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DIGITAL CONVERGENCE AND DIVERGENCE IN EU AND ASEAN ECONOMIES

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ABSTRACT

This study examines the evolving digital economy in terms of convergence and divergence in European Union (EU) and Association of Southeast Asian Nations (ASEAN) countries over the period from 2010 to 2024, including the effects of the COVID-19 pandemic. This research uses a range of digital economy indices, including the ICT Development Index, E-Government Development Index, Online Service Index, Telecommunication Infrastructure Index, and Human Capital Index. It aims to identify and compare the patterns of convergence or divergence in digital indicators within and between the EU and ASEAN regions. The study employs beta convergence analysis, sigma convergence analysis, and difference-in-difference analysis to compare digital performance and assess the impact of the pandemic on the digital economy. By contrasting the digital development paths of the EU and ASEAN, the study provides insights into the digital gap and offers policy recommendations to promote more equitable digital development in both regions. The findings indicate that while the EU demonstrates more consistent convergence across digital indices, ASEAN exhibits both convergence and divergence, particularly during the post-pandemic period. The results reveal the urgent need for policy interventions aimed at reducing regional digital gaps, especially by enhancing digital infrastructure and improving human capital. This research offers valuable insights for policymakers in both regions, providing actionable strategies to foster inclusive digital development, enhance resilience in the face of global crises, and bridge the digital divide in an increasingly interconnected world.

Keywords: *Digital convergence, ICT development, Human capital, ASEAN-EU, Digital divide, COVID-19*

1. INTRODUCTION

Its The digital economy has been growing and expanding in recent years and it has become a major contributor to global development. COVID-19 pandemic and technology improvements have been the two significant factors driven the digital economy and transforming industries, governments, and society. This is especially true for the European Union (EU), where the digital economy has been widely adopted, making the region a major player globally. As a result, the European Union has established the Digital Economy and Society Index (DESI) to track and examine digitalization patterns in its member countries. Governments in the European Union

use this index to create policies aimed at improving digital integration and performance across the region.

In contrast to the European Union (EU), the Association of Southeast Asian Nations (ASEAN) is not part of the DESI database. Because of this reason, although the DESI has been a popular measure for analyzing digital trends within EU member states, it cannot be used as a standardized index to compare the level of digitalization between ASEAN countries or between the ASEAN and EU regions. However, several indices have been developed that include both ASEAN and EU countries in the database. These indices include the ICT Development Index, E-Government Development Index, Online Service Index, Telecommunication Infrastructure Index, and Human Capital Index. These indices enable a comparative analysis on the level of digitalization between EU and ASEAN countries.

The purpose of this research is to analyze convergence or divergence trends in the digitalization level across the EU and ASEAN regions during the period from 2010 to 2024. This time frame was chosen to capture the impact of the COVID-19 pandemic on digital trends in both regions. The reason for including this impact is that the pandemic has been a major catalyst in accelerating the adoption and integration of digital technologies in both regions. By using a range of digital economy indices, this study seeks to uncover patterns of digital development within and between these two regions, providing a deeper understanding of how global challenges influence digital economies.

To achieve this purpose, the research is guided by the two main questions. First, to what extent has digitalization converged or diverged in the EU and ASEAN regions from 2010 to 2024? This question aims to explore the overall trends in digital development across the two regions, identifying whether countries within these regions are becoming more similar (convergence) or more distinct (divergence) in their levels of digitalization. Second, how has the COVID-19 pandemic influenced digital convergence or divergence within these two regions? This question focuses on the specific impact of the pandemic, examining whether it has accelerated or decelerated digitalization trends and how this impact varies between the EU and ASEAN. By addressing these questions, this research will enhance understanding of the digital divide between developed and developing regions and provide valuable insights for policymakers aiming to achieve equitable digital growth.

This research addresses key gaps in the current literature, particularly the lack of focus on how global crisis, the COVID-19 pandemic, impact digital convergence and divergence differently. While prior studies have examined digitalization trends within specific regions, they often overlooked the broader comparative perspective between regions at different stages of digital development. This study fills the gap by explicitly analyzing the role of the pandemic in shaping digitalization trajectories, contributing empirical evidence to the understanding of global digital economy dynamics. As a result, this study provides a significant contribution to the existing body of literature by offering a comprehensive comparative analysis of digital convergence and divergence trends in the EU and ASEAN regions. Unlike previous research, which often focuses on individual regions or specific indices, this study uniquely integrates data from multiple digital economy indices: ICT Development Index, E-Government Development Index, Online Service Index, Telecommunication Infrastructure Index, and Human Capital Index. This approach presents a more holistic view of digitalization patterns and offers fresh insights into the dynamics of regional digital development.

The findings of this research have significant implications for policymakers in both the EU and ASEAN regions. This study helps to highlight the digital gaps between the EU and ASEAN regions and identifies areas where policy actions could help narrow these gaps. By means of pre- and post-pandemic data analysis, this study offers suggestions for improving digital

integration and ensuring that both regions fully benefit from the digital economy. The study provides practical recommendations for policymakers aiming to bridge the digital divide within and between the EU and ASEAN, promoting inclusive digital development. Moreover, the study pointed out the need for policies that enhance digital literacy and resilience, especially in the wake of the COVID-19 pandemic. Policymakers can use these findings to design strategies that address the specific challenges faced by different regions, ensuring that digital development efforts are both equitable and effective. Additionally, the study's results have broader implications for international organizations and global policymakers, providing a framework for understanding and addressing digital disparities on a global scale. The insights gained from this study can inform global policy frameworks, supporting efforts to promote sustainable and inclusive digital growth across diverse economic contexts. As such, the findings not only benefit the regions studied but also offer valuable lessons for other parts of the world facing similar digital challenges.

2. LITERATURE REVIEW

2. 1. OVERVIEW OF DIGITAL ECONOMY INDICES

The digital economy is an important component of current economic analysis, particularly in determining how technology affects growth and development across areas. Several indices have been created to monitor and compare the digital economy, with each focused on different aspects of digitalization. One of the most important indicators for digital economy analysis is the *ICT Development Index (IDI)* which is published by The International Telecommunication Union (ITU). The IDI is a composite index that measures the development of information and communication technology (ICT) across countries. The index is composed of different criteria such as population access to ICT, population use of ICT, and ICT skills of population in the country (ITU, 2017).

Another tool for assessing the digital economy is the World Bank's *Digital Adoption Index (DAI).* DAI looks at how much countries apply digital technologies in three key areas, which are businesses, government, and people (World Bank, 2016). Understanding how digital tools and platforms are being used in different industries is important for figuring out how digitalization is affecting the country's economy. However, the DAI data was only available during the year 2014-2016, so it was not included in the scope of this study.

The next useful indicator for digital economy is the *E-Government Index (EGI),* which is published by the United Nations. The EGI measures the preparedness and ability of national governments to utilize ICTs in providing public services (United Nations, 2020). This index assesses online e-government service provisions. It provides an overview of how well governments are embracing digital technologies. The EGI is composed of three sub-indices which are the Online Service Index (OSI), Telecommunication Infrastructure Index (TII) and Human Capital Index (HCI). The OSI measures the scope and quality of online services that governments provide to their citizens. The OSI evaluates the availability of essential public services through digital platforms, such as online tax filing, birth and death registrations, business licenses, and other key government services. It assesses not only the existence of these services but also their accessibility, ease of use, and integration with other government platforms. In addition, it examines whether these services are designed to be inclusive and reaching underserved populations such as rural communities or people with disabilities. High OSI scores indicate governments that are moving towards a more citizen-centric approach by offering seamless digital interactions that save time and reduce the need for in-person visits to government offices. The TII focuses on the physical and technological backbone necessary for digital services to thrive.

This sub-index measures the availability, quality, and accessibility of telecommunication networks, including internet access, broadband penetration, mobile subscriptions, and fixed telephone lines. A robust telecommunication infrastructure is critical for enabling the widespread use of digital government services and ensuring that citizens can access these services reliably. The TII highlights the importance of investments in national infrastructure to support digital connectivity, especially in remote and underserved regions. Countries with high TII scores typically have advanced telecommunications systems, high-speed internet, and widespread digital coverage, facilitating greater access to e-government services and fostering a more inclusive digital economy. Finally, the HCI measures the skills and knowledge that people in the country accumulate over the course of their lives. These skills and knowledge are essential for people to effectively live in the digital economy and benefit from it (World Bank, 2018). High HCI scores suggest that a country is well-equipped with a skilled and educated workforce. Since education and lifelong learning are important for economic growth, the HCI is essential for driving innovation and supporting the growth of digital economy.

