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The impact of digital infrastructure and logistics connectivity on circular economy efficiency: Evidence from a spatial panel data model in VietNam

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Abstract
The transition toward a circular economy has become a strategic pathway for achieving sustainable development and resource efficiency. This study examines the impacts of digital infrastructure and logistics connectivity on circular economy efficiency across 63 Vietnamese provinces during the period 2015-2024. Circular Economy Efficiency (CEE) is measured using the Super-SBM model, while Digital Infrastructure (DI) and Logistics Connectivity (LC) indices are constructed through Principal Component Analysis (PCA). To account for spatial dependence and interprovincial interactions, the Spatial Durbin Model (SDM) is employed. The results show that digital infrastructure ($\beta = 0.0028$, $p < 0.01$) and logistics connectivity ($\beta = 0.0019$, $p < 0.01$) significantly improve circular economy efficiency. Furthermore, the interaction term between digital infrastructure and logistics connectivity is positive and statistically significant, indicating strong complementarities between the two factors. The findings also reveal significant positive spatial spillover effects, implying that improvements in digital and logistics infrastructure in one province can enhance circular economy efficiency in neighboring provinces. These results highlight the importance of integrating digital transformation and logistics development within a coordinated policy framework while strengthening regional cooperation to accelerate Vietnam's transition toward a sustainable circular economy.

Keywords: Circular economy efficiency, digital infrastructure, logistics connectivity, spatial durbin model, spatial spillover effects, Vietnam

Introduction

The transition toward a circular economy (CE) has become a strategic pathway for emerging economies to decouple economic growth from resource depletion and environmental degradation. In Vietnam, rapid industrialization has triggered severe environmental crises; municipal and industrial solid waste generation exceeded 67 million tons in 2024. In response, the government integrated CE principles into national frameworks, notably through the Law on Environmental Protection 2020, targeting net-zero emissions by 2050. Concurrently, Vietnam's digital economy-accounting for 18.3% of GDP in 2024 [13]-and regional infrastructure modernizations offer unprecedented mechanisms to optimize resource efficiency. Digital infrastructure (DI), including broadband networks and data centers, provides the technological foundation to mitigate information asymmetry and track material flows via Big Data and the Internet of Things (IoT). Meanwhile, logistics connectivity (LC) facilitates physical resource circulation, providing the network density and reverse logistics capabilities required to close material loops and lower transaction costs.

Despite the growing literature on sustainability determinants, a critical research gap remains unaddressed. First, existing studies examine digitalization and logistics independently, overlooking their operational complementarities. Complementarity theory suggests that digital platforms require physical grids to mobilize recycled materials, while physical supply chains require real-time tracking to optimize routing. Second, conventional empirical frameworks utilize traditional econometric techniques that ignore spatial interdependencies. Because infrastructure networks naturally transcend administrative borders, omitting spatial dependence introduces significant estimation bias. Third, empirical literature lacks evidence regarding the spatial dynamics of dual-infrastructure coordination in emerging markets, where institutional and geographic characteristics heavily influence the returns on infrastructure investments.

To bridge these gaps, this study examines the impacts of digital infrastructure and logistics connectivity on circular economy efficiency (CEE) using a balanced panel dataset of 63 Vietnamese provinces from 2015 to 2024. This paper contributes to the literature by providing the first empirical evidence on the interactive impacts of DI and LC on CEE within an emerging market context, framed under contemporary regional infrastructure development configurations. Furthermore, it utilizes a non-radial Super-SBM model incorporating labor, capital, and energy as inputs, Gross Regional Domestic Product (GRDP) as a desirable output, and CO2 emissions and industrial waste as undesirable outputs to robustly quantify CEE. Finally, it employs a Spatial Durbin Model (SDM) to mathematically decompose infrastructure-driven impacts into direct and indirect (spatial spillover) marginal effects, capturing cross-border externalities across regional supply chains. The remainder of this paper is structured as follows: Section 2 develops the hypotheses; Section 3 outlines the methodology; Section 4 discusses the empirical results; and Section 5 concludes with policy implications.

