICT is insufficient. These issues [25] suggest a need to address the problem of technological advances in economy or growth retardation in production factors and a need to examine marginal products. In other words, the more efficient the ICT environment, the better the ICT influence.

If ICT achievement is inefficiently operated in a successful ICT environment, it will require efforts to raise efficient productivity. Therefore, there is a need to redefine plans for raising efficient operation check-ups and ICT environment efficiency. In the method of measuring efficiency, Data Envelopment Analysis (DEA) is effective in comparing Decision Making Units (DMU) placed in a similar environment. Efficiency signifies that relatively similar resources are input to produce higher performance or fewer resources are needed to achieve the same performance [26]. It is necessary to find the cause of inefficiency and improve the input and output by measuring relative effectiveness between countries. Ineffective operating countries are required to benchmark efficient countries in order to find measures of operating potential improvement. In addition, the relations between external environmental factors and ICT production efficiency should be investigated.

DEA is suggested for efficient ICT operation. "The network readiness index (NRI)" announced by WEF should be used, which allows relative comparisons of ICT levels by country. This study compares each country's ICT development capability level with that of a relative country to derive the ICT strategy of Korea. It shows what efforts are required for e-government innovation by improving ICT operational efficiencies and reducing inefficiencies. In terms of achievement, national informatization is significant in planning a strategy that may strengthen the national economy and national competitiveness.

Most of the preceding studies performed research on current capabilities by examining other aspects of e-government; thus, empirical studies that researched on ICT network readiness level are lacking. Those studies have been limited to ICT investment or economic performance, and studies that applied the index were not suitable for relative comparison because they measured countries' indices simultaneously. It will be an empirical study that can measure the new efficiency of ICT if the efficiency is measured by collecting the NRI of each country to provide ICT performances of e-governments. In addition, the relative comparison is expected to be of great significance by objectively deriving efficiency and environmental factors and classifying the income ranges of each country by using the index, which improves the downside of the information index.

This study emphasizes the importance of network readiness. Network readiness is required for greater improvements in each country's efficient ICT influence—that is, sustainable economic growth and increased productivity. A higher level of network readiness is effective in overcoming limitation on productivity and environmental factors. However, most of the studies related to ICT focuses only on technology and performances [27,28]. This study not only measures efficient ICT performance and degree of information but also inspects inefficient network readiness and discovers unproductive external environmental factors. This is a measure for solving growth delay problems or limitation on productivity. These efforts provide guidelines for sustainable development [29]. It also means understanding environmental factors for ICT network readiness of each country and acceptance of problems [21]. It is necessary to perform theoretical and empirical research on how to change this network's readiness environment.

This study presents questions as follows. First, what is the difference between an efficient country and an inefficient country? Second, what are the causes of inefficiencies in constant returns to scale? Third, what are the external environmental factors that mediate efficiency? We reviewed the preceding studies to develop a study method. Specifically, this study provides an approach and direction for the development of an efficient level of network readiness. The Network Readiness Index is the result of a government's effort to evaluate the performances of that government. As a result, it determines the ratings of efficiency that differs from traditional ratings.

The remainder of the paper is composed as follows. In Section 2, we examine the theoretical background of e-governments, ICT and informatization, and international comparison index. In Section 3, we introduce the methodology and present the research model and data. In Section 4, we show the results of efficiency analysis by country and expxlain the results. Finally, in Section 5, we provide our discussion with the results of the analysis.

2. Literature Review

2.1. The Future Direction of Innovative E-Government

Currently, the government perceives a barrier in early process, information security issues, and limitations caused by current government operation methods [30]. In this regard, e-government has a paradigm of using information technology across the economy to provide services and connect intergovernmental functions [1]. In the past, e-government focused on performing administrative tasks efficiently by using ICT technologies such as computers and the Internet. However, as e-government has become more advanced, it has overcome the limitations of supplier-based service and strengthened its approach toward all aspects of government by using ICT technology and the Internet [31]. Many countries have been focusing on ICT investment and technology development to advance information technology of the e-government and to enhance national competitiveness [4].

The use of information technology provides many possibilities to enhance the efficiency of government function [3,32,33]. It has improved the quality of e-government services [34,35], reduced corruption, and strengthened government power [2,36]. Furthermore, it has contributed to rapid change across various fields, including politics and government at the macro-level and reengineering management at the micro level [37–39]. In addition, e-government has been working as an important factor in economic growth, focusing on government policy innovation and making efforts to strengthen national competitiveness [4,40]. It is impossible to define a country's economy only by GDP or productivity. Batterbury and Fernando [41] explained that an environment with effective structures, institutions, and policies should be accompanied. Kharlamova and Vertelieva [42] emphasizes that national competitiveness will provide great potentialities of the industrial economy. To solve environmental pollution and social difficulties and to cope with changes in the political, economic, and social environment, the public sector demands high quality e-government innovation through the introduction and use of digital technology [43,44].

The government has focused on ICT readiness level. The government also focused on citizen's participation in planning and implementing ICT-based services prior to efficient government operation [45,46]. ICT's readiness capabilities may enhance the potential demand, supply, and maturity of e-government services and realize efficient e-government services according to high development capabilities. High quality readiness for technology development and implementation is a prerequisite for the public sector where e-government services are innovative. It makes a citizen's life more comfortable. Enterprises will be able to contribute to production in various economic sectors and enhance competitiveness according to the level of readiness of e-government. In other words, for e-governments to succeed, evaluation and measurement of e-government readiness are essential [47,48].

However, according to the ICT readiness of e-government, many countries fail to provide effective technology and performance. Moreover, poor readiness may reduce the capability and bring a bad environment that could take advantage of ICT opportunities. Koh et al. [48] distinguished e-government components by covering the planning of goals, policies, processes, and technologies to evaluate the readiness of the integrated e-government services. This study proposes the need to validate critical issues and confirm readiness before implementing services for e-government to be successful. Chanyagorn and Kungwannarongkun [49], Azman and Salman [50], and Wielicki and Arendt [51] mentioned that ICT measurement is necessary for a multi-dimensional aspect of a country. It is useful for understanding the impact of ICT readiness level from a macro perspective and for establishing international policies.

