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Nonlinear Threshold Effect of Telecommunications Infrastructure Development on Economic Growth in D8 Countries: Panel Smooth Transition Regression (PSTR) Model

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Abstract

This study explores the impact of telecommunication infrastructure development on economic growth in D8 countries from 2007 to 2022. A panel smooth transition regression (PSTR) model is utilized to analyze this relationship. The chosen transition variable is the information and communication technology (ICT) index. The findings indicate a nonlinear association between the variables examined. The estimated threshold for the logarithm of the transition variable is 4.4433. Moreover, the results demonstrate that gross capital formation and urban population have a positive and significant effect on economic growth in the first regime. Conversely, financial development has a negative and significant impact on economic growth in the first regime. Furthermore, the results reveal that the urban population continues to have a positive and significant influence on economic growth, although its impact is lower compared with before. Additionally, financial development has a positive and significant effect on economic growth in the second regime.

Keywords: Economic Growth, Telecommunication Infrastructure, D8 Countries, Principal Component Analysis (PCA), Panel Smooth Transition Regression (PSTR).

JEL Classification: O40, O33, C23.

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1. Introduction

Information and communication technology is one of the important elements in economic growth in the current era of global development. Economic operations, such as business, rely more on current internet resources. Nowadays, increasing usage of online shopping has an opportunity to contribute to financial development, international financial cooperation, gross domestic product (GDP), trade, development of productivity and organizational facilities, employment growth, and poverty reduction (Latif et al., 2018; Nabi et al., 2022).

Recent investments have fueled significant growth in the telecommunications industry and have become an important driver of economic growth in several other critical sectors. Information and Communication Technology (ICT) facilitates the exchange of information and influences modern society. Due to the effects of the information and communication technology revolution, a paradigm shift is taking place in human progress, which refers to the process of expanding the scope of society's choices, such as education, healthy living, and living standards (Yakunina & Bychkov, 2015; Kurniawati, 2022).

Information and communication technology (ICT) is one of the crucial factors for innovation and economic growth in global economies. In most OECD economies, the information industry accounts for a significant share of business expenditures on research and development (BERD), about 25% of business expenditures on research and development, and 0.2 to 0.4% of GDP. Notably, in Finland, Israel, Korea, and the United States, the information industry accounts for 40 to more than 50% of BERD, and ICT BERD alone accounts for between 6 and 8% of GDP, indicating the high intensity of research in these economies (Hong, 2017, p. 70).

The expectation of economic progress resulting from the information and communication technology era has led developed and developing countries to invest a significant portion of their resources in developing their telecommunications and communications infrastructure (King et al., 1994; Oliner & Sichel, 2000; Colecchia & Schreyer, 2002; Daveri, 2002; Datta & Mbarika, 2006; Dimelis & Papaioannou, 2011; Pradhan et al., 2014). In general, these studies have neglected or omitted the role of other macroeconomic variables.

The mediating role of telecommunication infrastructure in the relationship between fixed capital formation, urban population, and financial development with economic growth is of interest in D8 (Bangladesh, Egypt, Indonesia, Iran, Malaysia, Nigeria, Pakistan, Turkiye) countries, and telecommunication infrastructure, such as mobile phone, internet, and landline has an important role in influencing economic growth.

In recent years, these communication infrastructures have been essential tools to facilitate economic activities, promote communication, and enable information exchange. These infrastructures have revolutionized the way people communicate, do business, and access services. So that the impact of these infrastructures on various aspects of economic development cannot be ignored.

First, the existence of reliable and efficient communication networks, including mobile phones, can help the fixed capital formation in the D8 countries. These infrastructures facilitate better coordination and communication between businesses and lead to increased productivity and investment. By improving communication, companies can effectively manage their operations, collaborate with partners, and communicate with customers, thereby increasing their competitiveness and contributing to the growth of fixed capital.

Second, telecommunications infrastructure has played an important role in shaping urban population dynamics in the D8 countries. Access to mobile phones, the use of the Internet, and landlines enable people to communicate with each other regardless of geographical distances. This connectivity has led to the emergence of virtual communities, online marketplaces, and remote work opportunities. As a result, urban areas have experienced population growth as people are attracted to the opportunities and amenities offered by cities that are connected through these communication infrastructures.

Finally, the development of financial systems in D8 countries is strongly influenced by communication infrastructure. Mobile banking, online payment platforms, and digital financial services expand access to financial services, especially in underserved areas. These infrastructures facilitate financial inclusion, allowing individuals and businesses to participate

in formal financial systems, access credit, and engage in electronic transactions. The availability of these services has helped the overall development of the financial sector and supported economic growth.

The above statement highlights the significance of studying the impact of communication infrastructure on economic growth. It emphasizes the need to understand the non-linear nature of this relationship, which is often overlooked in existing research. To bridge this gap, it is crucial to empirically analyze how communication infrastructure influences economic growth in specific countries. Therefore, this study attempts to examine the impact of threshold and indirect communication infrastructure on economic growth and other factors affecting economic growth of D8 countries over the period 2007-2022 by using a panel smooth transition regression model.

