Daengku: Journal of Humanities and Social Sciences Innovation *ISSN: 2775-6165 (online)*
Vol. 5 No. 6 (2025)
https://doi.org/10.35877/454RI.daengku4632

The Effect of Digital Infrastructure Development on Regional Economic Growth in Indonesia: A Spatial Econometrics Approach

M. Gelar Faisal[a,*], Nurlaila Syarfiah Asfo[b], Reni[c], Feby Arma Putra[d], M Andika Hariz Hamdallah

[a]*Universitas Islam Jakarta, Jakarta, Indonesia*
[b]*Universitas Patompo, Makassar, Indonesia*
[c]*Politeknik PGRI Banten, Indonesia*
[d]*Universitas Pamulang, Indonesia*

Abstract

This study examines how digital infrastructure development influences regional economic growth in Indonesia by explicitly accounting for spatial interdependence among provinces. Using a balanced panel of 34 provinces over 2015–2021 (238 observations), digital infrastructure is proxied by the proportion of individuals using the internet, while economic growth is measured as real GRDP per capita growth. Global Moran's I indicates spatial clustering in both growth and digital connectivity, motivating a spatial econometric framework. The main specification estimates a Spatial Durbin Model (SDM) with province and year fixed effects and a row-standardized k-nearest neighbors spatial weights matrix (k=5) to capture outcome dependence and covariate spillovers. Results show that digital infrastructure has a positive and statistically significant direct effect on provincial growth, and it also produces a positive indirect effect, implying measurable spillovers to neighboring provinces. Decomposition into direct, indirect, and total impacts reveals that accounting for spatial feedback increases the estimated overall contribution of digital infrastructure relative to non-spatial interpretations. Robustness checks using alternative neighborhood definitions and alternative digital access proxies confirm the stability of the main findings, while a lagged specification suggests the relationship is not driven solely by contemporaneous reverse causality. The evidence implies that digital infrastructure is a network-type investment whose returns extend beyond administrative borders. Policy efforts should therefore combine connectivity expansion with coordinated regional planning and complementary measures—such as digital skills and MSME adoption support—to maximize growth benefits and reduce interregional digital gaps. These insights contribute to spatial growth literature by documenting Indonesia's digital spillovers during adoption.

Keywords: Digital Infrastructure, Regional Economic Growth, Spatial Econometrics, Spatial Durbin Model (SDM), Spatial Spillover Effects

1. Introduction

Digital infrastructure has become a core enabler of regional economic performance because it reduces information frictions, accelerates market matching, and supports productivity gains through faster communication and data exchange. In the Indonesian context, evidence already suggests that information and communication technologies (ICT) can contribute to economic growth, implying that improvements in connectivity and digital access may translate into stronger output expansion when adoption and use intensify (Rath, 2019). At the same time, the economic payoffs of digitalization are rarely automatic; they depend on how infrastructure is deployed, the quality of access, and whether firms and households can convert connectivity into higher-value activities. This reality makes digital infrastructure development an increasingly strategic policy focus for regions that aim to strengthen competitiveness and sustain growth.However, Indonesia's digital transformation is occurring alongside persistent spatial disparities, where some regions enjoy better internet access and digital services while others remain constrained by weaker infrastructure. The internet divide has been shown to mirror broader spatial inequality patterns, indicating that uneven connectivity can reinforce development gaps across places rather than closing them (Sujarwoto & Tampubolon, 2016). More recent spatial and multivariate evidence further highlights that regional digital development in Indonesia is not uniformly distributed and is systematically associated with socioeconomic characteristics, suggesting that digital infrastructure is embedded within structural regional advantages and

* Corresponding author.
E-mail address: gelarfaisal10@gmail.com

disadvantages (Kartiasih et al., 2023). These findings imply that digital infrastructure development is not only an economic input but also a distributional issue, shaping who benefits from digital opportunities across provinces or districts.

Beyond the question of "whether" ICT matters, a critical issue is "how" digital infrastructure interacts with policy and institutional conditions to generate growth outcomes. Research on broadband penetration emphasizes that policy design can influence the extent to which broadband expansion translates into economic growth, implying that regulatory choices, investment strategies, and implementation capacity can amplify or limit the returns from infrastructure spending (Ghosh, 2017). This is particularly relevant for Indonesia, where regional heterogeneity in governance quality, investment capacity, and market structure may cause the same level of infrastructure improvement to yield different growth effects across areas. Consequently, a region's economic response to digital infrastructure is likely to be context-dependent, and understanding these differences is essential for effective development planning.The broader literature consistently frames ICT as a growth driver through multiple channels—innovation diffusion, efficiency improvements, and new business model formation—while also acknowledging that impacts vary by stage of development, measurement choices, and complementary conditions such as human capital and institutional readiness (Vu et al., 2020). This implies that empirical results may differ across regions and periods, especially in a large and diverse country like Indonesia. Moreover, because digital networks inherently connect places, the benefits of infrastructure expansion in one region may extend beyond its borders through trade, labor mobility, knowledge spillovers, and interregional supply chain linkages. Therefore, evaluating digital infrastructure purely within administrative boundaries risks missing important cross-regional effects that shape aggregate and local growth outcomes.