In summary, the ICT Development Index (IDI) provides a comprehensive measure of digital readiness by assessing access to and use of information and communication technologies. In addition, the E-Government Development Index (EGI) measures governments' ability to utilize digital technologies to provide public services. The Online Service Index (OSI) assesses the availability and quality of government services delivered online. The Telecommunication Infrastructure Index (TII) measures the development and accessibility of the telecommunication infrastructure necessary for digital services. Finally, the Human Capital Index (HCI) focuses on the educational levels and skills of the population, determining their ability to engage with and benefit from digital services. All together, these indices offer a comprehensive overview of the digital economy, which allows for a comparative analysis of the digital trends across countries in EU and ASEAN. Understanding these indicators helps policymakers to assess digital success and identify areas where improvement can be done in both established and underdeveloped areas. This research takes these digital indicators to evaluate the digital economies of ASEAN and EU nations. In addition, the study also employs these indices to investigate if digital indicators are having convergence (moving closer together) or divergence (farther away). Finally, it investigates the impact of the COVID-19 epidemic on the digital trends in the two regions. The results would help generating policy recommendations for narrowing the digital gaps between ASEAN and EU regions.

2. 2. IMPACT OF COVID-19 ON THE DIGITAL ECONOMY

The COVID-19 pandemic has caused changes in a variety of sector and it has great impact on the digital economy. The epidemic's unexpected and broad disruptions pushed businesses, governments, and people to quickly adjust to a more digital-centric environment. This change has had significant consequences for digital economies across the world. However, regions across the world, especially The European Union (EU) and Southeast Asia, have responded differently to the challenges arisen from the epidemic. Driven by the necessity to preserve company continuity and public service delivery among lockdowns and social distance policies, the epidemic sped digital adoption across all sectors in the European Union.

Studies by Eurofound (2020) and the European Commission (2021) show that countries in the European Union have been through a substantial increase in the overall usage of digital technology. They have experienced notable rise in the level of remote working, e-commerce, and digital public services. With nations with better digital infrastructure and greater degrees of digital literacy managing the crisis more successfully, the DESI report emphasizes how the epidemic has underscored the need of digital resilience (European Commission, 2021).

In contrast, the ASEAN region faced more varied impacts. Although Southeast Asia similarly has been through digital transformation triggered by the COVID-19 pandemic, Southeast Asia has experienced different challenges. A study by Lim (2021) reveals that Southeast Asia had a sharp rise in digital adoption, especially in e-commerce and digital financial services. This is because consumers and businesses have shifted their activities to online platforms so that they can continue their operations during the lockdown. Unlike in the EU where the pandemic led to digital gap convergence, in Southeast Asia region, the digital divide widened during the pandemic. Disparities in digital infrastructure and access to technology across the countries have been increasing. As a result, there is different impact on different populations and economies within ASEAN (ASEAN Secretariat, 2020; Lim, 2021). While countries like Singapore and Malaysia saw rapid digital adoption, particularly in e-commerce and digital financial services, other countries with less developed digital infrastructure struggled. Lim (2021) notes that the digital divide in Southeast Asia widened during the pandemic, with significant disparities in access to technology and digital services between urban and rural areas.

Moreover, the pandemic has pointed out the significant role of digital technologies in ensuring economic resilience. In both the EU and Southeast Asia, digital sectors have shown greater resilience compared to more traditional sectors. For instance, a study by OECD (2020) showed that digital-intensive sectors in the EU, such as information and communication technology (ICT), experienced less economic contraction and quicker recovery compared to less digitalized sectors. Similarly, in Southeast Asia, countries with more developed digital infrastructures, like Singapore and Malaysia, have been more successful in mitigating the economic consequences of the pandemic (OECD, 2020).

In summary, the COVID-19 pandemic has significantly impacted the digital economies of the EU and Southeast Asia differently. Although it has similarly led to acceleration of digital adoption and more development of digital infrastructure and literacy. This study builds on these findings by offering a detailed analysis of how the pandemic has differentially affected digital convergence and divergence in the EU and ASEAN regions. By comparing these regions, the research provides insights into the factors that drive digital resilience and adaptability during global crisis. The study's focus on the differential impacts of COVID-19 adds depth to the existing literature, highlighting the importance of context-specific policies to address digital inequalities exacerbated by the pandemic.

2. 3. CONVERGENCE AND DIVERGENCE IN DIGITAL ECONOMIES

Convergence in economic growth has long been a topic of research, especially when it comes to regional differences in productivity and income levels. This concept has been expanded to the digital economy, where it is employed to analyze whether countries with lower initial levels of digital development are making progress in catching up with those that are more advanced. Convergence theories, such as Beta convergence, have been an important tool used in analyzing these trends.

Beta Convergence suggests that regions or countries with lower development tend to experience faster growth compared to more developed ones. This phenomenon will eventually result in a gradual narrowing of the economic performance gap. This perspective can be applied to evaluate digital indicators such the use of digital technology, internet penetration, and digital literacy. Empirical studies conducted by Solow (1956) and Barro and Sala-i-Martin (1992) have laid the groundwork for comprehending economic convergence. Expanding on this foundation, Sala-i-Martin (1996) conducted an empirical analysis that examined regional convergence in different countries. This analysis emphasized that convergence dynamics can be observed not only at the national level, but also within smaller regions. This is particularly applicable in today's fragmented digital landscapes.

Recent studies have expanded on this analysis to explore different aspects of digitalization, including internet usage, digital literacy, and the integration of digital technologies. For example, a study conducted by Balland and Rigby (2017) on the convergence of digital infrastructure in OECD countries uncovered that less technologically advanced nations have made notable progress. These results suggested a movement towards convergence. In a more recent study, Fernández-Portillo et al. (2020) investigated into the convergence of ICT development among EU countries. Their findings revealed a trend of convergence, especially in terms of the adoption of mobile technologies and internet access, despite the initial disparities.

Several research showed that countries with lower initial levels of digitalization are catching up with more digitally advanced nations, indicating Beta convergence. For example, Noh and Yoo (2008) conducted an analysis on the convergence of the ICT sector within the European Union. Their findings suggested that while digital convergence is occurring, the speed and scope of this convergence are greatly influenced by the starting conditions and national policies. In addition, a study by Kauffman and Kumar (2008) further supported these findings by showing that electronic commerce diffusion in the EU indicated signs of Beta convergence, especially among small and medium-sized enterprises. In a recent study conducted by Potluri et al (2020), it was discovered that there was an evidence of Beta convergence in the adoption of e-government services among EU member states. Their results suggested that countries with lower levels of digital public service integration initially have seen faster growth in this area compared to countries with higher initial levels. Another recent study conducted by Andrei et al. (2022) applied an analysis of Beta convergence in broadband adoption across European countries. Their findings confirmed that countries with lower initial broadband penetration rates experienced higher growth rates. This discovery provided support for the Beta convergence hypothesis.

On the other hand, the digital economy in Southeast Asia is quite different. While certain ASEAN countries, like Singapore and Malaysia, are making significant progress in digital development, others are falling behind, resulting in a combination of convergence and divergence evidence. Poushter's (2016) conducted an analysis focusing on the digital divides observed in emerging markets including various ASEAN countries. The study revealed that while there has been a general increase in internet access, there were notable disparities, especially among different socioeconomic groups. In addition, the study by Yue et al. (2019) explored the impact of digital literacy on promoting convergence within ASEAN. The results implied that not only infrastructure development is important but also improvements in digital literacy are essential to ensure that the benefits of digital advancements are distributed more equally. Expanding on this discussion, a recent study conducted by Rhee et al. (2022) shed light on the disparities in digital literacy and infrastructure among different ASEAN countries. The study suggested that if specific policy measures are not implemented, the digital gaps within the region may continue to grow. Furthermore, a study conducted by Phan (2023) supported these conclusions, revealing that the digital divide remains solid in Southeast Asia. The results from this study revealed notable discrepancies in the availability of digital technologies between urban and rural regions.

According to Fosu (2013), government policies could play a crucial role in reducing digital inequalities, especially in developing economies. Fosu supported the idea that inclusive policy frameworks are necessary for narrowing the digital gap in the countries. Similarly, Jorgenson and Vu (2016) suggested that government interventions in digital infrastructure and education have the potential to speed up the convergence process. By creating an environment that supports quick digital adoption and innovation, these interventions can have a significant impact on narrowing the gap. In a study conducted by Nguyen et al (2024), the importance of government policies in addressing these disparities was also emphasized. The study pointed out that countries that have implemented proactive digital strategies have made significant movements

in reducing the digital divide within the countries. These findings implied the importance of implementing specific policies that could foster digital development in underdeveloped regions. The government policies to narrow the gap could also promote digital equity on a broader scale. An examination of convergence in digital economies of these studies offers valuable insights into the efficacy of digital policies and the progress of digital development. Therefore, it is essential for policymakers to realize these trends in order to promote inclusive digital growth and bridge the digital gaps within and between regions.

While the existing literature provides a robust framework for analyzing digital economies, several gaps and inconsistencies remain. Previous studies often focus on digitalization trends within individual regions or countries, without offering a comparative perspective across regions with varying levels of digital development. For instance, much of the research on digital convergence has centered on developed regions like the EU, with less attention given to developing regions like ASEAN. This gap is significant because it overlooks how differences in economic development, governance, and infrastructure may influence digital convergence and divergence. Moreover, the literature has addressed the impact of global crisis, such as the COVID-19 pandemic, on digital development. While some studies have noted the acceleration of digitalization due to the pandemic, they often fail to explore how this impact varies between regions with different levels of digital infrastructure and readiness. This study contributes to the literature by systematically analyzing the differential impacts of the COVID-19 pandemic on digital convergence and divergence between the EU and ASEAN, addressing these gaps and providing new insights into how crisis can reshape digital landscapes.