This study tracked other aspects of e-governments. As a result, we highlight readiness that opposes current capabilities. However, there are relatively few empirical studies that evaluated the readiness level of e-governments as it is limited to analyses of specific part [52,53]. For efficient operation, an approach toward changing the production environment or ICT influence power should be taken according to ICT readiness of e-governments. Therefore, it is necessary to conduct various evaluation systems and empirical studies to prove that ICT readiness environments promote efficient supply and improve the ICT effect by using government resources.

2.2. Informatization and International Comparison Index

The world is advancing into an information society and is influencing general information society structure, new technologies, environment, and economy. The progress in informatization is not limited to individuals or companies. However, it is a key factor that determines national competitiveness [54]. In order to prepare for a rapidly growing information society, accurately analyzing the level of informatization and predicting the development of changes are necessary [55]. Therefore, tools that may analyze the information objectively and systematically are necessary, which are various indicators related to informatization [56,57]. In line with the rapidly developing environment of information generation, many countries contribute much effort to raise the level of ICT. International organizations and civilian departments also make efforts to understand the degree of informatization by a country and develop indicators to measure the level of informatization as informatization advances.

The International Ranking (Index) is a tool evaluating the development of Information and Communication Technologies (ICT). In particular, the most influential tools are the ICT Development Index (IDI) made by ITU, Network Readiness Index (NRI) made by WEF, and e-Government Development Index (EGDI) of the United Nations. The international comparative index of major informatization is shown in Table 1.

Table 1. International comparative index of major informatization.

Organizations		International Comparative Index of Informatization
International organizations	ITU	ICT Development index, IDI ICT Opportunity Index, ICT-OI Digital Opportunity Index, DOI
	UN	e-Government Development index, EGDI e-Participation Index, EPI
	WB	Knowledge Economy Index, KEI
Civilian departments	WEF	Networked Readiness Index, NRI Global Competitiveness Index, GCI
	IMD	World Competitiveness Index, WCS
	EIU	Digital Economy Rankings
	CIW	Global Innovation Index, GII

The informatization index used so far has difficulties in reflecting the changed level of national informatization due to the rapid progress of informatization. Therefore, developing appropriate informatization indicators is required, according to the information generation, in order to objectively understand the progress and level of national informatization. However, national informatization level measurement by the informatization index has difficulties with respect to expressing it as an index. This is because all kinds of national and social structure and informatization levels related to informatization in a country's society must be included. Moreover, incorrect statistical indicators of each article in several informatization-related integrations may cause problems in interpretation [58]. In other words, new integrated methods and statistical index development that may reflect new information technology should be the subject to research. Additionally, informatization influence variables that may consider various environments should also be subject to research.

As mentioned above, the international comparison index for a country covers a wide range of information society categories. Therefore, there is a limit to preparing detailed statistical indicators. Since the information gap is a relative concept, measurement value fluctuates according to the figures of other countries. Thus, national index calculation is considered a difficult method. Cuervo and Menéndez [59] points out that the development of statistical indicators for digital society changes into the availability of data and the quality and reliability of information sources. In other words, the international comparative index, which is used in the analysis, should be carefully considered. The international comparative index, mentioned above, and e-Government Development Index (EGDI) must correct statistical flaws when calculating index [18]. Global efforts are still insufficient in providing a proper measurement for achieving SDG [60]. Individual indicators and sub-index, weighted by country, are subjectively estimated figures or indexed based on inadequate statistical measurement models. As a result, ICT Development Index (IDI) cannot solve the problem of predicting specific result criteria connected to socio-economic performance [58]. Currently, ITU has been expanding its efforts to draw details of national indicators that may be analyzed objectively. In addition, the DEA approach is not suitable for indexes such as IMD, EIU, and CIW. They have ambiguous boundaries between input and output and lack thorough subfactors. Therefore, the effort to develop a new index of evaluation is necessary. A careful approach is needed for seeking availability and quality of data in the measurement of ICT efficiency.

On the other hand, WEF introduces a new NRI developed jointly with the Harvard Institute for International Development to supplement inherent problems in recent data quality and credibility of ICT. NRI, revised in 2019, consists of NRI experts, is measured based on more than 30 technology-related review indicators, and surveys the development process. Sitnicki and Netreba [20] proved that the algorithm developed by WEF improved discrimination between indices of network readiness values.

Many economies applied NRI for ICT plan strategies, often cited by leaders, in public and private institutions [17]. In more than 120 countries, NRI has been used to include necessary contents to find reliable index development with a broad global scope and strengthened competency. NRI guides us to prepare for more changes of new technological innovation in the future by solving current ICT problems. Network readiness ensures governance mechanisms and efficiencies for achieving a broader goal. Furthermore, it influences the economy and quality of life to gain insights into achieving SDGs [61,62].

3. Materials and Methods

3.1. Selection of Data and Variables

For a relative comparison, each country must have an objective basis for the effectiveness of ICT technologies and usage efficiency compared to accessibility for relative comparison. By performing this, we will see how efficiency inputs required for production in a country have been operated and produced results. Therefore, this study applied NRI provided by WEF for data analysis. Many countries apply the ICT informatization index and reflect it in their national informatization strategy. The operational definition of variables is shown in Table 2.

Table 2. Operational definition of variables.

Factors	Measuring Indicator	Sub-Indicator Contents	
Input	Technology	Access Content Future Technologies	Index
	People	Individuals Businesses Governments	
	Governance	Trust Regulation Inclusion	
Output	Impact	Economy Quality of Life SDG Contribution	

As a strategy to increase effectiveness and productivity of ICT, this study proposes a Data Envelopment Analysis that can measure efficiency by applying Technology, People, Government, and Impact indices found by the ICT environment of each country.

After analyzing DEA and comparing the relative efficiency of each country, the point of projection is derived, and potential improvement value is deduced that may convert inefficient countries into efficient countries. In addition, external influencing factors are used as independent variables to analyze environmental factors by reflecting the efficiency value, which is the dependent variable. ICT environment in the country is the result of government efforts. It discovers rankings of efficiency that differ from traditional rankings. Therefore, it is a methodology from the point of view of efficient operation and production.

This study applied DEA to measure the relative effectiveness of the ICT environment. The data used for analysis in this study include NRI announced by the WEF. The 2020 NRI is the second version of the renewed NRI model, which measures the economies of a total of 134 countries based on ICT results across 60 variables. The second version was redesigned to reflect how it should be integrated within governance structure for technology and people to effectively impact the economy and society. NRI comprises rankings and subindices for digital innovation of a total of 134 countries.