2. Literature Review

ICT refers to the integration and use of computer science and technologies to disseminate information to a destination or consumer without time and space constraints. Operationally, ICT includes digital devices that are either hardware or software used to transmit information. This includes low-cost devices such as television, radio, and cell phones (Sofowora, 2009, p. 136).

The adoption of information and communication technologies and the use of new technologies in various forms in business and commerce are now in full swing. It is expected that the acceptance of businesses and consumers will increase the importance of ICT in the economies of countries. Some analysts see the development of telecommunication infrastructure as an opportunity for developing countries, referred to as leapfrog growth. Therefore, developing countries can accelerate their development and reduce their digital and economic gap with developed countries (Pourfaraj & Issazadeh Roshan, 2010, p. 78).

Dewan and Riggins (2005) and Jorgenson and Stiroh (1999) believed that there was a body of evidence that ICT is a substitute for labor input and capital due to its lower price and that this substitution creates benefits for consumers and producers.

On the other hand, with the development and diffusion of ICT, which is one of the crucial dimensions of globalization, societies are moving

towards the construction of communication systems, good management of these systems, and the development of infrastructures and the ability to use them (Spence & Smith, 2010, p. 11).

2.1. Economic Growth and the Development of the Telecommunication Infrastructure

The domain of Information and Communications Technology (ICT) has emerged from the convergence of information technology and communications technology (Ølnes & Jansen, 2018). This field encompasses the understanding of hardware and software processes involved in organizing and managing information. These technologies allow users to electronically compile and analyze data, as well as digitally transmit and retrieve information. Given the continuous evolution and rapid obsolescence of ICT infrastructure, it is crucial for researchers, economists, and policymakers to understand its role and impact on economic growth. Traditionally, indicators such as computers, phones, internet, and servers have been considered for economic analysis (Bahrini & Qaffas, 2019), but there are other emerging indicators, such as video conferencing, cloud computing (Al-Hujran et al., 2018), artificial intelligence (Sejati et al., 2020), disaster management systems (Rogers & Tsirkunov, 2011), e-commerce, and e-governance systems (Etro, 2009) that also need to be taken into account. These indicators are essential components of ICT infrastructure and play a significant role in economic development (Sarangi & Pradhan, 2020, p. 364). The supply-leading hypothesis (SLH) states that telecommunication infrastructure is necessary for economic growth. Therefore, the causal relationship leads from telecommunication infrastructure to economic growth. Proponents of this hypothesis believe that telecommunication infrastructure contributes to economic growth by directly supporting other infrastructures and factors of production (Dutta, 2001; Roller & Waverman, 2001; Cieslik & Kaniewsk, 2004). ICT infrastructure, particularly telecommunication infrastructure, plays a critical role in various sectors, enabling cost reduction, innovation, economic restructuring, and improved performance (Sharafat & Lehr, 2017). By facilitating business operations and connecting customers, suppliers, and manufacturers across different barriers, ICT enhances economic growth. However, further

financial support is needed to invest in new ICT projects and adhere to open trade policies imposed by specific countries. Furthermore, establishing a robust ICT infrastructure necessitates high internet speed, expensive setup and operational costs, and increased electricity consumption. Consequently, the rapid advancement of information and communication technology requires enhanced financial development and trade openness (Kumari & Singh, 2023, p. 7070). On the other hand, the demand-driven hypothesis (DFH) shows that the causal relationship exists from economic growth to telecommunication infrastructure. Proponents of this hypothesis believe that telecommunication infrastructure plays a minor role in economic growth and is only a byproduct or outcome of economic growth (Pradhan et al., 2014, p. 635). Information and communication technology services are considered as a by-product or result of economic growth by proponents of the demand-driven hypothesis. According to this hypothesis, on the one hand, it is clear that the development of information and communication technology has contributed significantly to the economic growth of many countries. The increased use of computers, the Internet, and other digital technologies enables businesses to become more efficient and productive, leading to increased productivity and greater profits. This situation, in turn, leads to increased investment in ICT infrastructure and further technological development, creating a virtuous growth cycle (Awad & Albaity, 2024, p. 6).

A number of studies have been conducted, including Assari and Aghaei Khondabi (2008), who wrote an article examining and testing the relationship between ICT and economic growth of the OPEC countries using the Cobb-Douglas production function and considering the ICT variable. For this purpose, the data panel method was used in the period 1998-2004. The results of this test indicated a significantly strong relationship between economic growth and ICT.

Babaei et al. (2015) investigated the impact of IT on economic growth by using the data panel method in 50 countries. The results of the fixed effects method showed that the coefficients of all explanatory variables were positive and significant.