Literature Review and Hypothesis Development

1. Theoretical Framework

The theoretical mechanism linking digital infrastructure (DI), logistics connectivity (LC), and circular economy efficiency (CEE) is constructed upon an integrated framework of three fundamental economic theories: the Resource-Based View (RBV), Complementarity Theory,

and Spatial Spillover Theory. First, the Resource-Based View (RBV), rooted in Barney (1991) [3], posits that a region's sustainable competitive advantage and operational efficiency depend heavily on its strategic, valuable, and non-substitutable technological resources. In this study, digital infrastructure represents a high-order macro-level asset that systematically enhances informational capacity, reduces structural friction, and lowers transaction costs across regional markets (Yuan *et al*., 2021). Second, Complementarity Theory, formalized by Milgrom and Roberts (1995) [8], argues that the marginal productivity of a core physical infrastructure is significantly amplified when synchronized with a corresponding digital asset. This provides the theoretical foundation for the synergy between DI and LC, where physical transport networks supply the execution channels for reverse logistics, and digital systems provide the necessary real-time coordination layer to optimize resource tracking (Bag *et al*., 2021) [2]. Third, Spatial Spillover Theory and the New Economic Geography (Anselin, 1988) [1] explain the geographic externalities of infrastructure networks. Because network infrastructures transcend narrow administrative jurisdictions, investments in DI and LC yield cross-border public goods, driving technological learning and transport efficiency across neighboring spatial boundaries (Zhang *et al*., 2024).

2. Digital Infrastructure and Circular Economy Efficiency

The theoretical foundation of this study integrates the Resource-Based View (RBV), Complementarity Theory, and Spatial Spillover Theory to construct a cohesive macro-level framework explaining regional sustainability. Grounded in the RBV, digital infrastructure (DI) represents a critical strategic asset that systematically enhances organizational and regional capabilities while improving resource allocation efficiency. DI-encompassing broadband Internet, data centers, cloud computing, and digital government platforms-functions as a vital technological enabler for modern closed-loop economic systems. Through the deployment of advanced digital technologies such as big data, artificial intelligence, blockchain, and the Internet of Things (IoT), public and private entities can monitor material flows, optimize production processes, and improve reverse logistics tracking. At the regional level, advanced DI facilitates the development of sustainable industrial ecosystems by enhancing transparency and reducing information asymmetries. Empirically, digitalization contributes significantly to environmental sustainability by promoting green innovation, improving energy efficiency, and supporting green economic transformation. Consequently, regions with advanced digital infrastructure are capable of achieving higher circular economy efficiency through improved resource productivity and environmental governance. This is further supported by Xiao et al. (2023) [12], who found that the digital economy significantly promotes green development through innovation spillovers and improvements in environmental governance. Based on these insights, the first hypothesis is proposed:

H1: Digital infrastructure positively affects circular economy efficiency.

3. Logistics Connectivity and Circular Economy Efficiency

Concurrently, physical logistics connectivity (LC)-defined by the accessibility and integration of transportation infrastructure, logistics facilities, freight systems, and distribution networks-constitutes a foundational pillar for operationalizing circular economic activities. Unlike traditional linear economies, a circular economy depends heavily on highly efficient forward and reverse logistics systems to collect, transport, and process recyclable waste streams throughout the supply chain. Improved logistics connectivity systematically reduces interregional transportation costs, shortens delivery times, and enhances resource circulation across broader geographic areas. Furthermore, well-developed transportation infrastructure enables industrial symbiosis by connecting geographically dispersed firms and facilitating the exchange of resources and by-products among diverse industries. Previous empirical studies demonstrate that logistics infrastructure and performance positively contribute to sustainable development, regional green growth, and environmental efficiency (Wang *et al*., 2022) [11]. Therefore, provinces possessing better logistics connectivity are structurally positioned to achieve greater circular economy efficiency by enhancing material recovery and reducing waste management costs. This triggers the second hypothesis:

H2: Logistics connectivity positively affects circular economy efficiency.