Examining how ICT impact is exerted effectively is required through relative comparisons with the countries concerned in applying input resources, ICT technology, people, and government environments. For a relative comparison, each country must have an objective basis for ICT impact efficiency compared to ICT input resources. By performing this, we will observe how the ICT environment has operated the inputs efficiently needed for production in a country to produce results.

3.2. Collection of Analysis Targets

The Decision-Making Unit (DMU), which is the target of efficiency analysis, must be determined first in order to measure efficiency. DEA should premise homogeneity for relative comparisons between DMUs. Homogeneity between DMUs means that DMUs must be comparable to each other by securing similar corporate activities, similar kinds and ranges of resources, and similar external environmental factors [63]. Therefore, homogeneity is applied to the criteria for selecting the subjects of analysis in this study.

The NRI 2020 result index is closely related to income levels (high-income countries, upper-middle-income countries, lower-middle-income countries, low-income countries). Considering each country's income level, WEF should divide them into four types of incomes (1st–4th quartile) and use DMU with homogeneity. For DEA efficiency analysis, it is desirable to have a large population of DMUs. If the number of DMU units is small, most DMUs correspond to the efficiency frontier, resulting in incorrect measurements. This is because the relative efficiency of DMU may be close to 1. As an important factor in achieving the goal of DMU, the number of input and output variables may affect the same decision factors as much as the number of DMUs. Banker et al. [64] argues that DMU units must be satisfied more than three times the sum of inputs and outputs (calculation variables) to improve this.

This study applies technology, people, and governance corresponding to the ICT environment as input variables. The impact is selected as an output that may be measured because of the ICT environment. Countries divided by four types of income and measurement variables have no problems in analyzing efficiency.

3.3. Data Envelopement Analysis

In terms of various methods of measuring efficiency, DEA measures efficiency by several input and output indicators. This has the advantage of considering input and output indicators, and there is no need to assume a production function. First proposed by [65], the DEA measurement model is based on the [26] concept of relative efficiency. Considering several criteria of relative effectiveness of an organization that operates with the same goal through DEA, the "Linear Programming" model has been developed to systematically evaluate and reflect decision making.

This model determines empirical efficiency limits on the set constructed by the observed value of the input and output factors of DMU. It also measures the relative efficiency of the set that is evaluated by comparing the value of DMU. This has been applied in various fields to measure input and output index for production [66]. Sutopo et al. [67] explained that it is a useful method for assessing and describing performance effectiveness, which is meaningful in modeling the production frontier to provide a level of efficiency.

An environment that may produce a specific level of output through a specific level of input from a measurable value is defined as "producible." These associations are called a "producible set." The producible set is defined as Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS). The viewpoint expands or contracts equally if a CRS exists. On the other hand, VRS signifies that Increasing Returns to Scale (IRS) or Decreasing Returns to Scale (DRS) exist if Constant Returns to Scale is not established. In this respect, DEA is a method of analysis applying a producible set. According to the study of [26], efficiency is about reducing inputs while producing the same output from an economic perspective or increasing output while using the same inputs. In other words, technical efficiency is considered when improving at a higher rate than inputs.

The following are the advantages of measuring efficiency: First, it is possible to derive the production possibility frontier or efficiency frontier by applying various figures as a non-parametric statistical technique that considers input and output simultaneously without assuming a production function. Second, it can grade weights that are advantageous to DMUs without subjectively weighting the number of inputs and outputs and analyzing efficiency by securing objectivity. Third, DMUs are feasible for relative comparison for measuring how efficient they are. Finally, inefficient DMUs are moved into efficient DMUs with potential improvements that enable efficient operation.

DEA introduces different models depending on the purpose of the study and the data character. Typical models are Charnes, Cooper, and Rodes (CCR) and Banker, Charnes, and Cooper (BCC) models. The CCR model is designed to evaluate other DMUs based on the most efficient DMU without considering economies of scale for DMU. Therefore, the CCR model is assumed to be a Constant Returns to Scale (CRS) model because there is no change in revenue depending on the scale.

On the other hand, the BCC model considers economies of scale or non-economics. This Variable Return to Scale (VRS) model assumes that "there is a change" in revenue depending on the scale. The VRS model defines scale inefficiency that may occur when the scale is not optimal. The calculation standard of the mathematical model for a producible set that satisfies this is as follows. VRS model defines scale inefficiencies when the scale is not optimal. The following expressions describe a standard of computation of a mathematical model for a product set that satisfies the definition.

$$\phi^{k*} = \max_{\theta, \lambda} \phi^{k}$$

$$\text{subject to}$$

$$x_m^k \geq \sum_{j=1}^{J} x^j \lambda^j (m = 1, 2, \ldots, M); \tag{1}$$

$$\phi^k y_n^k \leq \sum_{j=1}^{J} y^j \lambda^j (n = 1, 2, \ldots, N);$$

$$\lambda^j \geq 0 (j = 1, 2, \ldots, J)$$

When deriving a virtual price for VRS model, it may obtain predictable results through the observed value.

$$\phi^{k*} = \max_{\theta, \lambda} \phi^{k}$$

$$\text{subject to}$$

$$x_m^k \geq \sum_{j=1}^{J} y_m^j \lambda^j (m = 1, 2, \ldots, M); \tag{2}$$

$$\phi^k y_n^k \leq \sum_{j=1}^{J} y_n^j \lambda^j (n = 1, 2, \ldots, N);$$

$$\sum_{j=1}^{J} \lambda^j = 1;$$

$$\lambda^j \geq 0 (j = 1, 2, \ldots, J)$$

Based on this model, efficiency is measured by dividing it into input-oriented and output-oriented values. The reason for separating input and output criteria is that the relative efficiency is measured differently depending on the criteria used. Input-based technology efficiency is focused on fixing the output value and the degree of reducing input proportionally.

However, output-based technology efficiency may identify how much the input value can be fixed, and the output can be expanded. This measures how much output can be increased compared to a relative set in an environment with fixed inputs. The results are divided into efficient groups and inefficient groups according to efficiency indicators obtained through input and output values. It has advantages of numerically providing results that may protect the decrease in savable resources and can increase outputs in decision making.