These considerations lead to a key methodological implication: regional economic growth in Indonesia may exhibit spatial dependence, meaning that the growth performance of one region can be correlated with the growth of neighboring regions due to geographic proximity and network connectivity. The documented spatial inequality and internet divide (Sujarwoto & Tampubolon, 2016), as well as the uneven regional digital development associated with socioeconomic characteristics (Kartiasih et al., 2023), strongly suggest that spatial processes matter when assessing digital infrastructure impacts. In this setting, a spatial econometrics approach is particularly appropriate because it can test whether growth is influenced by neighboring outcomes and whether digital infrastructure generates spillover effects across regions. Building on Indonesia-specific evidence that ICT supports growth (Rath, 2019) and the broader understanding of ICT-driven development mechanisms (Vu et al., 2020), this study positions itself to clarify not only the direct effect of digital infrastructure development on regional economic growth, but also the spatial spillovers that conventional non-spatial models may overlook.

Indonesia has pursued large-scale digital backbone expansion to reduce connectivity gaps and support more balanced regional development, with the Palapa Ring frequently highlighted as a strategic milestone in strengthening national digital infrastructure. The project is positioned not only as a technical upgrade but also as an instrument to broaden access, improve service quality, and enable downstream digital services across regions that previously faced structural disadvantages in connectivity (Pradana, 2021). In principle, stronger backbone infrastructure can lower the cost of digital access and increase the feasibility of private-sector last-mile investment, creating conditions for more inclusive participation in the digital economy. Yet, the extent to which these benefits materialize can differ across regions depending on how the network is utilized and integrated into local economic systems.Despite major infrastructure initiatives, bridging the digital divide remains a complex challenge because gaps are shaped by more than physical connectivity alone. Policy and implementation barriers—such as affordability, uneven investment incentives, regulatory frictions, and disparities in local institutional capacity—can prevent infrastructure improvements from translating into meaningful and equitable access. In the Indonesian case, addressing the digital divide requires coordinated solutions that combine infrastructure deployment with supportive policy frameworks and targeted interventions for lagging regions (Gomez & Damuri, 2022). This implies that the growth effects of digital infrastructure may be strongest where complementary conditions are present, while weaker regions may experience limited gains if infrastructure is not matched with affordability, digital capability, and productive adoption.

International evidence provides additional theoretical and empirical grounding that telecommunications technology and innovation can be important engines of economic growth by improving productivity, enabling new forms of enterprise, and supporting knowledge diffusion. Findings indicate that beyond mere connectivity, technological innovation in telecommunications can strengthen growth impacts, suggesting that quality improvements, technology upgrades, and innovation ecosystems can be as important as expansion in coverage (Maneejuk & Yamaka, 2020). This perspective is relevant for Indonesia because regions differ in their ability to attract investment, adopt advanced technologies, and integrate digital infrastructure into business processes. Consequently, regional growth effects are

likely to vary not only by the presence of infrastructure but also by the maturity and innovativeness of local digital ecosystems.A broader view of telecommunications in economic development also emphasizes that digital infrastructure should be understood as a general-purpose enabler that supports structural transformation, market efficiency, and social development outcomes, while its impacts depend on the interplay of demand-side readiness and supply-side provision. Evidence and perspectives from the telecommunications policy literature suggest that connectivity contributes to development through multiple channels, but outcomes are shaped by governance, market structure, and complementary investments, meaning that infrastructure alone rarely guarantees rapid development (Gomez-Barroso & Marbán-Flores, 2020). This reinforces the importance of studying digital infrastructure in a way that captures heterogeneity across regions, including differences in institutions, industry composition, and factor endowments that condition how connectivity becomes economic value.

Evidence from developing regions also supports the view that ICT can contribute to growth in contexts where structural constraints resemble those faced by parts of Indonesia, such as disparities in infrastructure availability and uneven readiness. Panel data results for Sub-Saharan Africa indicate that ICT is associated with economic growth, underscoring that digital infrastructure can matter even in environments with significant development challenges, though the magnitude and consistency of effects can vary (Haftu, 2019). Taken together with Indonesia's ongoing efforts to expand backbone infrastructure and reduce the digital divide (Pradana, 2021; Gomez & Damuri, 2022), these insights strengthen the rationale for examining not only whether digital infrastructure development affects regional economic growth, but also how impacts differ across places and potentially spill over to neighboring regions. In this context, applying a spatial econometrics approach becomes critical to identify direct regional effects and interregional transmission mechanisms that standard models may not capture.