Ahmadzadeh and Nasri (2018) conducted a study to investigate the effects of economic and social infrastructure on the distance of economic

growth using the panel data method in the provinces of the country during the period 2006-2012. In this context, the hypothesis of convergence of conditional and unconditional economic growth in the provinces was tested. The results indicated that both types of convergence of economic growth in the provinces of Iran were confirmed. Moreover, the results showed that the impact of economic infrastructure, including communication and energy, on economic growth was positive and significant. A review of the studies shows that no studies have been conducted on the threshold and indirect effects of telecommunication infrastructure development on economic growth. Therefore, for the first time in the D8 countries, this study seeks to examine the effect of the variable of telecommunication infrastructure development as a transition variable on economic growth in the form of the PSTR approach.

Many studies have been conducted within and outside the state, some of which are briefly discussed in this section. The study by Pradhan et al. (2014) examined the relationship between development of telecommunications infrastructure (DTI), economic growth, and four key indicators, including gross capital formation, FDI flow, urbanization rate, and trade in G20 countries, over the period 1991-2012, using a vector autoregressive panel model to establish Granger causality. Their results indicated that there was a long-run relationship between the variables. The results also confirmed a two-way causal relationship between telecommunication infrastructure and economic growth.

Similarly, in an article, Ward and Zheng (2016) examined the role of communication infrastructure and economic growth over the period 1991-2010 in 31 provinces in China. For this purpose, they used the generalized method of moments (GMM). The results showed that the communication infrastructure was the most important factor for economic growth in China. The results also suggested that mobile services contributed much more to growth, but that the effect decreases as the provincial economies develop.

Hong (2017) studied the causal relationship between ICT R&D investment and economic growth over the period 1988-2013 in Korea. A cointegration test and a vector error correction model (VECM) were used to estimate the model.

The results showed that there is a two-way causal relationship between ICT R&D investment and economic growth. And the results of the long-run relationship indicated that economic growth causes economic growth and vice versa. The private ICT R&D investment has a stronger property of leading economic growth and inducing investment by economic growth than the public ICT R&D investment. The results also show that there is a two-way causal relationship between private ICT R&D investment and public ICT R&D investment.

[Albiman and Sulong \(2017\)](#) investigated the linear and nonlinear effects of ICT on economic growth for the three income levels in the SSA region using the pooled mean group (PMG) model over the period 1990-2014. Based on income level, middle-income countries benefit more from ICT than high-income and low-income countries. In addition, the impact results for fixed lines are higher than those for mobile lines. Although the linear impact of internet penetration and use is positive and significant for middle-income countries, the results remain inconclusive when compared to other ICT innovations.

Another paper by [Pradhan et al. \(2018\)](#) studied the relationship between IT infrastructure and economic growth in the G20 over the period 2001-2012. For this purpose, they used panel cointegration and the vector error correction model (VECM). The results of the cointegration test showed that there was a cointegration relationship between the variables, and a long-run relationship was estimated. The results of the estimated model also indicated that upgrading the IT infrastructure is a necessity in formulating the policies of IT for both fixed broadband and internet users to promote economic growth.

[Bahrini and Qaffas \(2019\)](#) show that, except for fixed telephones, other information and communication technologies such as mobile phones, Internet usage, and broadband adoption are the main drivers of economic growth in the developing countries of MENA and SSA in the recent period of 2007-2016. In addition, the results show the superiority of MENA countries over SSA countries in the field of Internet usage and broadband adoption.

[Ghaem Zabihi et al. \(2021\)](#) using the seemingly unrelated regression (SUR) method show that information and communication technology has a positive and significant effect on economic growth

by 0.003 percent and on the human development index by 0.192 units in MENA countries.

[Kurniawati \(2022\)](#) states that high-income Asian countries have achieved significant positive economic development from high Internet penetration. In addition, middle-income countries are beginning to benefit from Internet ICT. Also, the results show that the telephone line and mobile phone penetration have a high ability to promote economic growth in Asian countries with middle income.

[Nabi et al. \(2022\)](#) show that the expansion of information and communication technology has a significant negative effect on economic growth in the long term in N11 countries. In addition, the results state that financial development reduces economic growth in the short and long term. Foreign direct investment and trade show a positive and significant relationship with economic growth in the long run.

[Kouam and Asongu \(2023\)](#) state that the proportion of the population with high and low electricity access, where the relationship between fixed bandwidth and economic growth changes, sign is about 60%. The results also show that below this threshold, each one percent increase in fixed broadband subscriptions reduces economic growth by about 2.58 percent. Above the threshold, economic growth increases by 2.43% when fixed broadband subscriptions increase by 1%.