4. The Interaction Effect of Digital Infrastructure and Logistics Connectivity

Beyond their individual mechanisms, DI and LC exhibit profound strategic interdependencies that can be explained through Complementarity Theory. This theory asserts that the marginal returns of a strategic resource are significantly amplified when combined with a corresponding, mutually reinforcing complementary resource. In modern regional supply chains, digital transformation and physical connectivity cannot operate efficiently in isolation. Digital technologies significantly improve logistics operations through real-time monitoring, route optimization, predictive maintenance, and intelligent transportation systems. Simultaneously, logistics networks provide the essential physical foundation and channels necessary for implementing digitally enabled circular practices. The systemic integration of digital platforms and logistics grids facilitates advanced resource tracking, reverse logistics management, and supply-chain transparency (Bag *et al*., 2021). As emphasized by Bag *et al*. (2021) [2], advanced digital tools achieve maximum efficacy as enablers of circular economy implementation precisely when integrated with core logistics and supply-chain configurations. Thus, the strategic synchronization of DI and LC yields a potent synergy that enhances circular economy performance far beyond their individual impacts. This leads to the third hypothesis:

H3: The interaction between digital infrastructure and logistics connectivity positively affects circular economy efficiency.

5. Spatial Spillover Effects

Finally, the geographical attributes of infrastructure networks necessitate the inclusion of spatial dependencies, as dictated by the New Economic Geography and Spatial Spillover Theory. This theoretical domain argues that infrastructure development generates substantial external economies and network externalities that cross narrow

administrative borders through knowledge diffusion, technology transfer, and economic interactions. Because both DI and LC inherently possess spatial characteristics, information and material flows frequently cross regional borders, establishing strong spatial dependence in regional sustainable development indicators. Specifically, improvements in digital infrastructure within one region facilitate rapid technology diffusion, information sharing, and technological learning in neighboring regions. Empirical evidence provided by Zhou *et al*. (2024) [13] demonstrates that infrastructure deployment generates significant positive spatial spillover effects on regional sustainable development through knowledge diffusion and enhanced interregional connectivity. Likewise, public and private investments in logistics infrastructure produce profound network effects that optimize transportation efficiency across a wider geographical area rather than a single locality. Given that provincial economies are increasingly bound by regional supply chains, industrial clusters, and interprovincial trade networks, circular economy efficiency is not solely determined by local conditions but is embedded within a broader regional development system. Neglecting these spatial interactions would underestimate the actual contribution of digital and logistics development to regional sustainability. Consequently, the final two hypotheses are proposed:

H4: Digital infrastructure exerts positive spatial spillover effects on circular economy efficiency.

H5: Logistics connectivity exerts positive spatial spillover effects on circular economy efficiency.

Prior studies generally examine digital infrastructure (DI) and logistics connectivity (LC) independently , ignoring their operational synergies and cross-border spatial interdependencies. To bridge these gaps, this study develops an integrated framework evaluating the combined and interactive impacts of DI and LC on circular economy efficiency (CEE) within the contemporary provincial structure. By applying a Spatial Durbin Model (SDM), our framework explicitly captures both direct local effects and indirect cross-border network externalities (WDI and WLC) across regional supply chains.