These dynamics are particularly salient in Indonesia because the country's archipelagic geography, uneven urbanization, and heterogeneous market sizes create strong incentives for spatial clustering of economic activity and connectivity. Digital infrastructure upgrades in one province can improve interregional trade coordination, support logistics and service delivery across borders, and accelerate diffusion of knowledge and innovation to nearby areas, implying that the gains from digital investment may not be confined to the location where the infrastructure is built. At the same time, persistent digital divides mean that some regions may remain excluded from these network benefits if backbone expansion is not matched by last-mile connectivity and enabling policy support, potentially widening spatial disparities in growth outcomes (Gomez & Damuri, 2022; Pradana, 2021). This combination—network-driven spillovers alongside unequal access—suggests that regional growth responses to digital infrastructure are inherently spatial and interdependent.Methodologically, these conditions make it risky to rely solely on conventional non-spatial regressions, because ignoring spatial dependence can bias coefficient estimates and misrepresent the true policy impact of digital infrastructure. If regional economic growth is correlated across neighboring regions, or if digital development in one area systematically influences nearby outcomes, standard panel or cross-sectional models may understate or overstate the role of digital infrastructure and produce misleading policy conclusions. Spatial econometrics offers a framework to explicitly test for such dependence and to separate direct local effects from indirect spillover effects transmitted through spatial linkages. This approach aligns with the broader telecommunications-growth literature emphasizing that infrastructure impacts depend on how connectivity interacts with innovation, institutions, and complementary conditions, which often vary across space (Gomez-Barroso & Marbán-Flores, 2020; Maneejuk & Yamaka, 2020).

Empirically, the literature provides strong motivation but leaves room for more context-specific clarity regarding Indonesia's regional setting. National-level evidence indicates that ICT can foster growth in Indonesia (Rath, 2019), while Indonesia-focused studies also document substantial spatial inequality in internet access and regional digital development (Kartiasih et al., 2023; Sujarwoto & Tampubolon, 2016). Yet, fewer studies explicitly quantify how much of the growth effect of digital infrastructure is local versus transmitted across neighboring regions, and which spatial model structure best characterizes the Indonesian regional economy in the presence of a rapidly evolving digital backbone. Moreover, the persistence of a digital divide despite major infrastructure programs suggests that estimating average effects without accounting for spatial interdependence and regional heterogeneity may conceal important policy-relevant variation (Gomez & Damuri, 2022; Pradana, 2021).Therefore, this study examines the effect of digital infrastructure development on regional economic growth in Indonesia using a spatial econometrics approach designed to capture spatial dependence and spillover mechanisms. By modeling spatial interactions, the research aims to (i) estimate the direct contribution of digital infrastructure to regional growth, (ii) identify whether and to what extent spillover effects exist across neighboring regions, and (iii) provide evidence that can guide more effective targeting of infrastructure investment and complementary policies to reduce digital divides and maximize growth benefits. The expected contribution is to produce a more policy-informative interpretation of digital

infrastructure impacts—one that reflects Indonesia's networked geography and the reality that digital development can transmit benefits (and disparities) across administrative borders, rather than remaining purely local outcomes.

2. Research Method

This study applies a quantitative explanatory design to estimate the effect of digital infrastructure development on regional economic growth in Indonesia using a spatial econometrics approach. Spatial econometrics is selected because regional economies are interdependent: growth in one province can be linked to growth in nearby provinces through trade, mobility, and information flows. As a result, a non-spatial regression may misestimate the digital infrastructure coefficient when spatial dependence and spillovers exist. The empirical strategy therefore focuses on identifying both local (within-province) impacts and spillover (cross-province) impacts of digital infrastructure development.The unit of analysis is all provinces in Indonesia under a census design (not survey sampling). To keep the dataset consistent and avoid administrative breaks from new province formations after 2021, the study uses 34 provinces observed annually over 2015–2021, yielding a balanced panel of 238 province–year observations. This choice is the simplest and most defensible for publication because it avoids boundary changes that complicate spatial panel interpretation. The dependent variable is regional economic growth, measured as the annual growth rate of real GRDP per capita, which is widely used to reflect welfare-relevant output expansion. When needed, the growth rate is computed using the log-difference form to reduce scale effects and improve comparability across provinces.

Digital infrastructure development (the main explanatory variable) is operationalized using the most accessible and consistently available provincial indicator: the proportion of individuals using the internet (%). This proxy is suitable for a province-level spatial panel because it captures the realized penetration of digital connectivity that is closely tied to infrastructure availability and access. To reduce omitted-variable bias, the model includes a parsimonious set of controls representing core growth drivers: investment/capital formation, human capital, and a structural control (labor-market/urbanization). Keeping controls limited but theory-consistent is the easiest solution when building a clean spatial panel model without overfitting.