Various research has been conducted in the fields of ICT and R&D to measure relative efficiency. Beccheti et al. [68] conducted research on investment, productivity, and efficiency regarding ICT, and Lee et al. [69] performed efficiency analyses to obtain objective evidence concerning R&D investment. This suggests that decision makers provide clear justification and quickness for policymaking and resolve conflicts easily that may occur during the policy enforcement process, in addition to the need to consider the possibility of creating new industries or economic effects.

Aristovnik [70] deduced the significance of ICT effects by measuring the effects of ICT on education performance in EU and OECD countries. Hawng et al. [71] measured the efficiency of the Royalty System to assert the R&D environment, a new approach from the perspective of open innovation. It deduced the potential improvement level of inefficient organizations and proposed direction.

Milana and Zeli [72] researched ICT impacts on productivity. Susiluoto [73] researched deviations from existing statistical approaches and expert opinion methods of ICT impact on the local economy. It has different meanings from the preceding studies in that it is necessary to consider the effect of enhancing efficiency. These results have many advantages over parametric methods, unlike traditional ratio analysis methods for evaluating the results [74].

It is divided into an efficient and inefficient group according to the efficiency index obtained through input and output values. It has the advantage of providing results numerically that may protect decreases in savable resource but can increase outputs in terms of decision making.

3.4. Tobit Regression

Tobit analysis is a model proposed by Tobin [75], which is a method used to analyze factors affecting the efficiency calculated by DEA. The basic model of Tobit analysis is presented based on the regression analysis model. Tobit analysis is used to correct situations in which the values of the regression analysis are outside 0 and 1.

If the predicted values do not proceed outside the boundary of a specific range, it corresponds with regression analysis. However, the efficiency calculated by DEA is only counted in a limited range between 0 and 1 for its characteristics of the analysis; thus, there is a limit that efficiency is distributed to a certain direction. Therefore, biased estimates or inappropriate inference results may be obtained if a general regression analysis model is applied [76,77]. Therefore, Tobit analysis is a suitable model if a dependent variable of the regression model is limited to a specific range of values [78].

$$E(\theta|z) = \sum \beta_k z_k \left[F\left(\frac{1-\sum \beta_k z_k}{\sigma}\right) - F\left(\frac{\sum \beta_k z_k}{\sigma}\right) \right] + \sigma \left[f\left(\frac{\sum \beta_k z_k}{\sigma}\right) - f\left(\frac{1-\sum \beta_k z_k}{\sigma}\right) \right] + \left[1 - f\left(\frac{1-\sum \beta_k z_k}{\sigma}\right) \right] \quad (3)$$

Partial differentiation equation z_m is deduced as follows to figure out if a certain causal variable affected efficiency.

$$\frac{\partial E(\theta|z)}{\partial z_m} = \beta_m \left[F\left(\frac{1 - \sum \beta_k z_k}{\sigma} \right) - F\left(\frac{-\sum \beta_k x_k}{\sigma} \right) \right] \quad (4)$$

Secondly, a decision factor is the degree that affects the increase and decrease in efficiency. The marginal effect of certain variables on the effective value must be calculated in a manner that meets the standard to identify the magnitude of influence. This study verifies what variables affect ICT production efficiency and further discusses how variables are influenced.

4. Analysis

4.1. Descriptive Statistics

The basic statistics of the input and output variables for the model suggested in this study are as shown in Table 3. The number of input and output variables is 134, which is consistent with the number of DMUs. The average value of the technology pillar of the input was 42.22. The country with the highest value was Switzerland (85.67), and the lowest country was DR Congo (6.45). For the people pillar, the average was 46.49. The country with the highest score of people was Denmark (80.81), whereas Chad scored the lowest (8.25). Governance pillar showed that Norway has the highest score (91.30). On the other hand, Yemen (16.95) received the lowest governance score. The governance pillar average was 56.92. The standard deviation of the inputs was shown to be similar between each pillar.

Table 3. Descriptive statistics of input and output variables.

Variable	DMU	Pillar	Min	Max	Mean
Input	134	Technology	6.45 (Congo, Dem. Rep)	85.67 (Switzerland)	42.22
	134	People	8.25 (Chad)	80.81 (Denmark)	46.49
	134	Governance	16.95 (Yemen)	91.30 (Norway)	56.92
Output	134	Impact	21.32 (Chad)	88.17 (Singapore)	52.34

The average impact of the output variables was 52.34. Singapore (88.17) showed the highest ICT impact score for the technology, people, and governance environment; however, Chad (21.32) showed the lowest score.

4.2. Efficiency Results by Country

As mentioned above, the DEA model may be distinguished by the CCR model and BCC model according to the assumption of the effect of scale. According to the purpose of measuring efficiency, it is distinguished by input-oriented model and output-oriented model. This study calculated efficiency values by applying both the CCR model and the BCC model and the efficiency of the scale. In addition, the calculation-oriented model was applied in the selection of input-oriented and output-oriented models. The results of calculating the efficiencies for each national income bracket are shown in Tables 4 and 5.

Table 4. Efficiency analysis results of 1st quartile high-income countries and 2nd quartile upper-middle-income countries.