[Handoyo et al. \(2024\)](#) investigated the relative impact of information and communication technology on manufacturing industry exports using a panel data technique with PPML (pseudo-poisson maximum likelihood) during the period 2010-2018. Their results show that the use of the Internet only promotes high technology-intensive manufacturing exports in OECD countries. Exports of low technology intensity manufacturing are negatively affected by increased Internet use in all samples of non-OECD and OECD economies. Except for advanced technologies, an increase in mobile phone subscribers is associated with an increase in manufacturing exports in all industry categories and all sample countries. Bandwidth sharing has a positive effect only on low technology intensity exports in OECD countries and a negative effect on medium technology exports in non-OECD countries.

[Awad and Albaity \(2024\)](#) show that there is a one-way causal association between per capita

income and the ICT index. The results also demonstrated that capital and employment were the leading causes of per capita GDP growth. The findings suggested that accelerating economic growth in developing economies was essential to promoting ICT investment.

Bouhari et al. (2024) investigated the nonlinear effects of ICT diffusion on economic growth in 30 countries in the MENA region from 2000 to 2020 using the PSTR model. The results show that in countries with high levels of ICT development, ICT diffusion positively impacts economic growth when ICT diffusion is below a threshold of 3.88. Above this threshold, the effects change. In less ICT-developed countries, ICT development initially negatively correlates with economic growth up to a threshold of 2.10. Beyond this threshold, the relationship reverses, becoming positive. Second, in the least ICT-advanced countries, a "leapfrog effect" is observed, where ICT's impact on economic growth shows a continuous upward trend.

This study aims to bridge the gap in previous research by considering the non-linear relationship between communication infrastructure and economic growth. While previous studies have primarily investigated the linear relationship between economic growth and information and communication technology (ICT), this study recognizes the potential for non-linear effects. It recognizes that enhancing ICT capabilities can lead to increased productivity, innovation, and competitiveness for businesses, thereby driving economic growth.

Understanding the link between ICT and economic growth is crucial for crafting effective policies. Governments can play a significant role in fostering economic growth by incentivizing the adoption of ICT, promoting digital literacy, and supporting technological innovation. Policies that improve broadband accessibility, provide support for tech startups, and invest in digital skills education can create a conducive environment for ICT development, ultimately leading to income growth. To analyze the dynamics of economic growth, this study employs the Panel Smooth Transition Regression (PSTR) method. Unlike traditional linear regression models, the PSTR method accounts for regime differences and provides more reliable experimental findings. By considering the non-linear nature of the

relationship between communication infrastructure and economic growth, this study aims to identify thresholds and explore the effects of other factors, such as fixed capital formation, urbanization, and financial development, on economic growth in D8 countries from 2007 to 2022.

3. Data and Methodology

3.1. Panel Smooth Transition Regression (PSTR) Model

In this study, the nonlinear threshold effect of telecommunication infrastructure development on economic growth in D8 countries is examined using a PSTR model. For this purpose, following Gonzalez et al. (2005) and Colletaz and Hurlin (2006), a PSTR model with two regimes and a transition function is defined as follows:

$$Y_{it} = \mu_i + \beta_0 X_{it} + \beta_1 X_{it} F(q_{it}; \gamma, c) + u_{it} \tag{1}$$

$$i = 1, \dots, N \quad t = 1, \dots, T$$

Where Y_{it} is the vector of exogenous variables, μ_i is the fixed effects, and also $u_{it} \approx iid(0, \sigma^2)$. Moreover, $F(q_{it}; \gamma, c)$ indicates a continuous bounded function over the interval $[0, 1]$, which is logistic following Gonzalez et al. (2005):

$$F(\gamma, c, q_{it}) = \left[1 + \exp\left(-\gamma \prod_{j=1}^m (q_{it} - c_j)\right) \right]^{-1} \tag{2}$$

$\gamma > 0, c_1 \leq c_2 \leq \dots \leq c_m$

Where c_i is an m -dimensional vector of location parameters, and the slope parameter γ determines the smoothness of the transitions. q_{it} represents the transition variable and, according to the study of Colletaz and Hurlin (2006), can be chosen among the explanatory variables, the lag of the dependent variable, or any other variable outside the model that is theoretically related to the model under study and causes a nonlinear relationship.

Gonzalez et al. (2005) suggest that, in practice, considering one or two thresholds, $m = 1$ or $m = 2$, is sufficient to account for parameter variability. For $m = 1$, the model implies that the two extreme regimes are associated with low and high values of q_{it} with a single monotonic transition of the coefficients from β_0 to $\beta_0 + \beta_1$ as q_{it} increases, with the change centered around c_1 . When $\rightarrow \infty$, $F(q_{it}; \gamma, c)$ the model becomes an indicator function $I[q_{it} > c_1]$, defined as $I[A] = 1$ when event A occurs and 0 otherwise. In this case,

the PSTR model in (1) reduces to the two-regime panel threshold model of Hansen (1999). For $m = 2$, the transition function has its minimum at $(c_1 + c_2)/2$ and reaches 1 at both low and high values of q_{it} . In this case, the transition function (2) becomes constant for any value of m when $\gamma \rightarrow 0$. In this case, the model collapses into a fixed effects homogeneous or linear panel regression model. Accordingly, in the PSTR model, based on the observations of the transition variable and the slope parameter, the estimated coefficients are continuous and bounded between $F = 1$ and $F = 0$, specified as follows:

$$y_{it} = \begin{cases} \mu_i + \beta'_0 x_{it} + u_{it} & F = 0 \\ \mu_i + (\beta'_0 + \beta'_1) x_{it} + u_{it} & F = 1 \end{cases} \quad (3)$$