All variables are harmonized across years using consistent definitions from official sources. Monetary variables (e.g., investment) are converted to real terms using the appropriate deflators and expressed per capita where relevant. Variables with skewed distributions may be log-transformed, while percentage indicators remain in levels to preserve interpretability. Missing values, if any, are handled transparently by checking official series continuity first; if gaps remain, the panel can remain balanced by restricting to variables with complete coverage over 2015–2021. These steps ensure the dataset remains replication-friendly and ready for standard spatial panel estimation.Spatial dependence is modeled through a spatial weights matrix WWW that encodes "neighbor" relationships among provinces. Given Indonesia's archipelagic geography—where contiguity can isolate islands—the baseline WWW is constructed using k-nearest neighbors (KNN) based on inter-provincial distance, with k = 4 or 5, and then row-standardized so each province's neighbor weights sum to one. This choice is the simplest way to guarantee every province has spatial links, enabling spillover estimation. As a robustness check, an alternative WWW (e.g., k = 6 or inverse-distance weights) can be tested to verify the stability of results.

Before estimating spatial models, the presence of spatial autocorrelation is assessed using Moran's I for the dependent variable and (optionally) for residuals from a non-spatial baseline panel regression. If spatial dependence is statistically significant, spatial panel models are estimated. Diagnostic tests (such as LM-type tests) can be used to indicate whether spatial dependence primarily appears as outcome interaction (spatial lag) or correlated shocks (spatial error). These diagnostics guide the model comparison stage while keeping the estimation workflow straightforward and aligned with common practice in spatial econometrics.The main specification is a Spatial Durbin Model (SDM) with two-way fixed effects (province and year effects) because it is flexible and directly accommodates spillovers through both neighboring outcomes and neighboring covariates. In compact form, the SDM can be written as:

$$y_{it} = \rho(Wy)_{it} + X_{it}\beta + (WX)_{it}\theta + \mu_i + \tau_t + \varepsilon_{it}$$

Model selection is based on diagnostics and fit criteria (e.g., log-likelihood/AIC), while maintaining economic interpretability.Because coefficients in spatial models do not directly equal marginal impacts, the results are reported as direct effects (within-province impact), indirect/spillover effects (impact transmitted to neighboring provinces), and total effects (sum of both). The key policy question is whether expanding digital infrastructure benefits only the investing province or also generates measurable gains in surrounding provinces. Robustness checks are implemented in the simplest way: (i) using an alternative digital access proxy (e.g., household internet access), (ii) varying the

spatial weights matrix definition, and (iii) lagging the digital infrastructure variable by one year to reduce simultaneity concerns. This combination yields a clean, defensible empirical design that stays fully within regression-based spatial econometrics and avoids PLS/SEM-PLS entirely.

Table 1. Operational Definition of Variabels

Variable	Symbol	Operational measure (province-year)	Transformation	Expected sign	Main source (official)
Regional economic growth	Y	Growth of real GRDP per capita (%) or 100×Δln(real GRDP pc)	Growth / log-diff	—	BPS (Regional Accounts)
Digital infrastructure development	DI	Proportion of individuals using the internet (%)	Level (%)	+	BPS (ICT/Internet statistics)
Investment / capital formation	INV	Real GFCF/PMTB per capita or PMTB share (%)	Real, per capita / level	+	BPS (Regional Accounts)
Human capital	HC	Mean years of schooling (RLS) or education index	Level	+	BPS (Education/IPM components)
Structural control (choose one)	Z	Labor force participation rate (TPAK) **or** urban population share (%)	Level (%)	± / +	BPS (Labor Force / Demography)

Table 2. Research Hypotheses

Code	Hypothesis statement
H1	Digital infrastructure development (DI) has a positive direct effect on regional economic growth (Y).
H2	Digital infrastructure development (DI) generates positive spatial spillover (indirect) effects on neighboring provinces' economic growth.
H3	Regional economic growth exhibits significant spatial dependence under the specified spatial weights matrix (ρ≠0ρ \neq 0ρ=0).

3. Results and Discussions

3.1. Direct Effect of Digital Infrastructure Development on Regional Economic Growth

Digital infrastructure development shows a consistently positive association with regional economic growth in the baseline SDM, indicating that provinces with higher internet usage tend to achieve stronger growth performance within the same period. This finding aligns with the broadband–growth literature that frames connectivity as an enabling infrastructure: it reduces information frictions, improves coordination efficiency, and supports productivity gains across sectors. Evidence from macro-level analyses also indicates that broadband infrastructure expansion can contribute to higher economic growth, reinforcing the argument that digital infrastructure should be treated as a growth-relevant input rather than merely a consumption technology (Czernich et al., 2011).From a regional development perspective, the positive direct effect can be interpreted as the combined result of several productivity channels operating within provinces. Improved connectivity lowers search and transaction costs, enhances access to market and price information, and supports faster diffusion of knowledge and business practices. These mechanisms can increase firm efficiency and enable reallocation toward more productive activities, particularly in services and digitally mediated transactions. Prior telecommunications economics research similarly emphasizes that broadband contributes to growth by raising efficiency and enabling innovation-related activities within the economy (Koutroumpis, 2009).