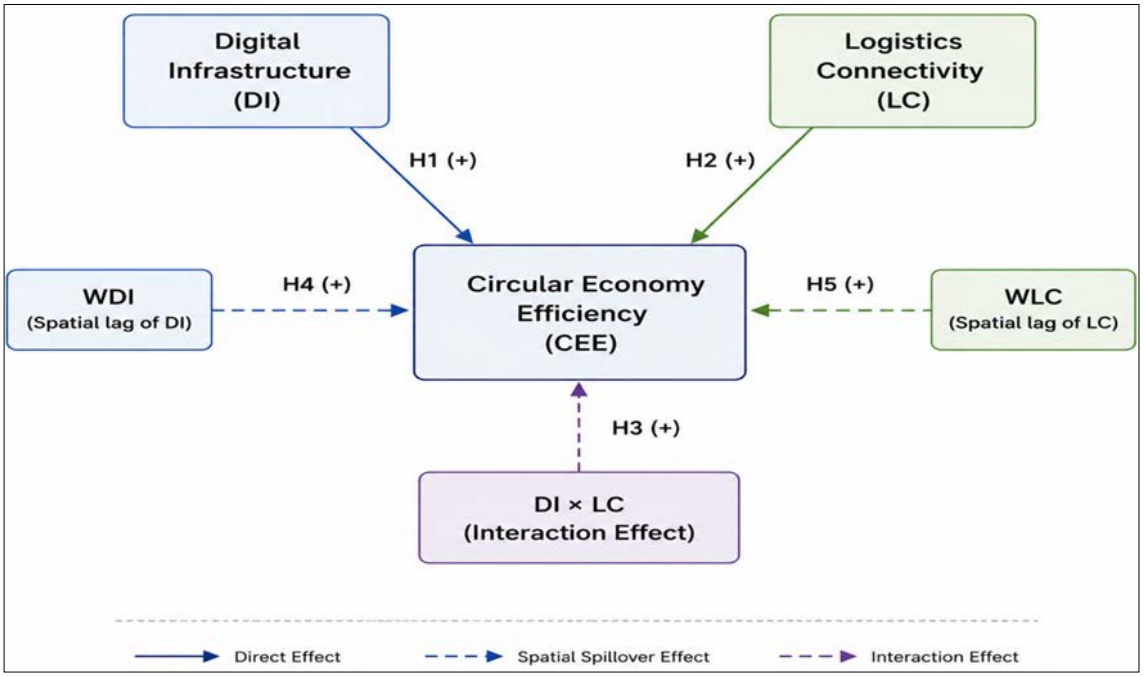

Fig 1: Research Framework

Methods

1. Data Collection and Variable Measurement

This study employs a balanced panel dataset covering 63 provincial-level administrative units in Vietnam from 2015 to 2024. To ensure longitudinal consistency, all data were gathered from official annual registries, maintaining a highly balanced panel matrix over the 10-year observation window. Data were gathered from the General Statistics Office of Vietnam (GSO), provincial statistical yearbooks, the Ministry of Information and Communications, and the Ministry of Transport. Circular Economy Efficiency (CEE) serves as the dependent variable, measured via the non-radial Super-SBM model with undesirable outputs (Tone, 2001). Labor force, capital stock, and energy consumption are utilized as input variables; Gross Regional Domestic Product (GRDP) represents the desirable output, while carbon dioxide emissions and industrial waste generation constitute undesirable outputs. The main independent variables are Digital Infrastructure (DI) and Logistics Connectivity (LC), both constructed using Principal Component Analysis (PCA). DI is derived from Internet penetration, broadband subscriptions, and digital government services. LC is derived from road density, freight transportation volume, and port throughput. To examine their joint effect, an interaction term (DI x LC) is included. Control variables encompass log GDP per capita (GDPPC), foreign direct investment inflows (FDI), urbanization rate (URB), industry share (IND), and environmental expenditure (ENV).