As mentioned earlier, another salient feature of the PSTR model is that it provides a parametric approach to cross-country heterogeneity and time instability of the slope coefficients, allowing the parameters to change smoothly as a function of the threshold variable y_{it} . More precisely, the income elasticity for the i^{th} country at time t is defined by the weighted average of the parameters β_0 and β_1 :

Case 1: The transition variable is included in the model as an explanatory variable:

$$e_u = \frac{\partial \ln y_u}{\partial \ln x_u} = \beta'_0 + \beta'_1 F(q_u; \gamma, c) + [\beta'_1 \ln x_u] \frac{\partial F(q_u; \gamma, c)}{\partial \ln x_u} \quad (4)$$

Case 2: The transition variable does not include any explanatory variables:

$$e_u = \frac{\partial y_u}{\partial \ln x_u} = \beta'_0 + \beta'_1 F(q_u; \gamma, c) \quad (5)$$

Finally, the generalized form of the PSTR model with more than one transition function is specified as follows:

$$y_{it} = \mu_i \beta'_0 x_{it} \sum_j^r = 1 [\beta'_j x_{it}] F_j(q_{it}^j; \gamma_j, c_j) + u_{it} \quad (6)$$

Where r represents the number of transition functions to specify the nonlinear behavior, and the other cases are already defined. It is worth noting that the estimation of the parameters of the PSTR model consists of eliminating the individual effects by removing the individual means and then applying nonlinear least squares (NLS) to the transformed model (see for details, Gonzalez et al., 2005). This method is equivalent to maximum likelihood (ML) estimation in the case of normal errors.

Following Gonzalez et al. (2005), Colletaz and Hurlin (2006), and Jude (2010), the estimation steps of a PSTR model are as follows: First, the

linearity test against PSTR is performed using Wald Tests (LM_w) coefficients, Fisher Tests (LM_F) coefficients, and LRT Tests (LR) coefficient statistics according to Colletaz and Hurlin (2006). Once we have rejected the linearity hypothesis, we can verify that nonlinearity no longer exists. Then it is a matter of testing whether there is a transition function or whether there are at least two transition functions.

3.2. Data

The objective of this study is to investigate the nonlinear threshold effect of telecommunication infrastructure development on economic growth in D8 countries during the period 2007-2022, and to model the relationship between the studied variables using the econometric technique PSTR and a nonlinear approach.

The general model is defined as follows, following the study by Pradhan et al. (2014) and Bouhari et al. (2024):

$$LGDPP = F(LDTI, LUP, LCREDIT, LGCF) \quad (7)$$

$LGPP_{it}$: The logarithm of GDP per capita (constant 2015 US\$), LUP_{it} : The logarithm of Urban population (% of total), $LGCF_{it}$: The logarithm of Gross fixed capital formation (constant 2015 US\$), $LCREDIT_{it}$: Domestic credit to the private sector by banks (% of GDP), $LDTI_{it}$: Logarithm of ICT indicators (communication infrastructure) (transition variable following the study by Bouhari et al. (2024). This variable follows the study of Pradhan et al. (2014) and is obtained by principal component analysis using three telecommunications indicators: Fixed telephone network, cell phones, and internet users. The three indicators used to obtain this index are: 1) fixed telephone network: fixed telephone lines per 100 people 2) cell phones: cell phone subscribers per 100 people, and 3) internet users: internet users per 100 people. In Equation 8, the index of telecommunication infrastructure development is calculated:

$$DTI = \sum_{i=1}^3 a_{ij} X_{ij} \quad (8)$$

Where DTI is our composite index of the development of telecommunication infrastructure, X_{ij} i^{th} variable in j^{th} year, and a_{ij} is the factor loading obtained from PCA. DTI thus captures the three DTI indicators we mentioned earlier, which

are summarized in Table 1.