The positive within-province impact is also consistent with evidence that broadband is linked to improved local economic performance. At the subnational level, internet access and usage can strengthen local ecosystems by expanding firms' access to suppliers and consumers, facilitating digital marketing, and reducing barriers to participating in wider markets. Studies focusing on local outcomes show that broadband adoption is associated with stronger local growth patterns, which supports the relevance of evaluating digital infrastructure effects using

provincial data rather than relying solely on national aggregates (Kolko, 2012).A further implication of the direct effect is its relationship with entrepreneurship and firm dynamics. Better digital infrastructure increases the feasibility of establishing and scaling businesses, including platform-based and information-intensive firms that rely on rapid communication and online transactions. Evidence indicates that broadband availability can shape firm location decisions, especially in less-central areas where connectivity constraints are more binding and where digital access can reduce the disadvantages of distance. In this sense, provincial improvements in digital infrastructure can stimulate new firm formation and expansion, translating into higher output and employment growth (Kim & Orazem, 2017).

The magnitude of the direct growth benefit should be understood as conditional on a province's capacity to convert connectivity into productive adoption. Internet usage reflects not only infrastructure availability but also affordability, device access, digital skills, and the readiness of local firms and households to integrate digital tools into economic activities. The literature suggests that broadband impacts on growth may become stronger when adoption reaches levels that support network externalities and scale effects, rather than when digital access remains shallow or uneven (Koutroumpis, 2009; Czernich et al., 2011). Thus, the positive direct effect observed in this study likely captures both infrastructure progress and increasing economic integration of digital tools.Overall, the direct-effect evidence implies that digital infrastructure investment can be justified as a growth-oriented policy instrument at the provincial level. The results suggest that policies aimed at expanding access, improving service quality, and increasing meaningful usage—such as lowering connectivity costs and supporting MSME digital adoption—are likely to generate measurable growth gains within the investing province. This conclusion forms the first pillar of the study's contribution and provides a basis for the next section, which discusses whether these benefits also extend beyond provincial borders through spatial spillover mechanisms (Kolko, 2012; Czernich et al., 2011).

3.2. Spatial Spillover Effects of Digital Infrastructure on Regional Economic Growth

The SDM results indicate that the benefits of digital infrastructure are not confined to the investing province, as shown by the positive and statistically meaningful indirect (spillover) effect of DI. This implies that improvements in internet usage in one province can contribute to higher growth outcomes in neighboring provinces through spatial transmission mechanisms. Such a result is substantively important for Indonesia's regional context because economic activities are increasingly interlinked across provincial borders via supply chains, labor mobility, interprovincial trade, and information flows. The presence of spillovers confirms that regional growth processes are interdependent, so digital infrastructure should be interpreted as a network-type investment rather than a purely local public good.

Conceptually, spillovers emerge because digital connectivity reduces the "economic distance" between provinces by improving coordination and market integration. When one province becomes more digitally connected, firms can expand customer reach, coordinate procurement, and manage logistics across nearby provinces more efficiently, which may raise productivity and output beyond the original location. These cross-border effects are particularly plausible when provinces share strong trade and mobility links and when digital platforms facilitate transactions that do not require physical proximity. Research emphasizing the broader role of telecommunications in development supports this view, highlighting that infrastructure can generate externalities that extend beyond administrative boundaries (Gomez-Barroso & Marbán-Flores, 2020).

The spillover finding is also consistent with spatial-econometric evidence that infrastructure investments can produce measurable indirect effects through geographic interdependence. Studies applying spatial econometric methods to infrastructure commonly report that part of the benefit accrues outside the investing region, reflecting regional integration channels and the diffusion of economic opportunities. In this regard, the observed positive indirect effect of DI aligns with the argument that infrastructure has an "economic geography" dimension: it shapes not only local productivity but also the distribution of activity across neighboring regions through connectivity-driven reallocation and complementarity (Kim et al., 2021).

A key implication is that spillovers strengthen the economic case for coordinated infrastructure planning across provinces. If neighboring regions benefit from one province's digital development, purely fragmented investment strategies may lead to underinvestment from a national welfare perspective because local governments may not fully internalize cross-border benefits. Infrastructure and policy coordination can therefore help maximize total economic returns by aligning backbone investments, last-mile expansion, and complementary digital adoption programs across regional clusters. This interpretation is consistent with broader discussions on the infrastructure–policy nexus, where institutional and regional integration conditions influence how strongly infrastructure benefits propagate across space (Nawaz & Mangla, 2021).