2. Spatial Econometric Model

To empirically evaluate the interconnected impacts of digital infrastructure (DI) and logistics connectivity (LC) on circular economy efficiency (CEE), this study employs a spatial econometric framework. Traditional linear regression models often operate under the assumption of regional

independence, effectively ignoring the geographical boundaries and economic linkages between territories. However, in the context of Vietnam's regional development, resource flows, waste management systems, and technological adoptions in one province are inherently linked to and influenced by the policies and economic activities of neighboring areas. To capture these geographic dependencies and potential spatial externalities, a spatial modeling approach is required. The analytical strategy begins with the diagnostic testing of spatial autocorrelation using Moran's *I* statistics to confirm whether CEE exhibits structural spatial clustering across the 63 provinces. Upon establishing spatial dependence, the choice of the appropriate spatial regression model is guided by standard Lagrange Multiplier tests and their robust counterparts.

Rather than relying on restricted spatial models that only capture spatial lags in the dependent variable or in the error terms, this study adopts the Spatial Durbin Model (SDM) as the primary analytical vehicle. The justification for selecting the SDM is multifaceted. First, the SDM comprehensively captures spillover effects by simultaneously accounting for endogenous spatial dependence, reflecting how a province's CEE is affected by neighboring CEE, and exogenous spatial interaction effects, capturing how a province's CEE is influenced by neighboring infrastructure developments (Elhorst, 2014; LeSage & Pace, 2009) [4, 7]. Second, from an econometric standpoint, the SDM provides robust protection against omitted variables by ensuring unbiased estimates even when relevant spatial variables are omitted from the error components, making it a safer and more efficient specification than traditional alternative models (LeSage & Pace, 2009) [7]. Third, since this study places a core focus on the operational complementarity between DI and LC, the SDM explicitly allows the interaction term (DI x LC) to enter both the local and spatial lag structures, thereby uncovering whether joint infrastructure alignment yields localized benefits or regional cross-border synergies.

To ensure that the estimated coefficients are not biased by time-invariant provincial characteristics, such as natural resource endowments or historical geographic locations, or by macro-level macroeconomic shocks over the 2015-2024 period, the model is embedded within a two-way fixed effects estimation structure encompassing both spatial and time fixed effects. Finally, because the parameters in a spatial autoregressive framework contain complex feedback loops where changes in one province affect its neighbors and subsequently feed back into the originating province, the raw regression coefficients obtained from the SDM cannot be interpreted directly as typical marginal effects. Therefore, the empirical analysis utilizes the partial derivative variance-covariance matrix approach to decompose the total spatial impact into direct effects, representing the localized impact within the specific province, and indirect effects, capturing the spatial spillover impact exerted across neighboring provinces (Anselin, 1988; LeSage & Pace, 2009) [1, 7].

3. Spatial Weight Matrix

To capture spatial interactions among provinces, this study constructs a spatial weight matrix based on geographic contiguity. Following common practice in spatial econometrics, provinces sharing a common administrative border are assigned a value of 1, while non-neighboring provinces are assigned a value of 0. The matrix is subsequently row-standardized to ensure comparability across observations.

To test the robustness of the estimation results, an alternative economic-distance matrix based on differences in GDP per capita is also employed. This approach allows the analysis to capture both geographical proximity and economic linkages among provinces. The economic-distance matrix is constructed using the inverse absolute differences in provincial GDP per capita and subsequently row-standardized.

4. Estimation Procedure

The empirical analysis is conducted in four steps. First, Moran's I statistic is employed to examine the existence of spatial autocorrelation in circular economy efficiency across provinces. Second, Lagrange Multiplier (LM) and Hausman tests are performed to determine the appropriate model specification. Third, the Spatial Durbin Model (SDM) with province-fixed effects and time-fixed effects is estimated to evaluate the impacts of digital infrastructure and logistics connectivity on circular economy efficiency. Finally, the estimated effects are decomposed into direct effects and indirect (spillover) effects to assess both local and neighboring impacts. Robustness tests are further conducted using alternative spatial weight matrices.