Table 1: Results of Principal Component Analysis for DTI

Eigenvalues (Sum=3, Average=1)					
Number	Value	Difference	Proportion	Cumulative value	Cumulative proportion variance
1	1.976	1.2072	0.6587	1.9761	0.6587
2	0.768	0.5139	0.2563	2.7450	0.9150
3	0.025	-	0.0850	3.00000	1.0000
Eigenvectors (loadings)					
Variables	PC1	PC2	PC3		
INTER	0.648322	0.204932	0.733267		
MOB	0.448371	-0.8811	0.1501		
TEL	0.615338	0.4261	0.6631		
Ordinary correlations					
	LINTER	LMOB	LTEL		
INTER	1.000000	-	-		
MOB	0.407534	1.0000	-		
TEL	0.731533	0.2819	1.0000		

Source: Research findings

The results of Table 1 show that the value of the eigenvalues for the first factor is equal to 1.976161. Since the cumulative proportional variance by the eigenvectors is obtained by dividing the first factor by 3 (number of DTI indicators), the ratio of the variance that can be estimated by the first factor is 0.6587, which is shown in the “Proportion” column. The criterion of the ratio of variance is one of the most important criteria for determining the number of factors. Based on the information in the table, it can be seen that only the first factor has specific values greater than one and explains a total of 65.87% of the total variance of the three variables. The scree plot for the factors in this study is shown in Figure 1.

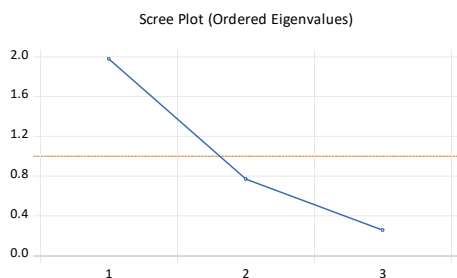


Figure 2: Eigenvalues of Principal Components
Source: Research findings

In order to investigate the indirect effect of telecommunication infrastructure development on economic growth, the PSTR econometric model is proposed as follows:

$$LGDP_{it} = \alpha_1 LGCF_{it} + \alpha_2 LUP_{it} + \alpha_3 LCREDIT_{it} + \sum_{j=1}^k [\beta_j LGCF_{it} + \beta_{L_2} LUP_{it} + \beta_3 LCREDIT_{it}] F(q_{it}; \gamma, c) + u_{it} \tag{9}$$

The statistics and data variables on an annual basis of parameters are from World Development Indicators, and for the estimation of the model, the development of communication infrastructure was used as a transition variable that causes a nonlinear relationship. The economic growth variable is considered to be a dependent variable, and other variables, including urban population, fixed capital formation, and financial development, are considered as explanatory variables.

4. Empirical Results

4.1. Panel Unit Root Test

If a series is non-stationary, it may lead to erroneous results before it is used for further analysis. To examine the stationary and non-stationary conditions in this study, the Levine-Lin-Chu (LLC) test is employed. The LLC test results, summarized in Table 2, reveal that all variables exhibit stationarity in levels, with a significance level of 5%.

Table 2: Panel Unit Root Tests (with Intercept and Trend) on Level

Variables	Levine-Lin-Chu (LLC) test	
LGDP	-1.84743	Stat.
	0.0323	Prob.
LDTI	-1.68634	Stat.
	0.0459	Prob.
LGCE	-2.72954	Stat.
	0.0032	Prob.
LUP	-2.85992	Stat.
	0.0021	Prob.
LCREDIT	-1.82668	Stat.
	0.0339	Prob.

Source: Research findings

4.2. Estimation of PSTR Model

In the PSTR model, the first step is to perform the linear test. This test examines whether the relationship between variables is captured by the linear model, i.e., the standard fixed effects panel model, or by the non-linear model, i.e., the PSTR model. For this purpose, following [Albiman and Sulong \(2017\)](#), the development of communication

infrastructure was used as a transition variable. Table 3 shows the p-value of the Lagrange multiplier and likelihood ratio test for the null hypothesis of linearity versus the alternative of logistic (m=1) or exponential (m=2) PSTR specification. We find that the null hypothesis of linearity is rejected at the 1% significance level.

Table 3: Nonlinear Relationship Test

(m=1)			(m=2)		
LM _w	LM _F	LR	LM _w	LM _F	LR
24.202	9.339	27.402	48.113	12.587	63.685
(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

H0: r = 0 vs H1: r = 1

Note: r represents the number of transition functions. The values in parentheses indicate the probability associated with each statistic.

Source: Research findings

Then, the presence of a nonlinear relationship must be investigated to assign the number of transition functions. The result is shown in Table 4. The result indicates that the null hypothesis (the PSTR with one transition or two regimes) is accepted and the alternative hypothesis (the PSTR with at least two transitions and three regimes) is rejected. In simple words, the PSTR technique with two regimes or one transition function is sufficient to investigate the nonlinear relationship between DTI and economic growth in D8 countries.

Table 4: Test for Residual Nonlinear Relationship

(m=1)			(m=2)		
LM _w	LM _F	LR	LM _w	LM _F	LR
2.560	0.736	2.591	9.349	1.390	9.778
(0.465)	(0.533)	(0.459)	(0.155)	(0.228)	(0.134)

H0: r = 1 vs H1: r = 2

Note: r represents the number of transition functions. Values in parentheses indicate the probability associated with each statistic.