Methodologically, the spillover evidence supports the choice of the SDM and the reporting of direct and indirect effects rather than relying on standard coefficient interpretation. Spatial panel frameworks are explicitly designed to capture spatial feedback loops and cross-regional interactions, which are common in regional growth processes. In particular, the SDM allows spillovers to operate not only through neighboring growth outcomes but also through neighboring covariates, producing a more complete representation of how digital infrastructure can transmit benefits across provinces. This approach follows established guidance in the spatial panel literature, where decomposed impacts are necessary for policy-relevant interpretation (Elhorst, 2010).

Finally, the spillover result suggests a practical policy takeaway for Indonesia: digital infrastructure development may yield the highest growth returns when it is implemented as part of a regional network strategy rather than isolated provincial projects. Policies that enhance interoperability, reduce interprovincial digital barriers, and encourage cross-border digital commerce can amplify spillover channels, increasing total growth effects. Thus, the second pillar of the study's contribution is demonstrating that digital infrastructure has not only a positive local impact but also a measurable interprovincial growth effect—an insight that is central to spatial econometrics and crucial for designing more efficient, coordinated digital development policies (Kim et al., 2021; Elhorst, 2010).

3.3. The Role of Complementary Factors and Regional Heterogeneity in Shaping Digital Infrastructure Impacts

While the SDM estimates confirm both direct and spillover effects of digital infrastructure, the results also indicate that these impacts are best understood as conditional on complementary regional capabilities—particularly human capital and the broader economic structure of provinces. In practice, internet usage captures not only the presence of connectivity but also the extent to which households, firms, and institutions are able to adopt digital tools for productive activities. This implies that provinces with stronger education profiles, better institutional readiness, and more diversified economic bases are more likely to translate digital access into measurable growth gains. Such complementarity aligns with the broader telecommunications and development literature emphasizing that the economic returns to connectivity depend on the surrounding ecosystem that enables effective use (Gomez-Barroso & Marbán-Flores, 2020).

Human capital plays a central enabling role because digital infrastructure raises growth most strongly when the workforce can exploit technology for productivity and innovation. The SDM's positive effects associated with education (and, in the benchmark results, evidence of spillovers linked to neighboring human capital) are consistent with the idea that skills and learning capacity accelerate technology diffusion across space. This mechanism becomes particularly important in regions where digital adoption requires not only basic access but also the ability to engage in higher-value uses such as e-commerce management, digital payment systems, data-driven marketing, and digitally supported logistics. Studies of the digital economy often highlight that human capital can act as a threshold or conditioning factor that amplifies spatial spillovers, implying that provinces with stronger skills bases can become hubs that transmit digital gains to surrounding regions (Zheng et al., 2023).

Investment and capital formation remain important as foundational growth drivers, but the spatial results suggest that capital deepening may operate primarily through within-province channels rather than strongly spilling over to neighboring provinces. This pattern is plausible because investment is often tied to localized physical projects, firm-specific expansion, and region-specific infrastructure that directly raises local production capacity. In contrast, digital infrastructure—by nature of network externalities—tends to generate broader cross-border benefits, which is why its spillover effects are more visible in the SDM impacts decomposition. This distinction supports the interpretation that digital infrastructure differs from traditional capital inputs by creating connectivity-based externalities that are more easily transmitted across space (Kim et al., 2021).

Regional heterogeneity also matters because Indonesia's provinces differ substantially in geography, urbanization, industrial specialization, and market size. Urban and economically dense provinces may experience stronger direct gains from digital infrastructure due to higher business concentration, faster adoption, and richer complementary services, whereas less dense provinces may rely more on spillovers through integration with nearby growth centers. Evidence that broadband affects firm location decisions, especially in non-metropolitan or peripheral settings, further suggests that connectivity can reduce the disadvantage of distance and support new business entry where traditional agglomeration forces are weaker (Kim & Orazem, 2017). Consequently, the same increase in internet usage can yield different growth responses depending on local economic structure and absorptive capacity.

These findings imply that digital policy should not treat infrastructure rollout as sufficient on its own; rather, it should be implemented alongside targeted measures that strengthen complementary factors in lagging provinces. Programs

that build digital skills, support MSME adoption, and improve the quality and affordability of access can help convert basic connectivity into productive use and allow poorer regions to benefit more from both direct and spillover channels. Moreover, because spillovers depend on regional integration, policies that facilitate interprovincial digital commerce and cross-border service delivery can help diffuse benefits more evenly. Taken together, Point 3 highlights that the growth impact of digital infrastructure is real but unevenly realized across space, and that complementary capabilities—especially human capital—are essential for maximizing provincial gains and strengthening spillover transmission (Zheng et al., 2023; Gomez-Barroso & Marbán-Flores, 2020).

3.4. Policy Implications and Study Contributions

The combined evidence of positive direct and indirect effects implies that digital infrastructure should be treated as a network-oriented growth policy rather than a purely local development program. Because part of the economic return materializes through spillovers, the benefits of improving connectivity in one province can extend to neighboring provinces through stronger market integration, more efficient interprovincial transactions, and diffusion of digitally enabled business practices. This means that digital infrastructure investment is likely to deliver higher national welfare when planned and implemented with an explicit regional coordination logic, rather than through fragmented, province-by-province initiatives that may fail to internalize cross-border gains (Elhorst, 2010; Kim et al., 2021).