1st Quartile High-Income Countries				2nd Quartile Upper-Middle-Income Countries			
DMU	**TE(CRS)** [(1)]	**PTE(VRS)** [(2)]	**SE** [(3)]	**DMU**	**TE(CRS)**	**PTE(VRS)**	**SE**
Australia	0.8616	0.8693(DRS)	0.9912	Argentina	0.9001	0.9008(DRS)	0.9992
Austria	0.8892	0.8893(IRS)	0.9998	Armenia	0.7814	0.8005(DRS)	0.9762
Belgium	0.9070	0.9071(IRS)	0.9999	Azerbaijan	0.8736	1.0000	0.8736(IRS)
Canada	0.8650	0.8706(DRS)	0.9937	Bahrain	0.7810	0.9224	0.8467(DRS)
Czech Republic	0.9428	0.9432(IRS)	0.9996	Belarus	0.9242	0.9244(DRS)	0.9998
Denmark	0.8501	0.8898(DRS)	0.9554	Brazil	0.8622	0.8632(DRS)	0.9989
Estonia	0.8520	0.8633(DRS)	0.9869	Bulgaria	0.7089	0.8222(DRS)	0.8622
Finland	0.8390	0.8573(DRS)	0.9787	Chile	0.7192	0.7736(DRS)	0.9297
France	0.9139	0.9168(DRS)	0.9969	China	0.7925	0.9154	0.8657(DRS)
Germany	0.9099	0.9171(DRS)	0.9921	Costa Rica	0.8561	0.8960(DRS)	0.9555
Hong Kong	0.9178	0.9408(DRS)	0.9755	Croatia	0.8305	0.8816(DRS)	0.9420
Iceland	0.8886	0.9628	0.9229(IRS)	Cyprus	0.7739	0.9419	0.8216(DRS)
Ireland	1.0000	1.0000	1.0000	Greece	0.7115	0.8474	0.8395(DRS)
Israel	0.9390	0.9726	0.9655(IRS)	Hungary	0.7809	0.9511	0.8210(DRS)
Italy	0.9619	1.0000	0.9619(IRS)	Kazakhstan	0.9407	0.9423(DRS)	0.9982
Japan	0.9576	0.9644(IRS)	0.9929	Kuwait	0.8628	0.8969(DRS)	0.9620
Korea, Rep.	0.9239	0.9355(DRS)	0.9877	Latvia	0.7436	0.9033	0.8232(DRS)
Lithuania	0.8633	0.8723(DRS)	0.9897	Mauritius	0.8367	0.8430(DRS)	0.9925
Luxembourg	0.8676	0.8679(DRS)	0.9996	Mexico	1.0000	1.0000	1.0000
Malaysia	1.0000	1.0000	1.0000	Montenegro	0.7217	0.7872(DRS)	0.9169
Malta	0.9992	1.0000	0.9992(IRS)	North Macedonia	0.8193	0.8195(DRS)	0.9998
Netherlands	0.8835	0.9218(DRS)	0.9585	Oman	0.9640	0.9657(DRS)	0.9982
New Zealand	0.8500	0.8586(DRS)	0.9900	Qatar	0.8159	1.0000	0.8159(DRS)
Norway	0.8888	0.9005(DRS)	0.9870	Romania	0.8010	0.9120	0.8783(DRS)
Poland	1.0000	1.0000	1.0000	Russia	0.7691	0.8370(DRS)	0.9188
Portugal	0.9105	0.9794	0.9296(IRS)	Saudi Arabia	0.7263	0.8381(DRS)	0.8666
Singapore	1.0000	1.0000	1.0000	Serbia	0.8232	0.8668(DRS)	0.9497
Slovenia	0.9466	0.9489(IRS)	0.9976	Slovakia	0.7933	0.9714	0.8166(DRS)
Spain	0.8960	0.8961(IRS)	0.9999	Thailand	0.8196	0.8776(DRS)	0.9339
Sweden	0.8786	0.9100(DRS)	0.9655	Turkey	0.7656	0.7681(DRS)	0.9968
Switzerland	0.9540	0.9716(DRS)	0.9819	Ukraine	0.7896	0.7912(DRS)	0.9981
UAE	0.9166	0.9563(DRS)	0.9584	Uruguay	0.8027	0.8795(DRS)	0.9126
United Kingdom	0.8927	0.8954(DRS)	0.9970	Viet Nam	1.0000	1.0000	1.0000
United States	0.8180	0.8354(DRS)	0.9792	Mean	0.8209	0.8891	0.9245
Mean	0.9113	0.9269	0.9833	Std.	0.0777	0.0677	0.0674
Mean	0.9113	0.9269	0.9833	2nd Quartile	CRS: 2, DRS: 10, IRS: 1/PTE: 21, SE: 10		
1st Quartile	CRS: 4, DRS: 17, IRS: 13/PTE: 25, SE: 5			(Returns to scale) indicate the cause of the inefficiency			

(1) Technical efficiency; (2) pure technical efficiency; (3) scale efficiency score.

In the CCR model, 12 out of all countries were found to be effective. The results by income bracket are as follows. For CCR model, the average technology efficiency (TE) of high-income countries was calculated as 0.91. Countries with an efficiency value of 1 were Ireland, Malaysia, Poland, and Singapore. The average TE of upper-middle-income countries was 0.82, and the countries with an efficiency value of 1 were Mexico and Vietnam. In lower-middle-income countries, El Salvador and Lao PDR showed an efficiency of 1 with an average efficiency value of 0.75. It was confirmed that Chad, DR Congo, Ethiopia, and Yemen of low-income countries have been efficiently operating. The average TE for low-income countries was 0.71. According to the average value of TE in each country, upper-middle-income countries have the highest value; however, low-income countries have the lowest average TE.

In the BCC model, 21 out of all countries were found to be effective. Considering the income bracket, Malta and Italy were added as high-income countries, including countries with a TE of 1. The pure technical efficiency (PTE) average was 0.93. In upper-middle-income countries, the PTE average was 0.89. Azerbaijan and Qatar have emerged as efficient countries, including Mexico and Vietnam. Lower-middle-income countries included Bolivia, Philippines, and Ghana, including countries with a TE of 1. The PTE average for lower-middle-income countries was 0.85. Lastly, low-income countries included Chad, DR Congo, Ethiopia, Yemen, Venezuela, and Guatemala; a total of six countries were found to have a PTE of 1. Low-income countries showed an average of 0.88. Thus, the average value of PTE in the BCC model was higher in the group of low-income countries than in the group of lower-middle-income countries.

Table 5. Efficiency analysis results of 3rd quartile lower-middle-income countries and 4th quartile low-income countries.