3. DATA AND METHODOLOGY

The This study utilized data from five key indices to analyze digital economy trends in the 26 EU and 10 ASEAN countries from 2010 to 2024. ICT Development Index (IDI) was collected from the International Telecommunication Union (ITU) database. E-Government Development (EGI), Online Service Index (OSI), Telecommunication Infrastructure Index (TII), and Human Capital Index (HCI) were gathered from the United Nations (UN) database. In both the European Union and the ASEAN region, the transition to a post-COVID-19 period has been marked by significant changes. In the EU, many experts and institutions identified early 2022 as the point when restrictions began to ease and vaccination rates led to a return to normalcy (European Centre for Disease Prevention and Control [ECDC], 2022). Similarly, in the ASEAN region, countries started to adopt "living with COVID" strategies around late 2021 and into 2022 as vaccination rollouts progressed (BMC Public Health, 2022). In summary, the phases of the pandemic can be delineated as follows: the pre-COVID period, spanning 2010 to 2019; the COVID period, including 2020 to 2021; and the post-COVID period, beginning in 2022 and continue through 2024. Data from the five indices were gathered to analyze pre-COVID (2010-2019), COVID (2020-2021), and post-COVID-19 (2022-2024) digital trends to provide a comprehensive view of digital development in both regions.

The study employs beta convergence analysis, sigma convergence analysis, and difference-in-difference (DiD) analysis to evaluate the digital performance and assess the impact of the COVID-19 pandemic on digital economies in the regions. The selection of these methods is driven by their suitability for capturing the dynamics of digital development over time and across different regions.

Beta convergence analysis was performed to investigate whether countries with lower initial levels of digital development were catching up with more advanced countries. This method is employed for understanding the convergence and divergence of digitalization trends This

involved regressing the growth rate of digital indicators on their initial levels, with a negative coefficient indicating convergence. The analysis was conducted using a framework by Dogan and Kindap (2019):

$$\frac{1}{T} ln\left(\frac{y_{i,t+T}}{y_{i,t}}\right) = \alpha - \left(\frac{1-e^{-\beta T}}{T}\right) ln(y_{i,t}) + u_{i,t} \quad (1)$$

Where y is the level of digitalization of a country i, measured by the digital index at time t, and T is the length of observation interval. β measures the convergence rate and u is an error term. The existence of convergence can be detected by the negative value of γ.

$$ln\left(\frac{y_{i,t+T}}{y_{i,t}}\right) = \alpha + \gamma ln(y_{i,t}) + u_{i,t} \quad (2)$$

Where $\gamma = -\left(1 - e^{-T\beta}\right)$.

Subsequently, sigma convergence was used to serve as a robustness check for beta convergence results. Beta convergence refers to testing whether countries with lower initial levels of a particular measure tend to grow faster than those with higher initial levels, indicating a reduction in disparities over time. However, beta convergence alone does not confirm that overall disparities are decreasing. Sigma convergence complements this by examining the dispersion or spread of the measure across countries; a decrease in dispersion over time supports convergence. By using sigma convergence analysis alongside beta convergence, researchers can confirm that not only are poorer countries catching up, but overall inequality among countries is also diminishing, thereby reinforcing the reliability of convergence results.

Finally, to further ensure the robustness of these findings, the impact of the COVID-19 pandemic on digital economies was assessed using the Difference-in-Differences (DiD) method, which compared changes in digital indicators before and after the pandemic between the two regions. This method is employed to assess the differential impact of the COVID-19 pandemic on digitalization trends between the EU and ASEAN regions. The DiD model can be specified as:

$$Y_{it} = \varphi_0 + \varphi_1 Post_t + \varphi_2 Treat_i + \varphi_3 (Post_t * Treat_i) + \varepsilon_t \quad (3)$$

Where Y_{it} = Digital indicator for region i at time t, $Post_t$ = Indicator variable that equals 1 for the post-COVID period and 0 otherwise, $Treat_i$ = Indicator variable that equals 1 if the country is in the treatment group (EU) and 0 if in the control group (ASEAN), and $Post_t$ * $Treat_i$ = Interaction term that captures the DiD effect, which is the differential impact of COVID-19 on the treatment group relative to the control group. The coefficient on the interaction term () represents the DiD estimate, which is the additional effect of COVID-19 on the treatment group beyond what would have happened in the absence of the pandemic. A positive and significant indicates that the digital indicators improved more in the treatment group (EU) compared to the control group (ASEAN) due to the pandemic, and vice versa. DiD provides additional validation by accounting for time-invariant differences and capturing the effect of specific treatments or interventions. Through this comprehensive approach, the convergence analysis results are strengthened, confirming the reliability and consistency of observed trends. Data processing and statistical analysis were performed using the R programming environment version 4.4.1 (Race for Your Life).

4. ANALYSIS OF RESULTS

Subtitles Data of ICT Development Index (IDI), E-Government Index (EGI), Online Service Index (OSI), Telecommunication Infrastructure Index (TII), and HCI (Human Capital Index) were available for 26 countries in EU and 10 countries in ASEAN (Brunei Darussalam, Cambodia, Indonesia, Lao P.D.R., Malaysia, Myanmar, Philippines, Singapore, Thailand, and Viet-

nam). IDI data was available for the pre- and post-COVID period while EGI, OSI, TII, and HCI data was available for the pre- and COVID period. Table 1 shows the average annual growth rate of ICT Development Index in each region.

Table 1. Average annual growth rate of ICT Development Index in each region

Region	V0	Country	2010	2024	growth (pre)	growth (post)	growth (all)
ASEAN	Min	Myanmar	15.8	63.8	8.72%	-2.93%	9.97%
	Max	Singapore	71.2	97.8	1.75%	0.41%	2.27%
EU	Min	Poland	45.6	95.8	5.90%	1.26%	5.30%
	Max	Sweden	78.4	95.3	1.00%	1.48%	1.39%

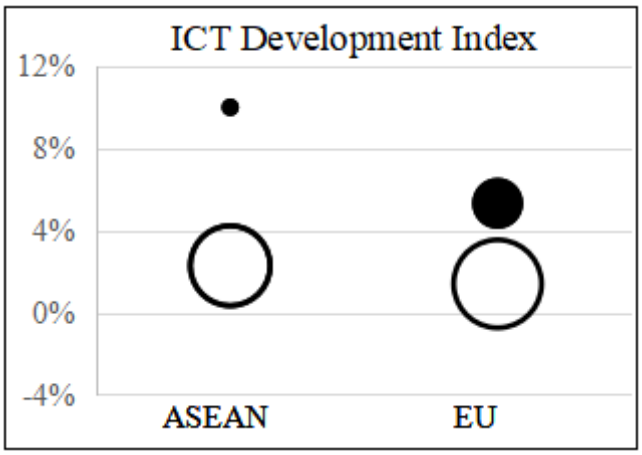
Source: Author's analysis based on data from ITU database

Table 1 provides a preliminary analysis of the average annual growth rate of the ICT Development Index (IDI) in ASEAN and EU regions, considering both pre-COVID and post-COVID periods. In the ASEAN region, the initial digital gap was significant, with Myanmar having the lowest IDI of 15.8 compared to Singapore's IDI of 71.2. Over the period from 2010 to 2024, Myanmar exhibited an impressive average annual growth rate of 9.97%, while Singapore's growth was modest at 2.27%. This suggests a reduction in the digital divide, as Myanmar appears to be catching up. The pre-COVID years highlight even more pronounced convergence, with Myanmar achieving an 8.72% growth rate compared to Singapore's 1.75%. However, in the post-COVID era, Myanmar faced a slight decline at -2.93%, while Singapore maintained steady growth at 0.41%, indicating a potential divergence likely due to pandemic-related challenges impacting Myanmar more severely.

Conversely, the EU region starts with an initial digital divide in 2010, with Poland having the lowest IDI at 45.6, whereas Sweden led with 78.4. Throughout the whole period, Poland demonstrated significant growth with a 5.30% average annual rate, outperforming Sweden's 1.39%, which suggests a notable narrowing of the digital gap within the EU. During the pre-COVID period, Poland's growth rate was robust at 5.90%, considerably higher than Sweden's 1.00%, reinforcing the convergence trend. Similarly in the post-COVID, both Poland and Sweden demonstrated resilience, with growth rates of 1.26% and 1.48%, respectively. This maintained the convergence trajectory, albeit at a slower pace. When comparing the ASEAN and EU regions, both exhibited convergence in the pre-COVID period, characterized by rapid improvements in countries with initially lower IDI levels. The ASEAN region showed pronounced convergence primarily due to Myanmar's rapid growth. However, the post-COVID analysis reveals differing narratives. The EU region sustained its convergence, reflecting stronger infrastructure and policy resilience. In contrast, ASEAN experienced divergence due to Myanmar's negative growth, highlighting varied pandemic impacts and recovery capacities.