Source: Research findings

In the next step, checking for nonlinearity and determining the number of transition functions, the optimal threshold should be estimated and the optimal model is selected by comparing the AIC and BIC criteria according to Jude (2010). The results of Table 5 show that after comparing the AIC and BIC criteria, the model selection based on the minimum value, the PSTR model with a threshold value is selected.

Table 5: Determination of the Number of Thresholds in a Transition Function

	RSS	BIC	AIC
m=1	0.079	-7.0031	-7.1814
m=2	0.079	-6.9641	-7.9641

Source: Research findings

After assigning the number of transition functions and the optimal threshold value, a two-regime model is estimated, the results of which are shown in Table 6.

Table 6: PSTR Model Estimation Results

The linear model		Non-linear part of the model	
LGCE ₀	0.3112 (10.5780)	LGCE ₁	0.0311 (2.1793)
LUP ₀	0.8803 (8.4325)	LUP ₁	-0.4422 (-4.2199)
LCREDIT ₀	-0.0627 (-3.4508)	LCREDIT ₁	0.2901 (9.4045)

Threshold C=4.4433 Anti-logarithm C=85.05516
Slope parameter $\gamma = 8.9762$

Source: Research findings

Based on the results of the model estimation, the slope parameter, which indicates the speed of adjustment from one regime to another, is 8.9762. The location of the occurrence of the regime changes and the crossing of the threshold was found to be 4.4433, and the magnitude of the antilogarithm is equal to 85.05516. Thus, as long as the ICT index (communication infrastructure) is less than 85.05516, the behavior of the variable corresponds to the first regime, and when this value exceeds 85.05516, it corresponds to the second regime.

In the first regime $\gamma \rightarrow \infty$ and the value of the transition variable is less than the threshold (the location of the regime change). In this case, the transition function has a numerical value of zero, and the model is specified as follows:

$$LGDP = 0.3112LGCE + 0.8803LUP - 0.0627LCREDIT$$

All coefficients estimated in the linear model above are statistically significant at the 1% level. The second regime also $\gamma \rightarrow \infty$, but the value of the transition variable (communication infrastructure) is greater than the threshold, in which case the transition function has a numerical value of one, and the model is specified in this mode as follows:

$$LGDP = 0.3423LGCE + 0.4381LUP + 0.2274LCREDIT$$

All coefficients estimated in the nonlinear and linear models are statistically significant at the 1% level. Since the coefficients of the variables for the different countries and over time are not the same and change depending on the level of the transition variable (communication infrastructure) and the slope parameter, the numerical value of the coefficients given in Table 6 cannot be interpreted directly, and only the signs should be analyzed.

Figure 2 shows that in the first regime, the impact of fixed capital formation on economic growth is positive. When crossing the threshold and in the second regime, at the high technology level, this effect has increased with the development of the communication infrastructure. This positive effect in the first regime and the low level of communication infrastructure can be justified by the fact that an increase in the quantity of investment can lead to increased economic power and a reduction in imports, an increase in foreign exchange reserves, and faster development of economic progress. The reason for the increase of this positive effect in the second regime and the high level of communication infrastructure can also be seen in the fact that the impact of technology in the form of embodied capital goods leads to an increase in the ratio of capital to labor and a deepening of capital, which leads to increased capital productivity and, consequently, an increase in production and economic growth.

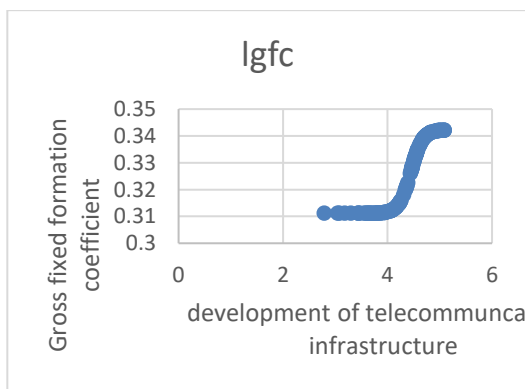


Figure 3: Coefficient of Gross Fixed Capital Formation against the Transition Variable (Communication Infrastructure)

Source: Research findings

Figure 3 shows the coefficient of the impact of

urban population on economic growth. The results show that in the first regime and the low level of communication infrastructure, the urban population has a positive effect on economic growth. And with crossing the threshold and entering the second regime, its effectiveness has gradually decreased; that is, with the increase of communication infrastructure, the increase of urban population at a high technological level has decreased, but is still positive. Level of communication infrastructure can be argued that through the use of information and communication technology and the increase of communication infrastructure, the negative impact of the increase of urban population, including the consumption of raw materials, vehicles, energy consumption and the like, which leads to increased environmental pollution and is itself an obstacle to sustainable development, is reduced and leads to increased economic growth.