3rd Quartile Lower-Middle-Income Countries				4th Quartile Low-Income Countries			
DMU	**TE(CRS) (1)**	**PTE(VRS) (2)**	**SE (3)**	**DMU**	**TE(CRS)**	**PTE(VRS)**	**SE**
Albania	0.7471	0.8448(DRS)	0.8844	Algeria	0.6459	0.9274	0.6964(DRS)
Bolivia	0.9042	1.0000	0.9042(I)	Angola	0.6949	0.7426(DRS)	0.9359
Bosnia *	0.7592	0.8410(DRS)	0.9027	Bangladesh	0.6851	0.9793	0.6996(DRS)
Botswana	0.7256	0.7369(DRS)	0.9847	Benin	0.6236	0.8130	0.7671(DRS)
Cabo Verde	0.7836	0.8838(DRS)	0.8867	Burkina Faso	0.9171	0.9831	0.9329(DRS)
Colombia	0.6895	0.8669	0.7953(DRS)	Burundi	0.9071	0.9945	0.9121(DRS)
Dominican, Rep.	0.7544	0.8764	0.8609(DRS)	Cambodia	0.6940	0.9803	0.7079(DRS)
Ecuador	0.8370	0.9155	0.9142(DRS)	Cameroon	0.5905	0.7673(DRS)	0.7696
Egypt	0.7277	0.8275(DRS)	0.8794	Chad	1.0000	1.0000	1.0000
El Salvador	1.0000	1.0000	1.0000	Congo *	1.0000	1.0000	1.0000
Georgia	0.5430	0.7604	0.7141(DRS)	Côte d'Ivoire	0.5651	0.7714	0.7325(DRS)
Ghana	0.7748	1.0000	0.7748(IRS)	Eswatini	0.6379	0.8006	0.7968(DRS)
India	0.5675	0.6847(DRS)	0.8288	Ethiopia	1.0000	1.0000	1.0000
Indonesia	0.6773	0.8708	0.7778(DRS)	Gambia	0.6754	0.8667	0.7792(DRS)
Iran, Islamic Rep	0.6763	0.7699(DRS)	0.8785	Guatemala	0.7037	1.0000	0.7037(DRS)
Jamaica	0.7808	0.9424	0.8286(DRS)	Guinea	0.6873	0.9096	0.7556(DRS)
Jordan	0.6270	0.7931	0.7905(DRS)	Honduras	0.6631	0.9571	0.6928(DRS)
Kenya	0.7347	0.7612(DRS)	0.9652	Lesotho	0.6999	0.8542	0.8194(DRS)
Kyrgyzstan	0.8897	0.8989(DRS)	0.9898	Madagascar	0.7383	0.8879	0.8315(DRS)
Lao PDR	1.0000	1.0000	1.0000	Malawi	0.9741	0.9861(DRS)	0.9878
Lebanon	0.6130	0.7258(DRS)	0.8446	Mali	0.7814	0.9453	0.8266(DRS)
Moldova	0.6846	0.8734	0.7838(DRS)	Mozambique	0.6180	0.7280(DRS)	0.8489
Mongolia	0.8219	0.8658(DRS)	0.9493	Namibia	0.5447	0.8453	0.6444(DRS)
Morocco	0.6622	0.7579(DRS)	0.8737	Nepal	0.5913	0.8309	0.7116(DRS)
Panama	0.7788	0.8930	0.8721(DRS)	Nigeria	0.5748	0.7304(DRS)	0.7870
Paraguay	0.9557	0.9557(DRS)	1.0000	Pakistan	0.5843	0.8567	0.6820(DRS)
Peru	0.7601	0.8609(DRS)	0.8829	Tajikistan	0.6529	0.9411	0.6938(DRS)
Philippines	0.8772	1.0000	0.8772(DRS)	Tanzania	0.6161	0.8185	0.7527(DRS)
Rwanda	0.7386	0.7632(DRS)	0.9678	Uganda	0.5146	0.7133(DRS)	0.7214
Senegal	0.7646	0.7650(IRS)	0.9995	Venezuela	0.7630	1.0000	0.7630(DRS)
South Africa	0.5480	0.6776(DRS)	0.8088	Yemen	1.0000	1.0000	1.0000
Sri Lanka	0.8067	0.8884(DRS)	0.9081	Zambia	0.6079	0.7803	0.7790(DRS)
Trinidad *	0.7355	0.8503(DRS)	0.8650	Zimbabwe	0.4348	0.5555(DRS)	0.7827
Tunisia	0.6645	0.7479(DRS)	0.8885	Mean	0.7087	0.8778	0.8035
Mean	0.7533	0.8500	0.8848	Std.	0.1532	0.1114	0.1066
Std.	0.1128	0.0925	0.0745	4th Quartile	CRS: 4, DRS: 29 / PTE: 7, SE: 22		
3rd Quartile	CRS: 2, DRS: 29, IRS: 3 / PTE: 20, SE: 12			(Returns to scale) indicate the cause of the inefficiency			

(1) Technical efficiency; (2) pure technical efficiency; (3) scale efficiency score. * Bosnia and Herzegovina, Trinidad, and Tobago, Congo, Dem. Rep.

4.3. Returns to Scale Analysis Results

The results of CCR and BCC models were applied to measure the scale efficiency of the output variable to figure out economies of scale. In the "Returns to Scale" column of Tables 4 and 5, constant returns to scale (CRS), increasing returns to scale (IRS), or decreasing returns to scale (DRS) may be distinguished. Economy of scale is important for efficient management. Not all countries operate efficiently by increasing the input. We need to classify, and act based on the state of economy of scale of current countries. In economy of scale, it is effective to maintain the current state of CRS. The state of DRS refers to no change in output despite an increase in input. Countries in a state of decreasing scale should consider maintaining current output by decreasing input rather than increasing it. The state of IRS refers to a state in which output increases when input increases. Countries that fall under this need to increase input and consider states where output increases with input.

High-income countries of Ireland, Malaysia, Poland, and Singapore have experienced CSR optimal economies or reached optimal conditions. In DRS, 17 countries showed low ICT impact results compared to input. Thirteen countries in the state of IRS showed output growth of ICT impact results as high scores. Since the increased output rate is higher than that of ICT environment input, increasing input of production factors may be efficient in improving efficiency. On the other hand, countries in other positions need to scale down because they are in a state of DSR. However, it is necessary to interpret it with a method of operating and managing the ICT environment as efficient rather than reducing the scale (Table 4).

The upper-middle-income countries of Mexico and Vietnam were the most efficient because their technical efficiency (TE), pure technical efficiency Score (PTE), and scale efficiency (SE) showed 1. In DSR, 30 countries, including Argentina, showed low ICT impact results. Countries with low NRI efficiency compared to input should consider ICT environments. On the other hand, only Azerbaijan was the country in a higher IRS state than optimal state only; therefore, a strategy to increase the ICT environment should be constructed. Upper-middle-income countries were found to be an inefficient group in overall output results compared to inputs. Therefore, we need a strategy to find methods in which the ICT input environment may affect the output and methods to improve outputs compared to inputs (Table 4).

In lower-middle-income countries, El Salvador and Lao PDR showed a constant state. For upper-middle-income countries, 29 countries including Albania were found to be DRS where inefficient causes are originated by the ICT environment. According to IRS, Bolivia, Ghana, and Senegal were found to have high ICT impact. In the state of high output, countries need to find a strategy to increase the input environment (Table 5).