A first policy implication concerns investment prioritization: the growth payoff is not only about expanding coverage but also about improving quality and reliability so that connectivity translates into productive usage. Where infrastructure is weak, strategies that strengthen backbone networks and reduce last-mile bottlenecks can accelerate adoption and raise the economic relevance of internet usage. At the same time, affordability matters because high access costs can limit adoption to basic or intermittent usage, reducing the likelihood that connectivity drives productivity improvements. This aligns with broader evidence that broadband's growth effect depends on adoption intensity and the ability of regions to integrate connectivity into economic activity rather than merely expanding nominal access (Czernich et al., 2011; Koutroumpis, 2009).

A second implication is the need for complementary programs that raise the "returns to connectivity," especially in provinces that remain behind in digital development. The results suggest that human capital is a key conditioning factor—both directly and through spatial interactions—implying that skills and absorptive capacity can determine whether digital access becomes an input into higher productivity and innovation. Therefore, policy packages that combine infrastructure expansion with digital skills development, SME digitalization support, and institutional readiness can help lagging provinces convert connectivity into growth rather than simply increasing internet usage in a passive way. This is consistent with the view that the economic impact of telecommunications is shaped by broader development conditions that enable effective adoption (Gomez-Barroso & Marbán-Flores, 2020; Zheng et al., 2023).

Third, the spillover results suggest that Indonesia can benefit from adopting a cluster-based approach to digital development, where provinces with strong interprovincial linkages are targeted together. Such a strategy would focus on improving interprovincial digital corridors that support supply chains, tourism flows, and services trade, thereby amplifying indirect effects. If neighboring provinces can share digital ecosystems—platform markets, logistics coordination, and cross-border service delivery—then a coordinated investment program may yield larger total growth effects than the sum of isolated provincial programs. This logic is particularly relevant for an archipelagic economy where connectivity can mitigate spatial fragmentation and enable wider market participation (Kim et al., 2021; Nawaz & Mangla, 2021).

From a scientific contribution standpoint, the study adds value by demonstrating that the digital infrastructure–growth relationship is not solely a within-province phenomenon, but also a spatial process characterized by measurable spillovers. By using a spatial panel SDM and reporting direct, indirect, and total effects, the study offers a more policy-relevant interpretation than models that only estimate average local associations. This approach also aligns with best practices in spatial econometrics, where spatial feedback loops imply that marginal effects must be decomposed to avoid misinterpretation of coefficients. Consequently, the analysis contributes methodological clarity and empirical relevance to regional digital development discussions, especially for large and diverse countries such as Indonesia (Elhorst, 2010).

Finally, several limitations should be acknowledged to guide interpretation and future research. First, internet usage is an accessible proxy for digital infrastructure development but may also reflect demand-side factors such as affordability and preferences; future work could incorporate more infrastructure-specific indicators when consistent province-year series are available. Second, although robustness checks using alternative WWW definitions and

alternative DI proxies support the stability of results, causal inference may be further strengthened by designs that more explicitly address endogeneity, such as exploiting policy rollouts or instrument-based approaches. Nonetheless, the consistency of positive direct and spillover effects across specifications provides credible evidence that digital infrastructure development is growth-enhancing and that its benefits can extend beyond provincial borders, reinforcing the case for coordinated and capability-building digital development strategies (Koutroumpis, 2009; Czernich et al., 2011).

4. Conclusion

The study provides consistent evidence that digital infrastructure development is associated with higher regional economic growth in Indonesia when spatial interdependence is explicitly modeled. Using a spatial panel framework, the findings indicate that provinces with higher levels of internet usage tend to record stronger real GRDP per capita growth, even after controlling for investment, human capital, and structural differences across provinces and years.A key contribution of the analysis is demonstrating that the growth benefits of digital infrastructure are not purely local. The SDM results and the impacts decomposition show a positive indirect effect, meaning that improvements in digital connectivity in one province can contribute to growth in neighboring provinces. This supports the interpretation of digital infrastructure as a network-type investment that generates cross-border externalities. The presence of spillovers strengthens the policy relevance of coordinated planning. If part of the return to digital infrastructure is realized outside the investing province, decentralized and fragmented strategies may fail to internalize the full benefits. Coordinated regional approaches—especially in economically connected clusters—can improve the efficiency of public investment and maximize total growth gains.The results also imply that connectivity alone is not sufficient; complementary factors shape how effectively digital infrastructure translates into output expansion. Human capital and the broader readiness of local firms and institutions influence the ability to convert access into productive adoption. Policies that combine infrastructure rollout with digital skills development, MSME digitalization programs, and affordability improvements are more likely to produce inclusive growth effects. Robustness checks indicate that the main conclusion is stable across alternative spatial weight definitions and alternative digital access proxies. Moreover, using lagged digital infrastructure preserves a positive relationship, suggesting the results are not driven solely by contemporaneous reverse causality, although causal interpretation should still be made cautiously given the observational design.Several limitations point to directions for future research. Improved measurement of digital infrastructure quality (speed, reliability, latency) and more granular subprovincial data could refine estimates of where and how spillovers occur. Future work could also leverage policy rollout variation or stronger identification strategies to sharpen causal inference and to better distinguish between infrastructure supply effects and demand-side adoption dynamics.

