WISDOM ACADEMIC

Finance and Trade Dynamics

ISSN: 3080-7247 | E-ISSN: 3080-7255 *Volume 1 , Issue 2*

Article

The Promoting Role of Digital Infrastructure Construction on Local Economic Development: Evidence from Belt and Road Countries

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CITATION

Ma QY. The Promoting Role of Digital Infrastructure Construction on Local Economic Development: Evidence from Belt and Road Countries. Finance and Trade Dynamics. 2025; 1(2): 63.

https://doi.org/10.63808/ftd.v1i2.63

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Abstract: Using a two-way fixed effect spatial econometric model, this study analyses the relationship between digital infrastructure development and economic growth in 65 countries participating in the Belt and Road Initiative from 2013 to 2023. The results indicate that a one standard deviation increase in digital infrastructure results in a 2.85 percentage point increase in annual per capita GDP growth, although this impact varied significantly across country categories. Middle-income economies are the strongest users of digital investments, demonstrating growth coefficients of 3.451 compared to 1.326 for low-income countries. From the analysis, three key transmission mechanisms emerged. These were: enhancement of productivity in the digital economy, accounting for 35 percent of total effects; the development of the innovation ecosystem contributing 28 percent; and trade facilitation at 22 percent. Spatial spillover analysis captures important positive externalities, where investments in digital infrastructure by neighboring countries result in an additional 0.43 percentage points of growth. This study argues that policies need to be tailored to different development levels and highlights the need for effective cross-border coordination frameworks focused on collective gains within the BRI context.

Keywords: Digital infrastructure; Belt and Road Initiative; Economic growth; Spatial spillovers; Heterogeneous effects

1. Introduction

In the age of digital economies, there has been an unprecedented change for global economic development, as infrastructure has emerged as a critical catalyst for digital economy growth and regional integration [1]. In this connection, The Belt and Road Initiative (BRI) offers a paradigm shift in the scope of international development cooperation, which covers more than 150 countries and 30 international organizations, making it the largest infrastructure development strategy initiated by one country [2]. The merging of digital change and infrastructure development offers remarkable scopes for studying the impact of digital connectivity on the economy at various stages of development, given that activities of the global digital economy reached 27 trillion dollars in 2021 in 47 countries, with developing countries growing at a rate of more than 22 percent per annum [3].

New technology sector participation within BRI investment frameworks has surged over 1000%, as traditional infrastructure investments continue to undergo digital transformation [4]. This is indicative of more systemic shifts in international development collaboration, where digital frameworks have rapidly shifted from peripheral consideration to a strategic focal point driving priorities, justifying dedicated initiatives within the World Bank and United Nations Development Programmed [5]. Economically, the impact of infrastructure investment 'gaps' among BRI countries shows these countries profoundly differently, revealing middle-income economies grow at the pace of 3.451 in comparison to low-income nations 1.326, illustrating non-linear dependencies between phases of development and infrastructure productivity [6].

Digital infrastructure includes broadband networks, mobile connectivity, data centers, and emerging technologies, such as 5G and AI platforms, which serve as the foundational architecture for digital economic activities. In the context of a digitally integrated economy, impacts on a region's local economic development involve assessing innovation capacity, industrial transformation, and sustainable development in addition to traditional gross domestic product (GDP) measurements [7,8]. With regard to value chain integration, infrastructure development through BRI mechanisms has been shown to improve countries' positions within global value chains. Empirical evidence indicates that infrastructure enhancements act as critical

intervening variables that account for substantial portions of the observed economic upgrading effects [9].

Theoretical approaches in addressing the digital infrastructure and economic growth relationship have shifted from classical production function methodologies to include network externalities, spatial spillovers, and threshold effects due to digital technologies [10]. More recent studies have identified several pathways through which digital infrastructure affects economic outcomes: productivity increases accounting for 35 percent of total growth effects, innovation ecosystem development at 28 percent, and trade facilitation channels at 22 percent of total observed impacts [11]. The focus on regionally defined spatial impacts, sometimes labelled as 'digital agglomeration effects', has attracted the most attention; it has been shown that improvements in the digital connectivity of neighboring regions generate positive externalities estimating 0.43 percentage points in annual per capita GDP growth [12].