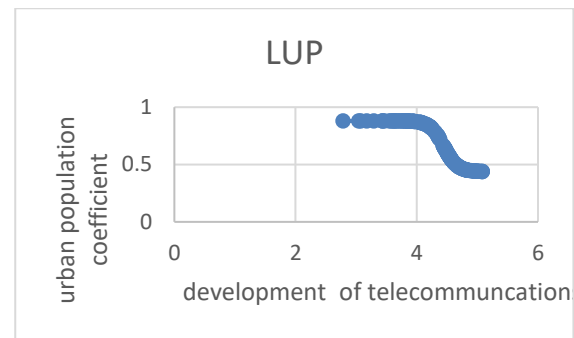


Figure 4: Coefficient of Urban Population Versus Transition Variable (Communication Infrastructure)

Source: Research findings

According to Figure 4, in the first regime, financial development has a significantly negative effect on economic growth, but in the second regime, with the development of communication infrastructure, this effect has become significantly positive. The reason for this effect can be seen in the fact that the D8 countries do not have integrated, active, and extensive financial markets when the level of communication infrastructure is low. It seems that the loans granted to the private sector in these countries were not appropriately allocated to increase economic growth, which makes the results of this study consistent with the study (Varahrami et al., 2015). Of course, this effect should be carefully analyzed due to the non-significant coefficient in this regime. The positive

effect of financial development on the second regime and high levels of communication infrastructure is also due to the fact that the development of communication infrastructure first increases the information used by the branches of brokerage firms and official representatives of the association. Thanks to this information system, other brokers and traders no longer need to go to a specific place, such as the stock exchange. They get the latest information about the highest buying price, the lowest selling price, and the total volume of transactions from the computer. On the other hand, the system controls billions of dollars' worth of transactions in the securities market every day. Another technology used in the financial markets is electronic communication network (ECN), which has led to a major transformation in the sector. As a result, the development of communication infrastructure improves financial development and eventually leads to high economic growth.

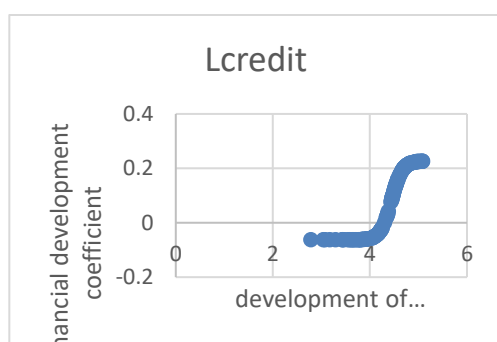


Figure 5: Financial Development Coefficient Against Transition Variable (Communication Infrastructure)
Source: Research findings

5. Conclusions

In this study, the threshold and indirect effects of telecommunication infrastructure development on economic growth in D8 countries during 2007-2022 were investigated. For this purpose, the index of communication infrastructure was first introduced using three variables, which finally became an index through PCA. Then, the PSTR model provided and developed by [Gonzalez et al. \(2005\)](#) and [Colletaz and Hurlin \(2006\)](#) was used. The estimation results suggested a nonlinear relationship between fixed capital formation, urban population, financial development, and economic growth. Moreover, considering a threshold with two regimes or a transition function is sufficient to

investigate nonlinear behaviors. The results show that the threshold of the transition variable is equal to 4.4433 and the slope parameter is equal to 8.9762, which includes only one transition function and only one threshold. The results in terms of estimated coefficients show that in the first regime, fixed investment and urban population have a significantly positive effect, and financial development has a negative and significant effect on economic growth, which becomes positive and significant by crossing the threshold (high level of communication infrastructure) for the financial development variable, and the positive effect on fixed investment increases. Also, in this regime, the effect of urban population on economic growth is still positive, but its amount has decreased compared to the first regime. Therefore, in line with the results of the study, the main policy recommendations are that the governments of these countries should develop the communication infrastructure based on its positive effects, such as productivity growth, reduction of production costs, improvement of financial development, and growth of innovation and technology, to achieve the desired economic growth. It is recommended to develop a communication infrastructure and areas for strengthening productive sectors, including the optimal allocation of facilities, monitoring the use of these facilities, and adopt appropriate policies, to increase productivity in productive sectors and reduce unproductive activities. Also, the governments should be concerned with creating economic security and a safe environment for investment, strengthening institutions involved in technology, emphasizing the role of capital stock in the research and development sector, and amending capital market regulations for transparency, corruption control, and stability, increasing savings and investment for economic growth. In order to promote growth in region D8, it is recommended to support local businesses through initiatives such as loans, subsidies, and mentorship programs. This will encourage entrepreneurship and lead to job creation. Additionally, investing in infrastructure, including the construction of roads, bridges, ports, and other necessary facilities, can attract investment and generate employment opportunities in the construction sector. Furthermore, improving education and training by offering relevant programs can equip individuals with the necessary

skills to actively participate in the modern economy, thus creating a more skilled labor force.

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