Figure 1 illustrates the growth rates of the ICT Development Index (IDI) for both ASEAN and EU countries over a given period. The y-axis represents the growth rate of the IDI, while the size of the circles corresponds to the initial IDI levels in 2010. In each region, the solid circles indicate the countries with the lowest initial IDI values in 2010, while the white circles represent those with the highest initial IDI values. The figure visually demonstrates a key trend: countries that had lower initial IDI levels in 2010—represented by smaller circles—tend to exhibit higher growth rates over the period. Conversely, countries with higher initial IDI levels, depicted by larger circles, experienced lower growth rates. This highlights a typical catch-up effect, where less developed countries in terms of ICT tend to grow faster than their more developed counterparts, showing significant progress in closing the development gap.

Figure 1. Comparison of ICT Development Index Growth between ASEAN and EU Countries



Source: Author's analysis based on data from ITU database

Table 2 presents average annual growth rates in E-Government Index (EGI) and its three key indicators which are Online Service Index (OSI), Human Capital Index (HCI), and Telecommunication Infrastructure Index (TII) within ASEAN and EU regions. The table compares countries with the lowest and highest initial index values in each region from 2010 to 2022, including growth rates in pre-COVID and COVID periods.

Table 2. Average annual growth rate of Digital Index and its Component in each region

Index	Region	V0	Country	2010	2022	growth pre	growth COV	growth all
EGI	ASEAN	Min	Lao P.D.R.	0.2637	0.3764	1.84%	6.76%	2.97%
		Max	Singapore	0.7476	0.9133	2.06%	-0.09%	1.67%
	EU	Min	Romania	0.5479	0.7619	2.46%	0.09%	2.75%
		Max	Netherlands	0.8097	0.9384	0.98%	0.84%	1.23%
OSI	ASEAN	Min	Lao P.D.R.	0.0794	0.3005	9.28%	21.85%	11.10%
		Max	Singapore	0.6857	0.9647	4.54%	-0.14%	2.82%
	EU	Min	Italy	0.2889	0.8659	14.90%	2.15%	9.15%
		Max	Spain	0.7651	0.8559	2.54%	-1.85%	0.93%
TII	ASEAN	Min	Myanmar	0.0045	0.6082	50.57%	7.51%	40.91%
		Max	Singapore	0.6386	0.8899	2.85%	-0.80%	2.63%
	EU	Min	Romania	0.3093	0.7954	7.13%	2.37%	7.87%
		Max	Netherlands	0.7666	0.9620	0.15%	1.82%	1.89%
HCI	ASEAN	Min	Lao P.D.R.	0.6845	0.5468	-3.31%	-0.65%	-1.87%
		Max	Singapore	0.9203	0.8904	-0.91%	0.65%	-0.17%
	EU	Min	Malta	0.8870	0.8734	-1.33%	2.61%	-0.13%
		Max	Denmark	0.9933	0.9559	-0.59%	-0.15%	-0.32%

Note: EGI=E-Government Index, OSI=Online Service Index, TII=Telecommunication Infrastructure Index, and HCI=Human Capital Index.

Source: Author's analysis based on data from United Nation database

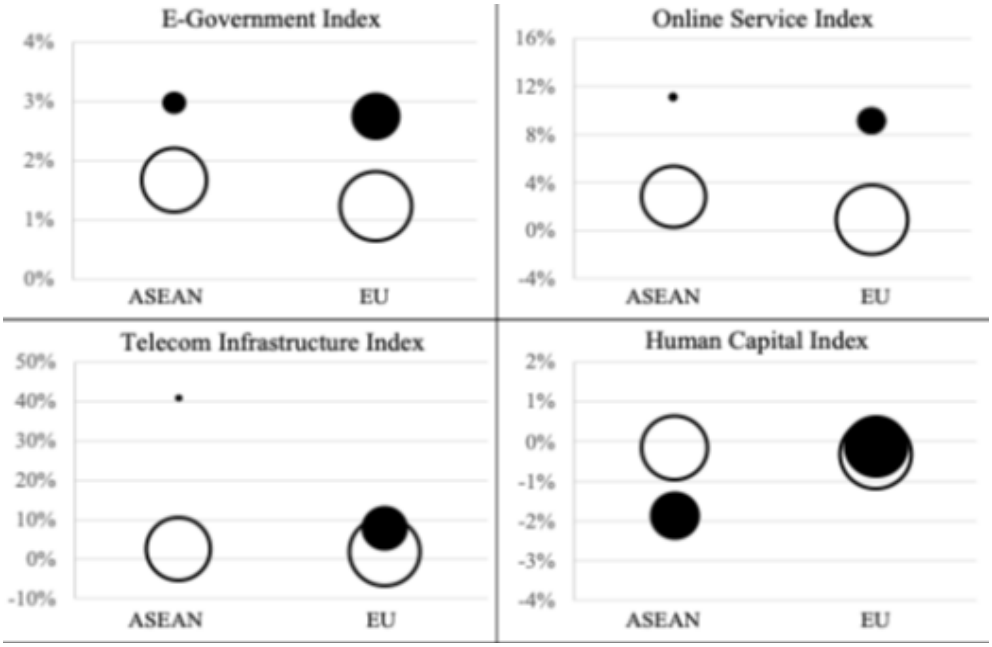
According to table 2, in the ASEAN region, EGI shows a significant initial gap, with Lao P.D.R. having the lowest index at 0.2637 and Singapore the highest at 0.7476. Lao P.D.R. exhibited a higher overall growth rate of 2.97%, compared to Singapore's 1.67%. Furthermore, during the COVID period, Lao P.D.R. showed remarkable growth at 6.76%, while Singapore growth was negative at -0.09%, indicating a trend toward convergence.

However, Within the EU region, an initial EGI gap is observed between Romania, with the lowest index at 0.5479, and the Netherlands, with the highest at 0.8097. Both countries showed strong overall growth, with Romania at 2.75% and the Netherlands at 1.23%, signifying convergence. Whereas the growth during the COVID period showed that Romania maintained positive growth at 0.09%, while the Netherlands exhibited a moderate growth of 0.30%. This divergence suggests that the pandemic may have adverse impacted Romania's e-government development.

Examining into each component of the EGI, the growth trends of OSI and TII in both ASEAN and EU reveal convergence for the overall period as well as for the COVID period. However, different pattern was observed for HCI. For the overall period, HCI in ASEAN had a divergence trend while HCI in EU had a convergence trend. Although both ASEAN and EU exhibited a divergence in the HCI during the pre-COVID period, ASEAN continued to have divergence in the HCI during the COVID period whereas EU showed a convergence in the HCI during the COVID period.

Figure 2 demonstrates the growth rates of four key indices—E-Government Index, Online Service Index, Telecom Infrastructure Index, and Human Capital Index—across ASEAN and EU countries. Each subplot in the figure presents the growth rate on the vertical axis, while the size of the circles represents the initial index levels in 2010. In each of the four subplots, the solid dark circles correspond to the countries in each region with the lowest initial index values, while the white circles correspond to those with the highest initial values. This visualization highlights a trend where countries with lower initial index levels tend to experience higher growth rates, indicating a catch-up effect, while countries with higher initial levels generally exhibit slower growth.

Figure 2. Growth Comparison of Digital Indices between ASEAN and EU Countries



Source: Author's analysis

Figure 2 indicates faster development in countries with initially lower values in E-Government Index and Online Service Index for both regions. The Telecom Infrastructure Index shows a significant disparity, with the less developed ASEAN country experiencing substantial growth, while more developed EU countries show moderate growth. Lastly, in the Human Capital Index panel, the growth rates were relatively low, and in some cases negative, for both regions,

especially in the ASEAN region, where the solid dark circle shows a substantial decline in Human Capital level. Overall, figure 2 demonstrates the relationship between initial index levels and growth rates, reinforcing the notion that less developed countries tend to catch up faster, while more developed countries experience slower growth across various ICT-related indicators. Table 3 to table 7 investigate into each index further and show the results from beta convergence analysis.

Table 3. Beta Convergence Results for The ICT Development Index (IDI)

IDI	Total Period			Pre_COVID			Post_COVID		
All	coef	-0.0013	***	coef	-0.0009	***	coef	-0.0013	***
	t	-28.2246		t	-12.5966		t	-2.7695	
	p	3.52E-25		p	2.32E-14		p	9.03E-03	
ASEAN	coef	-0.0013	***	coef	-0.0011	***	coef	-0.0012	
	t	-13.2336		t	-6.9663		t	-1.0634	
	p	1.01E-06		p	1.17E-04		p	3.19E-01	
EU	coef	-0.0010	***	coef	-0.0011	***	coef	-0.0015	*
	t	-14.7301		t	-8.9608		t	-2.0629	
	p	1.61E-13		p	4.00E-09		p	5.01E-02	

Note: ***=sig at 1%, **=sig at 5%, and *=sig at 10%

Source: Author's analysis

According to table 3, the presence of significant convergence for the entire period across all regions, including both the EU and ASEAN, indicates that countries with initially lower levels of ICT development experienced faster growth compared to their more developed counterparts. This suggests an overall trend towards reducing digital disparities globally and among these regions. Similar to the total period findings, the pre-COVID results show significant β-convergence across all regions. This indicates that the catch-up effect was active, with less digitally advanced countries making strides to close the gap with leading nations.