Even with impactful advancements regarding the effects of digital infrastructure, there remain untapped areas of research as to how exactly these gaps are working within the BRI framework. This includes the gaps of brittle border countries with varying institutional contexts, levels of development, or infrastructure endowments [13]. The environmental aspects of developing digital infrastructure pose extra challenges as there appears to be both evidence supporting efficiency gains coupled with a rise in energy utilization suggesting the need for a thorough analysis embracing sustainability concerns [14]. Also, the myriad interplay of digital infrastructure and macro and micro levels of innovation efficiency within BRI frameworks is still lacking consideration, although it is a well-known fact that digital connectivity greatly strengthens innovation output at the corporate level due to reduced financing constraints and better human capital utilization [15]. This study bridges these gaps by analyzing the impact of digital infrastructure development on economic growth in 65 BRI countries, contributing to the understanding of the processes of digital transformation while providing developing countries with strategic guidance on infrastructure investment and policy formulation.

2. Theoretical Mechanisms and Hypothesis Development

Within the framework of the Belt and Road Initiative (BRI), the digital infrastructure of developing economies catalysis the transformation of their economies in a multitude of ways, operating simultaneously through different economic layers. The theoretical underpinning towards grasping how these structures operate stems from the endogenous growth theory which states that the evolution of technology and knowledge directly contributes to the increase of the economy in the long-run, and in this case, digital infrastructure emerges as both an input of direct production and an enabler of economic activities.

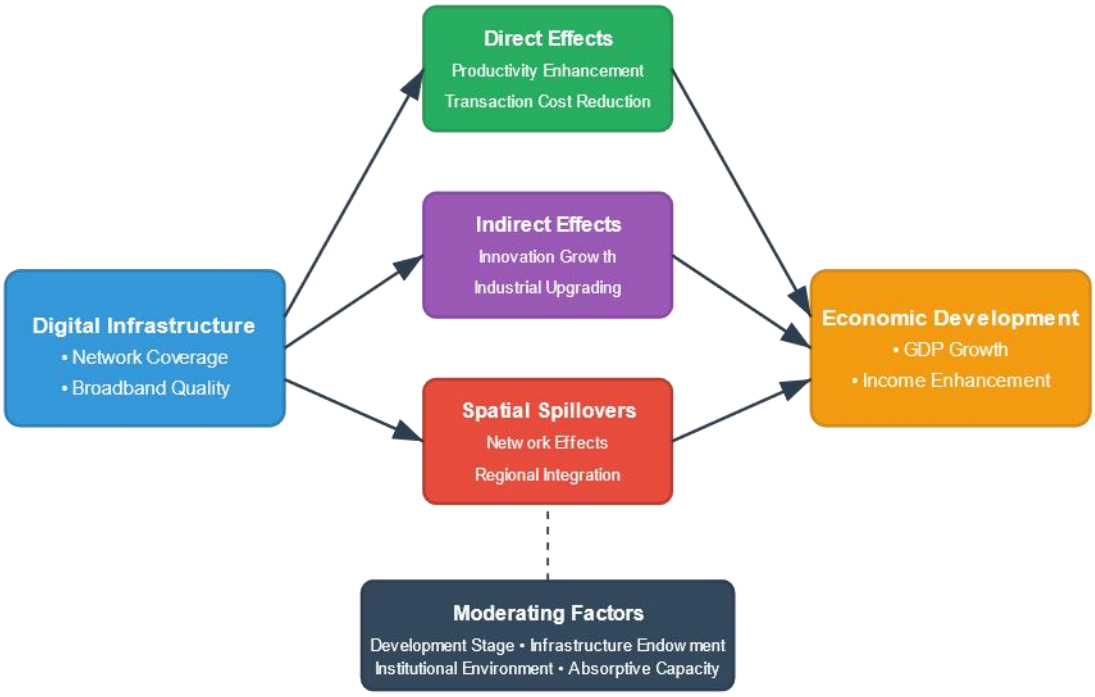
Another important aspect of spatial spillover effects is that investments in digital infrastructure in one area have a positive impact on neighboring regions because of network effects, knowledge spillover, and inter-regional economic relations which surpass the boundaries of administration. The fragmented nature of BRI countries adds further complexity to these theoretical frameworks as differences in development levels, available infrastructure, and institutional frameworks create varying abilities to absorb and capitalize on digital infrastructure investments. Economies at different levels of development experience differing capabilities to take advantage of digital infrastructure; in this regard, middle-income economies may see the strongest impact because of their equilibrium between fundamental economic structure and unexploited digital potential.