Low-income countries including Chad, DR Congo, and Ethiopia, and Yemen showed the economy of scale as the optimal state. This study identified that countries in "Constant" state were found more in low-income countries than in upper-middle-income or lower-middle-income countries. In low-income countries, IRS have not been found, and 29 other countries, except those that remained as "Constant," must consider the ICT environment of DRS (Table 5).

Considering the returns to scale of countries by income, 105 countries showed DRS, 17 countries showed IRS, and 12 countries were optimal in TE and PTE, and SE. The group of high-income countries made good use of the ICT environment and increased ICT impact. It has been confirmed that countries with IRS have consideration for expansion and investment in the ICT environment at a high level compared to those of other groups. In other words, the higher the income group, the more efficient the ICT environment. The results considering the country's input environment show efficient results of operation. Therefore, an informatization strategy is required, which considers the relationship between the efficient operation of resources and ICT impact.

4.4. Factors Affecting ICT Network Readiness Efficiency

As mentioned above, Tobit analysis is a model proposed by Tobin [75], which is a method used to analyze factors affecting the efficiency calculated by DEA. Examples of research applying Tobit analysis to verify efficiency may be found in various research fields. Hsu and Hsueh [79] pointed out that existing efficiency analysis methods do not consider external environmental influences and, therefore, applied the Tobit model to analyze environmental factors. Tobit regression analysis was applied to examine external environmental factors of projects or policies with high efficiency. It is significant in identifying external factors that affect ICT efficiency. An efficient approach that considered the external environment reduced the problem of extensive efficiency.

Twelve Global Competitiveness Indexes, which are expected to affect ICT efficiency, country's population, GDP per capita, 10-year average annual GDP growth, and 5-year average FDI inward flow (GDP Environmental), were selected as external environmental factors to conduct Tobit analysis. The analysis results of the regression model are shown in Table 6 below [80].

Table 6. Results of Tobit regression analysis of impact factors for efficiency.

Construct	Factor	Scale	Estimate	z Value	Pr(>∣z∣)
High income countries	GDP growth (1)	0.0507	0.0212	2.992	0.003 ***
	GDP Environmental (2)	0.0523	0.0019	2.258	0.024 **
	Institutions	0.0512	−0.0035	−2.493	0.013 **
	Skills	0.0476	−0.0056	−3.478	0.001 ***
	Business dynamism	0.0520	−0.0036	−2.246	0.025 **
Upper-Middle income countries	Institutions	0.0771	−0.0054	−1.967	0.049 **
	Skills	0.0753	−0.0049	−2.357	0.018 **
	Innovation capability	0.0773	−0.0037	−1.792	0.073 *
Lower Middle income countries	Population	0.1130	-1.619×10^{-4}	−1.887	0.059 *
	Institutions	0.0912	−0.0130	−4.809	1.52×10^{-6} ***
	Infrastructure	0.1104	−0.0068	−2.269	0.023 **
	Skills	0.1142	−0.0051	−1.773	0.076 *
	Financial system	0.1098	−0.0058	−2.349	0.019 **
	Market size	0.1113	−0.0027	−2.179	0.029 **
	Business dynamism	0.1074	−0.0074	−2.824	0.005 ***
	Innovation capability	0.0887	−0.0139	−5.067	4.04×10^{-7} ***
Low income countries	GDP per capita	0.1613	-4.272×10^{-5}	−2.073	0.038 **
	Institutions	0.1496	−0.0143	−3.253	0.001 ***
	Infrastructure	0.1487	−0.0093	−3.263	0.001 ***
	ICT adoption	0.1465	−0.0088	−3.486	0.001 ***
	Macro-economic stability	0.1623	−0.0035	−2.019	0.044 **
	Skills	0.1540	−0.0084	−2.793	0.005 ***
	Product market	0.1648	−0.0095	−1.832	0.067 *
	Labor market	0.1576	−0.0127	−2.573	0.010 **
	Financial system	0.1547	−0.0101	−2.783	0.005 ***
	Business dynamism	0.1428	−0.0129	−3.796	0.000 ***
	Innovation capability	0.1473	−0.0208	−3.369	0.000 ***

(1) 10-year average annual GDP growth (%); (2) year average FDI inward flow (%) GDP environment. Sign if. '***' 0.01 '**' 0.05 '*' 0.1.

As a result of the test, a total of five significant results were found in the group of high-income countries. As 10-year average annual GDP growth and 5-year average FDI inward flow (GDP Environmental) increased, it affected ICT efficiency. Global competitiveness factors impacted ICT efficiency as institutions, skills, and business dynamics decreased. These factors show that the more decreases there are in the group of high-income counties, the more positive effects there are on ICT efficiency. A total of three factors were found in the group of upper-middle-income counties. In the global competitiveness factor, it was found that the more decreases there are in institutions, skills, and innovation capability, the more meaningful the impacts are.

In the group of lower-middle-income countries, as population decreases, ICT efficiency showed more positive effects, and significant results were obtained in a total of eight global competitiveness factors, including institutions, infrastructure, skills, financial system, market size, business dynamism, and innovation capability. Lastly, in the group of low-income countries, 11 factors were found as the most influential factors; the same goes for the group of lower-middle-income countries. Specifically, it has been shown that institutions, infrastructure, ICT adoption, micro-economic stability, skills, product market, labor market, financial system, business dynamics, and innovation capability factors, including GDP per capita, affected ICT efficiency.

Institutions and skills were found to be common factors that significantly affect all brackets, and it was found that the more decreasing factors there are, the more positive effects there are.

5. Conclusions

5.1. Discusion

ICT promotes technology diffusion throughout society and influences economic activity from various angles. In a successful ICT environment, inefficient operating methods and marginal products are not guaranteed for effective growth. In other words, we need to recognize the limited resources pursued by economics and the efficiency of making the most efficient use of those resources. Optimal application of ICT resources overcomes marginal productivity and contributes to efficient economic growth.

Countries with similar environmental levels should be compared to increase ICT-oriented innovation competency. Relative comparison of countries with similar environment level is a significant factor for enhancing national competitiveness. Therefore, countries must confirm national ICT efficiency by comparing the results achieved with input resources. Governments must accurately assess whether their organizations are operating efficiently and recognize inefficiency problems. In addition, it has been confirmed that ICT operational efficiency is affected by factors necessary for global innovation.