The post-COVID period reveals distinct patterns of β-convergence across regions. For the total regions and within the EU, significant convergence was observed, indicating that digital convergence persisted despite the pandemic's disruptive impact. This trend reflects how the accelerated digital transformation, driven by the necessity for remote work, online services, and enhanced digital communication during the pandemic, helped less digitally advanced countries continue catching up with their more developed counterparts. However, in the ASEAN region, the absence of significant convergence post-COVID suggests that the pandemic may have exacerbated existing digital disparities or introduced new challenges that hindered convergence. This lack of convergence in ASEAN implies that not all countries within the region equally benefited from the digital opportunities presented by the pandemic.

Table 4. Beta Convergence Results for The E-Government Development Index (EGI)

EGI	Total Period			Pre_COVID			COVID		
All	coef	-0.0597	***	coef	-0.0310	***	coef	-0.0839	***
	t	-9.4031		t	-2.8953		t	-3.9236	
	p	5.51E-11		p	6.57E-03		p	4.03E-04	
ASEAN	coef	-0.0560	**	coef	-0.0023	**	coef	-0.1383	**
	t	-3.2084		t	-0.0917		t	-2.8998	
	p	1.25E-02		p	9.29E-01		p	1.99E-02	
EU	coef	-0.0788	***	coef	-0.0826	***	coef	-0.0760	*
	t	-8.3165		t	-5.0598		t	-1.7902	
	p	1.58E-08		p	3.57E-05		p	8.60E-02	

Note: ***=sig at 1%, **=sig at 5%, and *=sig at 10%

Source: Author's analysis

The finding from table 4 shows significant convergence in the E-Government Development Index across all periods. It suggests that countries with initially lower levels of e-government development have been improving at a faster rate than those with higher initial levels. This consistent pattern over time indicates a global trend towards reducing disparities in e-government services and infrastructure. The significance of convergence across all regions implies a widespread movement towards more equal e-government capabilities. Both the EU and ASEAN show trends where less advanced countries in terms of e-government are catching up with more developed ones. This reflects successful global and regional efforts to promote digital governance, where countries have collectively been enhancing their public digital services.

Table 5. Beta Convergence Results for The Online Service Index (OSI)

OSI	Total Period			Pre_COVID			COVID		
All	coef	-0.1443	***	coef	-0.1393	***	coef	-0.1869	***
	t	-14.1003		t	-7.0486		t	-4.1236	
	p	9.14E-16		p	3.88E-08		p	2.27E-04	
ASEAN	coef	-0.1518	***	coef	-0.1018	**	coef	-0.2467	**
	t	-7.9666		t	-3.0917		t	-2.8289	
	p	4.50E-05		p	1.49E-02		p	2.22E-02	
EU	coef	-0.1414	***	coef	-0.2006	***	coef	-0.2069	**
	t	-8.8722		t	-7.0318		t	-2.7721	
	p	4.82E-09		p	2.86E-07		p	1.06E-02	

Note: ***=sig at 1%, **=sig at 5%, and *=sig at 10%

Source: Author's analysis

The convergence results for the Online Service Index in table 5 show similar results to those of the E-Government Development Index, demonstrate significant convergence across all periods and regions, including both the EU and ASEAN. This indicates a consistent trend of countries with initially lower levels of online service provision catching up with those more advanced in this area.

Table 6. Beta Convergence Results for The Telecommunication Infrastructure Index (TII)

TII	Total Period			Pre_COVID			COVID		
All	coef	-0.2903	***	coef	-0.3581	***	coef	-0.1026	***
	t	-8.1911		t	-7.4157		t	-5.9444	
	p	1.48E-09		p	1.34E-08		p	1.02E-06	
ASEAN	coef	-0.4253	**	coef	-0.5377	**	coef	-0.1313	**
	t	-3.2006		t	-2.9436		t	-2.8463	
	p	1.26E-02		p	1.86E-02		p	2.16E-02	
EU	coef	-0.1298	***	coef	-0.1442	***	coef	-0.1021	***
	t	-16.9573		t	-13.5859		t	-3.7621	
	p	7.30E-15		p	9.19E-13		p	9.59E-04	

Note: ***=sig at 1%, **=sig at 5%, and *=sig at 10%

Source: Author's analysis

Table 6 shows the significant convergence of the Telecommunication Infrastructure Index across all periods and all regions, shows a widespread equalization in telecommunication infrastructure development. This indicates that countries with initially lower levels of telecommunication infrastructure are effectively catching up, reducing disparities in connectivity and access to telecommunication services. This trend reflects effective global and regional efforts to enhance digital connectivity and promote infrastructure investments.

Table 7. Beta Convergence Results for The Human Capital Index (HCI)

HCI	Total Period			Pre_COVID			COVID		
All	coef	0.0612	(***)	coef	0.0972	(***)	coef	-0.0335	*
	t	7.9399		t	7.3404		t	-1.8706	
	p	3.00E-09		p	1.66E-08		p	7.00E-02	
ASEAN	coef	0.0625	(***)	coef	0.0833	(**)	coef	-0.0632	
	t	4.1630		t	2.3754		t	-1.2210	
	p	3.15E-03		p	4.49E-02		p	2.57E-01	
EU	coef	0.0267		coef	0.1037	(***)	coef	-0.0420	
	t	1.0790		t	2.8601		t	-1.1168	
	p	2.91E-01		p	8.63E-03		p	2.75E-01	

Note: ***=sig at 1%, **=sig at 5%, and *=sig at 10%

Source: Author's analysis

The result from table 7 indicates the significant divergence in human capital development across all regions and specifically in ASEAN over the entire period. This result implies that disparities in digital skills and education levels have widened. This suggests that countries with initially lower levels of digital human capital have struggled to keep pace with those more advanced, possibly due to inadequate investments in education, training, and digital literacy. However, the lack of significant divergence in the EU for the overall period suggests relative stability in the disparities among member countries, possibly due to more cohesive educational policies and investments in digital skills across the region, although it did not result in convergence.

The pre-COVID period exhibits significant divergence in human capital across all measured regions, including the EU and ASEAN. This indicates that before the pandemic, differences in developing digital skills were increasing, potentially driven by varying national priorities, resource constraints, or differing levels of commitment to integrating digital competencies in education and labor markets. On the contrary, the shift to significant convergence of human capital during the COVID-19 pandemic suggests that the intense demand for digital skills prompted widespread efforts to enhance human capital. This period likely saw increased investments in digital infrastructure, education technologies, and online learning platforms, which facilitated more rapid improvement in digital skills across less developed countries. The lack of significant convergence specifically in ASEAN and the EU during the COVID period implies that while global trends showed convergence, these regions did not experience uniform gains in human capital development. Structural challenges, varying national responses to the pandemic, and pre-existing disparities may have influenced this outcome. Table 8 summarizes the significance of results from beta convergence analysis.

Table 8. Significance of Beta Convergence (Divergence) Coefficients

	All	EU	ASEAN	All	EU	ASEAN	All	EU	ASEAN
	Total Period			Pre-COVID			Post-COVID		
IDI	***	***	**	***	***	***	***	*	°
	Total Period			Pre-COVID			COVID		
EGI	***	***	**	***	***	°	***	*	**
OSI	***	***	***	***	***	**	***	**	**
TII	***	***	**	***	***	**	***	***	**
HCI	(***)	°	(***)	(***)	(***)	(**)	(*)	°	°

Note: IDI=ICT Development Index, EGI=E-Government Index, OSI=Online Service Index, TII=Telecommunication Infrastructure Index, and HCI=Human Capital Index. *** = sig at 1%, ** = sig at 5%, * = sig at 10%, and ° = not significant. ( ) = divergence

Source: Author's own analysis

Table 8 illustrates the significance of beta convergence (or divergence) coefficients for various digital indices across different regions and time periods. IDI and EGI both show strong convergence trends across all regions and time periods, particularly at the 1% significance level. However, there are notable exceptions. For IDI, ASEAN does not show significant convergence in the post-COVID period (◦), indicating a lack of convergence in digital development for this region after the pandemic. Similarly, EGI shows a lack of significance for ASEAN in the pre-COVID period (◦), suggesting that convergence in e-government development was not as strong in this region before the pandemic. This evidence indicated that COVID pandemic had a favorable impact on EGI convergence in ASEAN, while it had an adverse impact on the IDI convergence in ASEAN.

In contrast, both the OSI and the TII display significant convergence across all regions and time periods. Regardless of whether it was the total period, pre-COVID, or during the COVID period, these two indices consistently exhibit strong convergence trends. This highlights the global and regional resiliance to expand online services and improve telecommunication infrastructure, which were particularly critical during the pandemic.