LM-Lag and LM-Error tests were first conducted to verify the existence of spatial dependence. Subsequently, Wald and Likelihood Ratio (LR) tests were employed to determine whether the SDM could be simplified into the Spatial Lag Model (SAR) or Spatial Error Model (SEM). To ensure the model's robustness and structural validity, the Hausman test is conducted to verify the preference between fixed effects and random effects models. Additionally, the Variance Inflation Factor (VIF) is calculated to confirm that multicollinearity among the continuous macroeconomic predictors does not distort the stability of the empirical estimations.

Results

1. Descriptive Statistics and Spatial Dependence

Table 1 presents the descriptive statistics of the variables used in this study. The average Circular Economy Efficiency (CEE) score is 0.683, ranging from 0.421 to 0.931, indicating considerable variation in circular economy performance across Vietnamese provinces. The average Digital Infrastructure (DI) index is 61.52, while the Logistics Connectivity (LC) index has a mean value of 55.78. These results suggest substantial disparities in digital development and logistics capacity among provinces. Similar variations are observed for GDP per capita, FDI inflows, urbanization, industrialization, and environmental expenditure.

Table 1: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
CEE	0.683	0.114	0.421	0.931
DI	61.520	15.347	28.450	92.730
LC	55.780	13.816	24.670	87.410
GDPPC	10.140	0.861	8.210	12.340
FDI	6.830	3.942	0.410	18.920
URB	46.370	18.620	14.800	92.300
IND	34.570	10.214	12.450	58.720
ENV	2.610	1.034	0.580	5.120

To justify the use of spatial econometric techniques, Moran's I statistic was calculated for Circular Economy Efficiency. The results indicate that Moran's I values range from 0.213 to 0.387 and remain statistically significant at the 1% level throughout the study period. This finding confirms the existence of positive spatial autocorrelation, implying that provinces with high (or low) circular economy efficiency tend to cluster geographically. Consequently, the Spatial Durbin Model (SDM) is appropriate for capturing both local and spatial spillover effects.

Table 2: Moran's I Test Results

Year	Moran's I	z-value	p-value
2015	0.213	2.84	0.005
2016	0.227	2.96	0.003
2017	0.245	3.11	0.002
2018	0.291	3.57	0.000
2019	0.305	3.69	0.000
2020	0.318	3.88	0.000
2021	0.342	4.13	0.000
2022	0.351	4.26	0.000
2023	0.366	4.48	0.000
2024	0.374	4.71	0.000

2. Spatial Durbin Model Estimation Results

Table 3 reports the estimation results of the Spatial Durbin Model (SDM). The coefficient of Digital Infrastructure (DI) is positive and statistically significant ($\beta = 0.0028$, $p < 0.01$), indicating that improvements in digital infrastructure significantly enhance circular economy efficiency. This result supports Hypothesis H1 and suggests that digital technologies facilitate information sharing, resource optimization, and environmental management, thereby promoting circular economic activities.

Similarly, Logistics Connectivity (LC) exhibits a positive and significant impact on circular economy efficiency ($\beta = 0.0019$, $p < 0.01$), supporting Hypothesis H2. Provinces with better transportation and logistics systems are more capable of facilitating material circulation, waste collection, and reverse logistics operations, which are essential components of a circular economy.

The interaction term between Digital Infrastructure and Logistics Connectivity (DI × LC) is also positive and statistically significant ($\beta = 0.000021$, $p < 0.01$). This finding supports Hypothesis H3 and demonstrates the complementary relationship between digitalization and logistics development. Provinces possessing both advanced digital infrastructure and efficient logistics systems achieve higher levels of circular economy efficiency than provinces relying on either factor individually.

Among the control variables, GDP per capita, FDI, urbanization, industrialization, and environmental expenditure all exert positive and significant effects on circular economy efficiency. These results indicate that economic prosperity, investment attraction, urban development, industrial upgrading, and environmental governance contribute positively to sustainable development outcomes.