Governments should benchmark other countries that operate efficiently in earning. Countries with similar earnings should manage their ICT operations by referring to each other's ICT environment and accessibility. According to the results of this study, it was confirmed that country requirements for benchmarking by earning were different. Additionally, external environmental factors affecting efficiency were also different. In other words, they must gain insights from efficiency analysis by applying DEA methodology for problem-solving.

The implications of this study are summarized as follows. First, 12 countries, including Singapore, showed an efficiency value of 1 in the CCR model. Twenty-one countries, including Italy, showed an efficiency value of 1 in the BCC model. Ireland, Malaysia, Poland, and Singapore, which are the first quartile high-income countries, show efficient ICT performances among countries with high incomes. Comparative countries should benchmark countries with efficient ICT operation management skills. They should promote ICT efficiency by considering factors that affect efficiency such as GDP growth, GDP environmental, institutions, skill, and innovation capability. For second quartile upper-middle-income countries, Mexico and Vietnam were identified as inefficient countries. To increase efficiency, environmental factors such as institutions, skills, and innovation capability should be considered.

For third quartile lower-middle-income countries, El Salvador and Lao PDR were confirmed to be more efficient than other comparative countries. Countries that require advancements in efficiency should improve by comparing El Salvador and Lao PDR. Furthermore, environmental factors such as population, institutions, infrastructure, skills, financial system, market size, business dynamism, innovation capability, etc., are important. Input and production were carried out efficiently for Chad, DR Congo, Ethiopia, Yemen, which are fourth quartile low-income countries. The selected countries indicate that ICT impact, which corresponds to ICT performances, environment, and accessibility, operates efficiently. Countries with low income should benchmark Chad, DR Congo, Ethiopia, and Yemen. External environments that affect efficiency were identified as GDP per capita, institutions, infrastructure, ICT adoption, macro-economic stability, skills, product market, etc.

About 9% of the countries among all the countries showed the optimal state of economy scale in terms of efficiency of scale. However, about 78% of countries showed DRS. This study identified problems that ICT environment was the excessive, or ICT impact was not efficiently operated. If the production rate is low, it is necessary to reduce input factors or improve excessive input environment. The relations between the input environment and ICT impact should be carefully examined and ICT adequacy and the environment should be established. Non-homogeneous ICT construction negatively impacted the purpose of use and the environmental industry, and active system construction must be arranged to increase effectiveness and productivity. IRS showed that about 13% of countries need to increase their inputs because their output scale is larger than their inputs. Countries with IRS may operate ICT impact efficiently if the ICT environment is increased or the investment in the ICT environment is increased.

Second, this study conducted a Tobit test for 12 external environmental variables, including 12 Global Competency Indices that may influence ICT efficiency, the population of the country, GDP per capita, 10-year average annual GDP growth, and 5-year average FDI inward flow (GDP Environmental) as well as 16 external environment variables including the four above. The analysis results showed the effect on all brackets of institution and skill factors. Specifically, in the group of high-income countries, five external factors, including 10-year average annual GDP growth (%), were found to affect ICT efficiency. As 10-year average annual GDP growth (%) and 5-year average FDI inward flow (GDP Environmental) increased, ICT efficiency more affected. Moreover, if countries with the highest income showed negative estimate values on institutions, skills, and business dynamics factors, it is effective to establish an ICT development strategy for those factors.

In the group of lower-middle-income countries, as the population decreases, ICT efficiency was influenced more. It may be interpreted as a result of problems or impacts that the ICT use in third-percentile income countries has not expanded, or partially developed environments do not meet Networked Readiness efficiency. In addition, it was found that many external factors in global competitiveness have more influences in the lower-middle-income countries and low-income countries than in other groups. The results, therefore, suggest that a country should consider the external environment to increase ICT efficiency in the future. It requires a country to build an efficient ICT environment by applying each country's national competitiveness factors and planning a strategic ICT influence suitable for the relevant field. We, therefore, found that more efforts are needed for an ICT environment that has not yet been fully established in the group of lower-middle-income and low-income countries. The group of these countries may have a successful ICT influence only by applying competitive strategies and ICT environments suitable for their own environments considering the matters.

Each government should plan a business model that improves ICT operationality and efficiency. It is necessary to seek ICT-oriented innovation strategies by selecting external environmental factor that will promote ICT efficiency. Considerations for the state of ICT operation, environment, accessibility, and infrastructure of efficient country must be conducted as well. In conclusion, we recognized that the improvements for the inefficiency problems must be incorporated. At the same time, an informatization strategy that considers the external environment must be preceded.

This study proposes relative efficiency values for the NRI issued by WEF in 2021. Furthermore, we verified external environmental factors affecting ICT efficiency. The study is significant because it proposes a method to improve ICT impact effectiveness that is relatively inefficient. Many countries have made persistent efforts to improve ICT development's positive effects on industry and the national economy. However, technological advances in the economy or delays in growth of factors of production factors must be addressed to ensure successful effectiveness and productivity.

The ICT environment is very significant for national competitiveness and competitive advantage in terms of results. These issues indicate that there is a need to examine resources and marginal products that are being operated inefficiently. The findings led us to find a measure that may solve growth delay and increase the marginal product. It is important to understand the level through relative comparison with external environmental factors to improve ICT application effectively. The differentiation of this study is analyzing efficiency and deriving impact factors by considering income levels in 134 countries.

5.2. Further Research and Limitations

This study compared effective operational performance with the NRI level announced by WEF. Therefore, it shows insights for planning future strategies to solve problems. Nevertheless, some limitations may arise. First, detailed grouping is required for objective and relative comparisons. Efforts are needed for relative comparison with competitive countries based on population, income, and specific environments. Second, standardized indicators that may measure the external ICT environment should be developed. If objective indicator development is preceded, many studies should find the cause of the problem by using an objective approach.

Based on the results of the study, we sought strategies to make an efficient country by considering the potential improvement level of countries with insufficient impact efficiency. This paper may be used as an important reference for ICT policy managers of the government to increase ICT efficiency and improve ICT impact quality performance that is necessary for national competitiveness. The result of the efforts will become the foundation for national growth along with the development of science technology through the integration of ICT technology, environment, governments, and people.

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