Finally, the HCI presents an opposite trend compared to the other indices, as it shows divergence rather than convergence. For the total period and pre-COVID, HCI displays significant divergence, indicating widening gaps in human capital development. Even during the COVID period, HCI continues to show less significance in convergence trends, unlike other indices which show strong convergence patterns. This divergence in human capital development contrasts with the more consistent convergence seen in digital infrastructure and service indices, highlighting disparities in education and skills development across different regions. However, an important observation is that during the COVID period, the divergence in HCI disappeared in both regions. This shift implied that the pandemic might have led to increased efforts in education and skills development, possibly due to the increased reliance on digital skills and online learning during the crisis. This diminished divergence suggested that the EU and ASEAN responded to COVID-19 accelerated improvements in human capital, therefore narrowing the previous gaps.

Table 9. Significance of Sigma Convergence (Divergence) Coefficients

Index	Region	Coefficient	R^2	t	p	sig
IDI	ASEAN	-0.0250	0.9703	-14.0098	8.25E-06	***
	EU	-0.0077	0.9859	-20.4856	8.80E-07	***
EGI	ASEAN	-0.0081	0.3975	-1.9898	9.37E-02	*
	EU	-0.0055	0.7729	-4.5187	4.02E-03	***
OSI	ASEAN	-0.0254	0.8560	-5.9721	9.88E-04	***
	EU	-0.0131	0.7440	-4.1762	5.84E-03	***
TII	ASEAN	-0.0591	0.9816	-17.8713	1.97E-06	***
	EU	-0.0181	0.9620	-12.3261	1.74E-05	***
HCI	ASEAN	0.0061	0.6365	3.2413	1.77E-02	(**)
	EU	0.0026	0.5538	2.7290	3.42E-02	(**)

Note: IDI=ICT Development Index, EGI=E-Government Index, OSI=Online Service Index, TII=Telecommunication Infrastructure Index, and HCI=Human Capital Index. ***=sig at 1%, **=sig at 5%, *=sig at 10%, and ° =not significant. ( )=divergence

Source: Author's own analysis.

Table 9 presents the results of sigma convergence (divergence) for various digital indices, providing insights into the degree to which digital indicators have converged or diverged within

the EU and ASEAN regions over the study period. Sigma convergence measures the reduction in the dispersion of a variable across countries, indicating whether gaps between countries in digital development are closing over time.

For the ICT Development Index (IDI), both ASEAN and EU regions exhibit significant sigma convergence, with negative coefficients for both regions (-0.0250 for ASEAN and -0.0077 for the EU), indicating that countries with lower initial digital development are catching up with more advanced countries. The high R-squared values (0.9703 for ASEAN and 0.9859 for the EU) suggest a strong convergence trend.

The E-Government Index (EGI), Online Service Index (OSI), and Telecommunication Infrastructure Index (TII) all exhibit significant sigma convergence in both the ASEAN and EU regions, indicating that countries with lower initial levels of digital development in these areas are catching up with their more advanced counterparts. In ASEAN, the coefficients for EGI (-0.0081), OSI (-0.0254), and TII (-0.0591) are all negative and significant, suggesting a steady reduction in disparities in government services, online services, and telecommunications infrastructure across the region. Similarly, the EU displays significant convergence for these indices, with coefficients of -0.0055 for EGI, -0.0131 for OSI, and -0.0181 for TII, reflecting the same trend of narrowing digital gaps within the EU. These results confirm successful efforts in both regions to enhance public digital services, expand online service availability, and improve telecommunications infrastructure, particularly during the COVID-19 pandemic.

In contrast, the Human Capital Index (HCI) reveals sigma divergence in both ASEAN and the EU, with positive coefficients (0.0061 for ASEAN and 0.0026 for the EU). This divergence indicates that disparities in digital skills and education levels have widened over time, unlike the convergence observed in other digital indicators. The positive coefficients suggest that countries with initially lower levels of human capital have not managed to keep pace with those with more advanced educational and digital skillsets, pointing to a growing digital divide in terms of human capital. This divergence stands in evident contrast to the convergence trends seen in the other indices, suggesting that more focused efforts are needed to address disparities in digital skills and education.

The results from the sigma convergence analysis are aligned with the findings from the beta convergence analysis, further confirming the robustness of the study's conclusions. Both methods demonstrate significant convergence for the IDI, EGI, OSI, and TII in both the EU and ASEAN regions, indicating a consistent reduction in disparities in ICT development, e-government development, online services, and telecommunications infrastructure across countries. The consistency between the two analyses supports the conclusion that countries with initially lower digital development in these areas are catching up with their more advanced counterparts. Similarly, the divergence observed in the HCI across both analyses highlights growing disparities in human capital development, reinforcing the need for targeted policy interventions in digital skills and education. Altogether, the convergence trends confirmed by both sigma and beta analyses provide strong evidence of digital progress in infrastructure and services, while signaling persistent gaps in human capital.

Table 10. Difference-in-Difference Analysis of the COVID-19 impact on Digital Indicators

		Post*EU		EU		Post		Intercept
IDI	Coefficient	0.0034		-0.0186	**	-0.0141		0.0447
	t	0.3024		-2.3167		-1.4646		
	p	7.63E-01		2.35E-02		1.48E-01		
		COVID*EU		EU		COVID		Intercept
EGI	Coefficient	-0.0028		-0.0049		-0.0170	**	0.0313
	t	-0.2964		-0.7732		-2.2247		
	p	7.68E-01		4.43E-01		3.00E-02		
OSI	Coefficient	0.0112		-0.0168		-0.0763	***	0.0900
	t	0.4218		-0.9328		-3.5192		
	p	6.75E-01		3.55E-01		8.49E-04		
TII	Coefficient	0.1126	***	-0.1325	***	-0.1433	***	0.1713
	t	3.4412		-5.9691		-5.3730		
	p	1.08E-03		1.53E-07		1.43E-06		
HCI	Coefficient	-0.0186	***	0.0136	***	0.0366	***	-0.0263
	t	-3.0781		3.3164		7.4346		
	p	3.18E-03		1.58E-03		5.45E-10		

Note: IDI=ICT Development Index, EGI=E-Government Index, , OSI=Online Service Index, TII=Telecommunication Infrastructure Index, and HCI=Human Capital Index. ***=sig at 1%, **=sig at 5%, and *=sig at 10%

Source: Author's own analysis

Table 10 provides a summary of the Difference-in-Difference (DiD) analysis assessing how COVID-19 influenced various digital indicators between the EU and ASEAN regions. The results reveal distinct patterns in digital development across these regions during the pandemic.

For the IDI and TII, the analysis shows a negative and significant coefficient for the EU, suggesting that ASEAN experienced relatively stronger growth in ICT development and telecommunication infrastructure compared to the EU. This indicates that ASEAN, possibly driven by the necessity to bridge digital gaps, made considerable strides in their ICT development and telecommunication infrastructure.

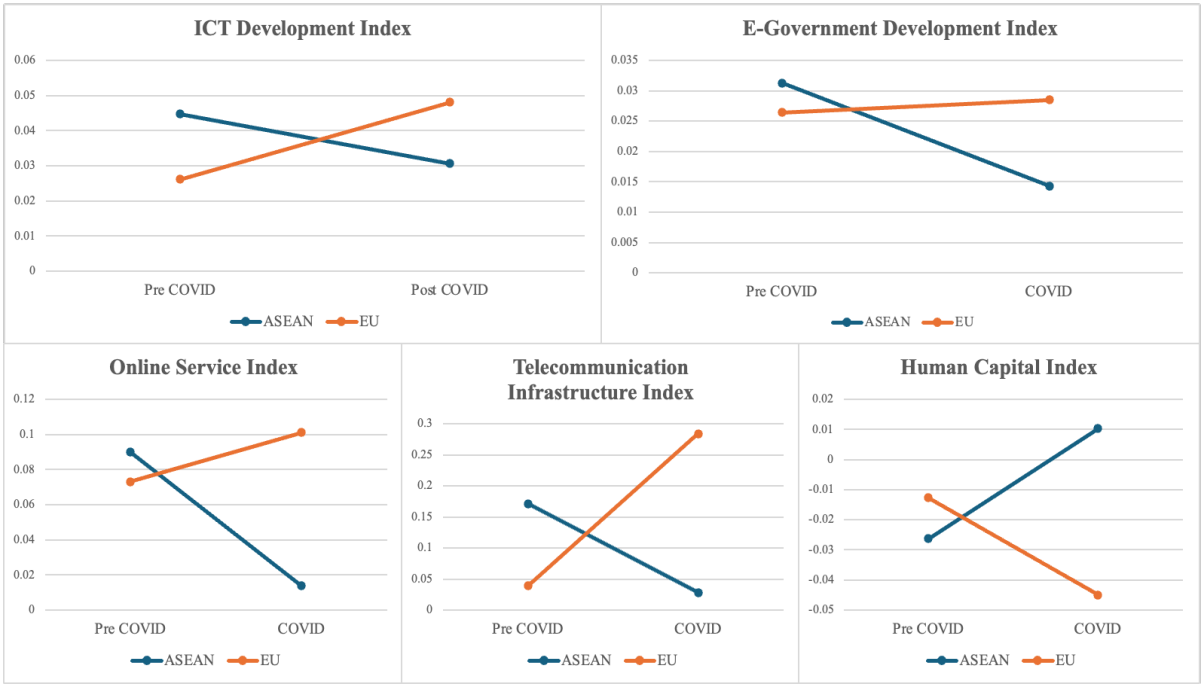
Conversely, for the HCI, the result exhibits a positive and significant coefficient for the EU, indicating that human capital improved more significantly in the EU compared to ASEAN. This divergence suggests that ASEAN countries may face more challenges in upskilling their populations to meet the demands of an increasingly digital economy.