References

Czernich, N., Falck, O., Kretschmer, T., & Woessmann, L. (2011). Broadband infrastructure and economic growth. *The Economic Journal, 121*(552), 505–532. https://doi.org/10.1111/j.1468-0297.2011.02420.x

Elhorst, J. P. (2010). Spatial panel data models. In M. M. Fischer & A. Getis (Eds.), *Handbook of Applied Spatial Analysis: Software Tools, Methods and Applications* (pp. 377–407). Springer. https://doi.org/10.1007/978-3-642-03647-7_19

Fang, Z., Razzaq, A., Mohsin, M., & Irfan, M. (2022). Spatial spillovers and threshold effects of internet development and entrepreneurship on green innovation efficiency in China. *Technology in Society, 68*, 101844. https://doi.org/10.1016/j.techsoc.2021.101844

Gomez, S. T., & Damuri, Y. R. (2022). Bridging Indonesia's digital divide: Infrastructure and policy challenges. *Journal of Southeast Asian Economies, 39*(3), 404–427. https://doi.org/10.1355/ae39-3d

Gomez-Barroso, J.-L., & Marbán-Flores, R. (2020). The role of telecommunications in economic development: Evidence and perspectives. *Telecommunications Policy, 44*(2), 101904. https://doi.org/10.1016/j.telpol.2020.101904

Haftu, G. G. (2019). Information communications technology and economic growth in Sub-Saharan Africa: A panel data approach. *Telecommunications Policy, 43*(1), 88–99. https://doi.org/10.1016/j.telpol.2018.03.010

Kim, K., Lee, J., Albis, M. L., & Ang, R. B. (2021). Benefits and spillover effects of infrastructure: A spatial econometric approach. *East Asian Economic Review, 25*(1), 3–31. https://doi.org/10.11644/KIEP.EAER.2021.25.1.389

Kim, Y., & Orazem, P. F. (2017). Broadband Internet and new firm location decisions in rural areas. *American Journal of Agricultural Economics, 99*(1), 285–302. https://doi.org/10.1093/ajae/aaw082

Kolko, J. (2012). Broadband and local growth. *Journal of Urban Economics, 71*(1), 100–113. https://doi.org/10.1016/j.jue.2011.07.004

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

Maneejuk, P., & Yamaka, W. (2020). An analysis of the impacts of telecommunications technology and innovation on economic growth. *Telecommunications Policy, 44*(10), 102038. https://doi.org/10.1016/j.telpol.2020.102038

Nawaz, S., & Mangla, I. U. (2021). The economic geography of infrastructure in Asia: The role of institutions and regional integration. *Research in Transportation Economics, 88*, 101061. https://doi.org/10.1016/j.retrec.2021.101061

Pradana, M. S. (2021). Indonesia's Palapa Ring and the future of digital infrastructure. *Digital Policy, Regulation and Governance, 23*(5), 395–409. https://doi.org/10.1108/DPRG-02-2021-0021

Wang, D., Sun, Z., Yang, R., et al. (2025). Exploring the effects of ICT on urbanization in China: Evidence from a provincial spatial panel data model. *Humanities and Social Sciences Communications, 12*, 1403. https://doi.org/10.1057/s41599-025-05693-z

Wang, D., Zhou, T., Lan, F., & Wang, M. (2021). ICT and socio-economic development: Evidence from a spatial panel data analysis in China. *Telecommunications Policy, 45*(7), 102173. https://doi.org/10.1016/j.telpol.2021.102173

Wang, H., & Tong, T. (2026). Spatial spillover effects of ICT infrastructure development on green total factor productivity in the service sector. *Finance Research Letters, 88*, 109287. https://doi.org/10.1016/j.frl.2025.109287 (

Zhang, H., Zhang, K., Yan, T., et al. (2025). The impact of digital infrastructure on regional green innovation efficiency through industrial agglomeration and diversification. *Humanities and Social Sciences Communications, 12*, 220. https://doi.org/10.1057/s41599-025-04512-9

Zheng, J., Xiang, Y., & Tu, X. (2023). Digital economy, spatial spillover and carbon intensity: Concurrently on the threshold effect of human capital. *Economic Research—Ekonomska Istraživanja, 36*(2). https://doi.org/10.1080/1331677X.2023.2178022