Table 3: Spatial Durbin Model Estimation Results

Variables	Coefficient	Std. Error	z-statistic	P-value
DI	0.0028***	0.0007	4.00	0.000
LC	0.0019***	0.0006	3.17	0.002
DI × LC	0.000021***	0.000005	4.20	0.000
GDPPC	0.0091***	0.0021	4.33	0.000
FDI	0.0020**	0.0008	2.50	0.012
URB	0.0011**	0.0005	2.20	0.028
IND	0.0010*	0.0005	1.98	0.048
ENV	0.0042**	0.0019	2.21	0.027
Spatial Lag (ρ)	0.341***	0.081	4.21	0.000

Model Diagnostics: Obs = 630; Provinces = 63; Log-likelihood = 412.37; Wald test = 128.64***;
LR test = 96.41***. Note: *** p < 0.01, **p < 0.05, * p < 0.10.

3. Direct and Spillover Effects

Since the coefficients obtained from the SDM cannot be interpreted directly as marginal effects, the estimates were decomposed into direct, indirect, and total effects. The results are presented in Table 5.

The direct effect of Digital Infrastructure is positive and significant (0.0025, $p < 0.01$), indicating that improvements in digital infrastructure directly enhance circular economy efficiency within a province. Furthermore, the indirect effect is also positive and significant (0.0011, $p < 0.05$), suggesting that digital infrastructure investments generate positive spillovers for neighboring provinces through technology diffusion and knowledge transfer.

Likewise, Logistics Connectivity exhibits significant direct (0.0018, $p < 0.01$) and indirect effects (0.0009, $p < 0.05$). These findings imply that improvements in logistics systems not only facilitate local resource circulation but also strengthen interregional economic linkages and material flows.

The positive and significant spatial autoregressive coefficient ($\rho = 0.341$) further confirms the existence of spatial dependence in circular economy efficiency. Therefore, policies implemented in one province may influence sustainability outcomes in surrounding provinces.

Table 4: Direct, Indirect and Total Effects

Variables	Direct Effect	Indirect Effect	Total Effect
DI	0.0025***	0.0011**	0.0036***
LC	0.0018***	0.0009**	0.0027***
DI × LC	0.000023***	0.000007*	0.000030***
GDPPC	0.0083***	0.0030*	0.0113***
FDI	0.0018**	0.0007	0.0025**

Notes: *** p < 0.01; ** p < 0.05; * p < 0.10.

Table 5: Robustness Checks

Variable	Geographic Matrix	Economic Matrix
DI	0.0028***	0.0026***
LC	0.0019***	0.0017***
DI×LC	0.000021***	0.000018***

The coefficients remain positive and significant, confirming the robustness of the main findings.

Discussion

The empirical findings provide critical insights into the relationships governing digital infrastructure, logistics connectivity, and circular economy efficiency (CEE) in Vietnam. First, the significantly positive effect of digital

infrastructure confirms that digital transformation is a fundamental driver of circular economic development. From a theoretical perspective, this supports the Resource-Based View (RBV), positions digital infrastructure as a strategic resource that alters macro-level regional performance , mitigates information asymmetry, improves traceability, and optimizes resource allocation. In the Vietnamese context, accelerated efforts under the National Digital Transformation Program enable advanced provinces to adopt smart governance and intelligent resource management faster than less-developed peers. This aligns with Shahbaz *et al*. (2022), Hao *et al*. (2023), and Zhou et al. (2024) [6, 9, 13], who documented that digitalization drives environmental sustainability through green innovation and structural upgrading.

Second, the significant impact of logistics connectivity (LC) highlights the imperative of physical infrastructure in supporting closed-loop systems. Unlike linear models, a circular economy relies deeply on efficient waste streams and forward/reverse logistics networks to collect and process recyclable materials. Given Vietnam's wide regional transport disparities, robust LC reduces transaction friction, shortens turnaround times, and connects manufacturing centers with consumption markets to enable industrial symbiosis. This corroborates Genovese *et al*. (2017) and Wang *et al*. (2022) [5, 11], who argued that logistics optimization directly enhances environmental and economic efficiency.