A negative and significant COVID coefficients for EGI, OSI, and TII indicate that e-government development, online service, and telecommunication infrastructure improved more during the pre-COVID compared to the COVID period. This suggests that, while these digital sectors may have continued to grow during the pandemic, their rate of development slowed down once COVID-19 hit. As for the EGI and OSI, it is likely because government resources and priorities were redirected to managing the health crisis. The urgent need to respond to the pandemic may have overwhelmed government capacities, leading to delays or interruptions in the rollout of new e-government services. This is particularly significant, as the demand for online government services likely increased during the pandemic, with lockdowns and social distancing measures reducing the feasibility of in-person services. The negative coefficient suggests that governments in both the EU and ASEAN may have struggled to keep pace with the growing need for digital services, potentially leaving gaps in service delivery at a time when digital access was most needed. As for the TII, the onset of COVID-19 may have disrupted supply

chains, delayed infrastructure projects, and diverted investment away from long-term infrastructure development to more immediate crisis responses. For example, lockdowns and travel restrictions likely delayed the physical deployment of new telecommunications equipment, and economic uncertainty may have led both public and private sectors to pull back from planned infrastructure investments. At the same time, the pandemic triggered a sudden surge in the need for reliable digital connectivity as work, education, and services moved online. While this increased demand highlighted the importance of strong telecommunication infrastructure, the negative coefficient suggests that the existing infrastructure struggled to meet these new demands, as the growth in this area had slowed compared to pre-pandemic levels.

In contrast, a positive and significant COVID coefficient for HCI suggests that the development of human capital, particularly in the context of digital skills and education, accelerated during the COVID-19 period compared to the pre-pandemic years. This result highlights an important trend. While infrastructure and online services may have faced disruptions or slower progress, the pandemic catalyzed rapid improvements in human capital, especially in digital literacy, skills acquisition, and education. This improvement is likely due to several interrelated factors driven by the unique challenges and opportunities presented during the pandemic.

Figure 3. Comparative Trends of Each Digital Index in ASEAN and EU



Source: Author's analysis

Figure 3 illustrates the comparative growth trends of the ICT Development Index, E-Government Development Index, Online Service Index, Telecommunication Infrastructure Index, and Human Capital Index for the ASEAN and EU regions, both pre- and post-COVID. The figure shows faster development in less developed ASEAN countries in telecommunication infrastructure, while the EU exhibits more consistent growth across indices, particularly in human capital. Notably, ASEAN shows a decline in E-Government and Online Services during the COVID period. One of the most significant changes brought about by the COVID-19 pandemic was the global shift to online education. With schools, universities, and training centers closed or operating at reduced capacity due to lockdowns and social distancing measures, both formal and informal education sectors had to quickly adapt to remote learning platforms. This transition created an urgent need for students, teachers, and educational institutions to rapidly

improve their digital literacy and embrace online tools. In many countries, the government and private sector responded by investing in digital education platforms, providing access to online courses, and offering training on how to use digital tools. This led to a substantial increase in the availability and usage of online learning resources, helping to improve human capital in terms of digital skills and knowledge acquisition.

In addition, the pandemic fundamentally reshaped the labor market, with many industries undergoing rapid digital transformation as businesses shifted to remote work and e-commerce became more central to economic activity. This shift significantly increased the demand for workers with strong digital skills, driving many individuals to seek out digital training programs, online certifications, and skills development opportunities in order to remain competitive in the job market. The pressure to adapt to a more digital economy prompted both governments and businesses to invest heavily in upskilling programs, workforce training, and digital literacy initiatives. Many countries introduced or expanded digital skills programs aimed at helping workers transition to remote jobs or acquire new skills needed for emerging industries. As a result, human capital experienced greater growth during the COVID period than in the years prior.

Moreover, the pandemic accelerated the trend toward lifelong learning, particularly in the digital domain. Many workers who experienced job disruptions due to the pandemic turned to online learning platforms to enhance their skills or pivot to new career paths. This increased focus on lifelong learning was facilitated by a growing number of online courses, digital certificates, and vocational training programs that became widely available during the pandemic. Governments, universities, and private companies also played a role by providing free or subsidized access to these platforms, helping people stay productive and build new skills even during periods of economic uncertainty. In particular, workers in industries that were hardest hit by the pandemic such as retail, hospitality, and manufacturing were incentivized to reskill and upskill in digital fields to transition to more resilient sectors like technology, e-commerce, and remote services.

The most striking finding is the TII, where the positive and significant COVID*EU interaction term suggests that the EU experienced more substantial improvements in telecommunication infrastructure than ASEAN due to the COVID-19 pandemic. This reflects the stronger policy frameworks and more developed infrastructure in the EU, which enabled rapid adaptation to the increased reliance on digital connectivity during the pandemic. Several factors contribute to ASEAN's underperformance. Prior to the pandemic, ASEAN countries already faced significant disparities in telecommunication infrastructure, particularly in rural areas, which were exacerbated during the crisis. In contrast, the EU, with its more advanced networks, adapted more quickly to the surge in demand for digital connectivity. EU governments implemented swift policies to expand telecommunication infrastructure, supported by subsidies and digital initiatives, while ASEAN nations focused more on addressing immediate health and economic challenges, leaving fewer resources for long-term infrastructure development. The EU's stronger financial resources allowed for greater investment in infrastructure, whereas ASEAN countries, facing economic downturns, struggled to prioritize these improvements. Additionally, the digital divide between urban and rural areas in ASEAN limited progress, while the EU had already invested in reducing this divide before the pandemic, ensuring more widespread connectivity. Lastly, the EU benefited from established partnerships between governments and private telecom providers, which enabled faster adaptation, whereas ASEAN's regulatory challenges and less competitive telecom sectors hindered their ability to respond as effectively. Overall, ASEAN's underperformance during the pandemic reflects its pre-existing infrastructure gaps, economic constraints, and less comprehensive policy frameworks compared to the EU.

In opposition, the HCI exhibits a negative and significant coefficient for the COVID*EU, indicating that human capital, particularly digital skills and education, improved more significantly

in the ASEAN during the pandemic compared to EU. This divergence highlights the varying capacity of the two regions to upskill their populations during a period of rapid digital transformation. while the EU has traditionally maintained a higher level of digital literacy and infrastructure, the pandemic accelerated the pace of digital skill acquisition in ASEAN countries, leading to a more rapid development of human capital relative to the EU. The pandemic created an urgent need for digital skills across all sectors, and ASEAN countries were forced to adapt quickly. Governments, educational institutions, and businesses across ASEAN responded by ramping up efforts to provide digital education and training. For example, many ASEAN countries launched initiatives to expand access to online learning platforms and vocational training programs, recognizing that upskilling was essential to maintaining economic stability during the crisis. The shift to digital education, combined with an increase in remote work opportunities, motivated many individuals to acquire new skills quickly, helping to bridge the gap in digital literacy.

In the EU, however, the rate of improvement in digital skills and education was more moderate, largely because the region already had a well-established foundation of digital literacy and educational infrastructure. While the EU certainly made progress in adapting to new digital demands during the pandemic, its human capital was not as drastically transformed as that of ASEAN, which had more room for growth. The EU's existing digital systems were already advanced, and while improvements were made, they were less dramatic compared to the rapid advancements seen in ASEAN. This divergence highlights ASEAN's capacity to rapidly adapt and improve digital skills during the pandemic, narrowing the gap in human capital development between the two regions.

5. DISCUSSIONS AND CONCLUSION

The results of this study provide important insights into digital convergence and divergence trends between the EU and ASEAN regions from 2010 to 2024, particularly in light of the COVID-19 pandemic. Both the ICT and EGI show strong overall convergence, with lower-developed countries catching up with more advanced nations. However, notable regional disparities emerge in ASEAN, especially in the COVID period and the post-COVID period. In ASEAN, ICT development has stalled during the post-COVID period. This lack of convergence suggests that the crisis disrupted efforts to bridge the ICT development gap, with uneven digital infrastructure and policy implementation hampering progress. Policymakers must address this ICT gaps to ensure equitable digital growth across ASEAN. In contrast, the **EGI** shows that the pandemic had a favorable impact on e-government convergence in ASEAN. Although there was no significant convergence in the pre-COVID period, the crisis pushed governments to rapidly adopt digital solutions for public services. The need to maintain government functions during lockdowns and increasing demand for digital services likely drove this progress. As a result, ASEAN countries made notable strides in e-government development, showing convergence in the COVID period.