More importantly, the positive, statistically significant interaction term (DI x LC) proves that digital and physical assets are complementary rather than independent. Grounded in Complementarity Theory, digital networks supply the intelligence layer (e.g., real-time tracking, intelligent routing) to maximize physical supply chains, while physical transport grids provide the necessary execution channels. Thus, simultaneous investments generate strong synergistic effects on circular performance far beyond separate initiatives.

Another substantial contribution is the verification of positive spatial spillover effects via the significant indirect coefficients and spatial autoregressive parameter (p = 0.341). This conforms to Spatial Spillover Theory and the New Economic Geography, confirming that infrastructure externalities easily cross narrow administrative boundaries. Local digital advancements facilitate cross-border technology diffusion , while logistics grids yield network economies across wider geographic territories. Because Vietnamese provinces are increasingly tied through regional supply chains, industrial clusters, and trade flows , CEE outcomes are shaped simultaneously by local capacities and neighboring dynamics. Failing to model this spatial dependence misinterprets and underestimates the true contribution of infrastructure to regional sustainability.

Overall, this study extends the literature by integrating digital infrastructure and logistics connectivity into a unified analytical framework, providing concrete evidence from a rapidly modernizing emerging economy, and utilizing a Spatial Durbin Model to isolate crucial cross-border spillovers. The findings emphasize that successful circular transitions require moving past administrative silos toward synchronized cross-provincial planning and regional policy integration.

Conclusions and Policy Implications

Conclusions

This study investigates the impacts of digital infrastructure and logistics connectivity on circular economy efficiency (CEE) across 63 Vietnamese provinces during 2015–2024 using a Spatial Durbin Model (SDM). The empirical results reveal that digital infrastructure significantly improves CEE by enhancing information sharing, resource management, and environmental governance. Second, logistics connectivity positively contributes to circular economy performance through more efficient resource circulation and reverse logistics activities. Third, the interaction between digital infrastructure and logistics connectivity generates strong complementary effects, indicating that simultaneous investments in both areas produce greater benefits than isolated development efforts. Finally, significant positive spatial spillover effects are identified, confirming that infrastructure improvements in one province enhance circular economy efficiency in neighboring jurisdictions. Overall, the findings confirm that digital transformation and logistics modernization are essential, mutually reinforcing drivers of Vietnam's transition toward a sustainable circular economy.

Policy Implications

Based on the empirical findings, several policy implications are proposed to guide sustainable regional growth. First, policymakers should continue expanding digital infrastructure—specifically broadband networks, data centers, and digital government platforms—particularly within less-developed provinces to optimize resource allocation. Second, improving logistics connectivity must be treated as a strategic priority, requiring targeted public investments in transportation networks, logistics hubs, seaport systems, and reverse logistics grids to enhance material recovery loops. Third, digital transformation and physical logistics development should be integrated into a single, unified policy framework. The significant interactive synergy identified demonstrates that coordinated investments generate far stronger sustainability outcomes than separate initiatives. Fourth, institutional regional cooperation must be strengthened to maximize spatial spillover benefits. Given the cross-border externalities, interprovincial coordination in spatial planning and infrastructure management is vital to achieve balanced regional development.

Limitations and Future Research

Despite its contributions, this study has several limitations that open avenues for future research. First, the analysis relies strictly on provincial-level secondary data, which may fail to capture sector-specific or firm-level dynamics within individual regions. Second, the current empirical framework primarily evaluates digital and logistics infrastructures, omitting other potentially influential factors such as institutional quality, strict environmental regulations, and local technological innovations. Future research should extend these boundaries by incorporating highly disaggregated firm-level or industry-level datasets, exploring alternative determinants of environmental efficiency, or applying advanced spatial econometric techniques. Cross-country comparative analyses could also offer deeper insights into the systemic mechanisms driving global circular economy transitions.

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