To improve the ICT development gap in ASEAN, governments should prioritize investment in rural digital infrastructure supporting information and communication technology development, leveraging public-private partnerships to expand broadband access and improve connectivity. Strengthening regional cooperation through initializing the ASEAN Digital Masterplan and promoting competition in the information and communication technology sector will further accelerate progress. Digital literacy and skills training programs should be expanded, particularly in less developed areas, to ensure widespread participation in the digital economy. Regulatory reforms that encourage innovation and competition in the information and communication technology industry, alongside targeted public-private collaborations, will drive ICT

growth. Finally, ASEAN should actively seek international funding and adopt inclusive ICT policies that focus on affordable access for marginalized communities, ensuring that digital transformation benefits all sectors of society.

The analysis of the Human Capital Index reveals a significant divergence in both the total and pre-COVID periods, suggesting that disparities in digital skills, education, and workforce readiness were widening across regions. This divergence indicates that countries with lower initial levels of digital skills and education were not catching up to more advanced nations and the gap was growing. However, the most notable finding is that this divergence disappears during the COVID period, although the HCI does not yet show signs of convergence. This suggests that while the pandemic may not have led to equal progress in human capital development across countries, it slowed the widening of the gap. The shift could be attributed to the significant global focus on digital education and workforce upskilling during the pandemic, as many countries transitioned to remote learning and work environments. Governments and institutions worldwide placed greater emphasis on improving digital literacy and access to education, which may have helped slow the pre-existing divergence. The lack of convergence, however, indicates that while the pandemic halted the divergence, significant inequalities in human capital development remain. Structural issues, such as limited access to digital resources, underfunded educational systems, and the rural-urban divide, continue to hinder less developed countries' ability to fully catch up with more developed countries in terms of digital skills. Overall, the results highlight that although the pandemic slowed the divergence in human capital development, further efforts are needed to foster true convergence.

To narrow the human capital gap in both regions, governments should invest in digital education and skills training, particularly for low-access populations including rural communities and lower-income groups. This can be achieved by providing affordable access to online learning platforms, integrating digital literacy into school curricula, and offering vocational training focused on in-demand digital skills. Public-private partnerships should support local tech hubs and community training centers to ensure accessibility. Additionally, governments should prioritize expanding internet access and providing affordable digital devices in underserved areas to enable equitable participation in the digital economy. These efforts will help reduce digital inequalities and foster long-term economic growth by building a more skilled and inclusive workforce.

In addition, the findings highlight a significant difference between the EU and ASEAN in terms of telecommunication infrastructure improvements during the COVID-19 pandemic. The EU was able to make more substantial advancements in telecommunication infrastructure compared to ASEAN. This result highlights the critical role that pre-existing infrastructure, policy frameworks, and financial capacity play in responding to crises like the pandemic. In the EU, stronger policy frameworks, substantial financial resources, and well-developed infrastructure enabled countries to rapidly adapt to the surge in demand for digital connectivity (Gajović, 2024). This reflects a well-coordinated, long-term strategy for digital resilience that had been set in motion prior to the pandemic, allowing the EU to maintain and expand its digital infrastructure more effectively during the crisis. In contrast, ASEAN faced significant challenges in adapting to the demand for telecommunication infrastructure. The region already had pre-existing disparities in telecommunication infrastructure and these gaps were worsened by the pandemic. ASEAN countries, many of which were focused on addressing immediate health and economic challenges during COVID-19, struggled to allocate sufficient resources for long-term infrastructure development. Economic constraints, moderated by the pandemic's adverse impact on national economies, further limited the capacity of ASEAN governments to invest in telecommunication improvements.

The contrasting experiences of the EU and ASEAN during the pandemic highlight the urgent need for ASEAN policymakers to narrow the gap in telecommunication infrastructure. To prevent further divergence within the region, ASEAN must prioritize substantial investments in expanding telecommunication infrastructure in terms of broadband networks, mobile networks, satellite communications and hardware that enables internet access, particularly in neglected areas. Enhancing competition in the telecommunication sector is also critical to drive innovation and lower costs, ensuring more equitable access. Policies promoting public-private partnerships, similar to the EU's model, can accelerate infrastructure development and improve digital connectivity. The pandemic has clearly shown that solid telecommunication infrastructure is vital for economic resilience, and ASEAN countries must act now to strengthen their digital foundation and prepare for future crises.

To enhance digital infrastructure and human capital development, both the EU and ASEAN regions can draw from successful interventions that have already demonstrated impactful results. In the European Union, the *Digital Single Market (DSM) Strategy, l*aunched in 2015, serves as a compelling example of how coordinated policy efforts can lead to significant improvements in digital infrastructure. The DSM removed barriers to online commerce, created a unified digital market, and incentivized investments in broadband and 5G technologies across Europe. Additionally, initiatives such as *WiFi4EU,* which provides free Wi-Fi in public spaces, have been critical in expanding internet access, especially in rural and underserved areas. These efforts highlight the importance of building robust digital infrastructure as a means to bridge the urban-rural divide and enhance economic integration across EU member states.

In ASEAN, Singapore's *Smart Nation Initiative* has proven to be a benchmark for digital infrastructure development. This initiative focuses on creating a fully connected city-state through nationwide fiber broadband, extensive 5G rollouts, and the integration of smart technologies in public services. The successful partnership between the government and the private sector to deploy IoT technologies across sectors such as healthcare and transportation demonstrates how ASEAN countries can harness similar strategies to accelerate digital adoption. Countries within ASEAN that face larger digital divides could benefit from adapting Singapore's model, particularly by fostering public-private partnerships that can support the expansion of critical digital infrastructure and ensure that technological benefits are broadly shared across urban and rural areas.

On the human capital front, Germany's *DigitalPakt Schule (Digital Pact for Schools)* is a key example from the EU that has focused on equipping schools with digital tools and infrastructure to boost digital literacy among students and educators. This initiative, which received a €5 billion investment, highlights the role of early and continuous digital education in preparing the future workforce for the demands of a digital economy. The COVID-19 pandemic further underscored the need for such programs, as they enabled students and teachers to transition smoothly to digital learning environments. ASEAN countries can draw from this experience by implementing similar large-scale educational reforms to boost digital skills at all levels, from primary education to professional training.

Similarly, Malaysia's *My Digital Blueprint,* part of the broader digital economy plan, emphasizes human capital development through targeted skills training. By partnering with private companies to offer digital skills certification and upskilling programs, Malaysia has made strides in preparing its workforce for the digital economy. This approach serves as a model for other ASEAN nations, where digital skills gaps remain a significant barrier to economic growth. Governments across ASEAN can replicate Malaysia's framework to address the growing demand for digital competencies and ensure that their populations are equipped to participate fully in the digital economy.

Several limitations should be considered when interpreting these results. First, data availability and comparability; one of the main challenges in this study is the comparability across regions posed challenges. The availability and completeness of data for the indices vary between the EU and ASEAN countries. For instance, some indices were formulated based on the survey questions, which could affect the robustness of cross-regional comparisons. Second, the beta convergence analysis assumes that the factors driving digitalization are consistent across regions. However, differences in economic conditions, policy frameworks, and technological infrastructure between the EU and ASEAN may influence the rate and direction of convergence. This could lead to variations in the results that reflect regional specificities rather than a general trend. Second, the beta convergence analysis assumes that the factors driving digitalization are consistent across regions. However, differences in economic conditions, policy frameworks, and technological infrastructure between the EU and ASEAN may influence the rate and direction of convergence. This could lead to variations in the results that reflect regional specificities rather than a general trend. Additionally, beta convergence results can be sensitive to the choice of time period and initial conditions. For instance, selecting different starting points or periods of analysis could yield different rates of convergence, especially if there are significant external shocks or structural changes during the observed period. Third, regarding cross-regional comparisons, comparing digitalization trends across the EU and ASEAN regions presents inherent challenges due to heterogeneities in economic development, governance structures, and digital infrastructure. These disparities may complicate direct comparisons and require careful interpretation of the results to account for context-specific factors. And finally, the impact of the COVID-19 pandemic on digitalization is likely to have varied significantly across countries within each region, influenced by factors such as government response, pre-existing digital infrastructure, and public health policies. These variations add complexity to the analysis and necessitate a region-specific interpretation of the DiD results.

Future studies should aim to address the limitations identified by expanding the scope of the analysis to include more detailed country-specific data, particularly within ASEAN. This could provide insights into how individual countries within each region responded to the pandemic and which specific policies were most effective in promoting digitalization. Additionally, studies could explore the long-term effects of the pandemic on digital trends, including the sustainability of the rapid growth in digital skills and infrastructure observed after the COVID period. Moreover, further studies could deepen an investigation by breaking down the analysis by sector or demographic groups to provide better understanding of how the pandemic impacted different economic sectors, demographic sectors, different characteristics of corporations (large vs small), or different areas (urban vs rural). Finally, further research is needed to explore the role of private sector investment in digital infrastructure and how public-private partnerships could be leveraged to address ongoing digital disparities, especially in developing regions.

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