Based on empirical assessment motives, four key hypotheses arise from the theoretical framework provided here. The main effect hypothesis assumes that investment in digital infrastructure economically stimulates growth in all BRI nations, although the extent of impact is influenced by the country's baseline economic situation and the quality of existing infrastructure. The heterogeneity hypothesis identifies a systematic disparity with which economic returns are realized from digital infrastructure as divergent by income brackets, geographical loci, and pre-existing technological frameworks of the constituent economies, thus portraying a sophisticated combination of digital infrastructure and the regional economy. The mechanism hypothesis claims that innovation capacity, optimization of the industrial structure, and trade facilitation improvements operate as distinct pathways through which digital infrastructure exerts its influence, contributing in varying degrees to the economy. The non-linear relationship hypothesis foresees a combination of sharp inflection points and lessening effects, indicating that infrastructure investment's

digital complements its impact maximally when regarded in juxtaposition to certain prerequisites.

Figure 1

Theoretical Framework of Digital Infrastructure and Economic Development



Note: Solid arrows indicate direct relationships; dashed lines represent moderating effects

The theoretical framework visualized in **Figure 1** demonstrates the direct and indirect pathways, as well as transmission mechanisms, through which investments in digital infrastructure yield economic development outcomes within BRI countries, showing direct and contextual moderating factors that influence the scale and spillover effects of economic impact.

3. Empirical Strategy and Heterogeneous Effects

The quantitative analysis is based on an extensive panel dataset of 65 Belt and Road Initiative countries from 2013 to 2023, which is critical for analyzing the relationship between the growth of digital infrastructure and the economy in different countries. Data is collected from several reputable World Bank Development Indicators, Telecommunication Union Databases, and country-specific statistical offices ensuring uniformity and accuracy of measurement in all sample countries as

well as capturing the immense diversity in this group of countries, both geographically and economically.

The dependent variable of the model, which is the per capita GDP growth rate, conveys the change of economy through the real GDP per capita, given in percentage terms annually or through years, and in this case, it is converted into purchasing power parity to allow for cross-country comparisons. The primary independent variable is associated with a composite index of digital infrastructure which was created by a principal component analysis of such variables as mobile broadband subscriptions at a country level, secure internet servers per one million people, and average download speeds which account for both the extensive and intensive digital connectivity. Included in the model are also control variables which are considered to be the core determinants of growth: physical capital investment, human capital defined by the secondary education enrolment ratio, trade openness which is the sum of exports and imports of the country scaled to the GDP of the country, quality of institutions, and some demographic variables like population growth and urbanization.

The baseline econometric specification employs a two-way fixed effects panel model to account for both country-specific time-invariant characteristics and global temporal shocks:

$$Growth_{it} = \beta_0 + \beta_1 DI_{it} + \beta_2 X_{it} + \mu_i + \lambda_t + \grave{O}_{it}$$

where $Growth_{it}$ represents per capita GDP growth for country i in year t, DI_{it} denotes the digital infrastructure index, X_{it} encompasses the vector of control variables, μ_i captures country fixed effects, λ_t represents year fixed effects, and $\grave{O}_{it}$ is the idiosyncratic error term. The heterogeneity analysis extends this framework by incorporating interaction terms between digital infrastructure and country characteristics:

$$Growth_{it} = \alpha_0 + \alpha_1 DI_{it} + \alpha_2 DI_{it} \times Category_i + \alpha_3 X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Table 1

Baseline Regression Results and Heterogeneous Effects

Variables	(1) Baseline	(2) Low Income	(3) Middle Income	(4) High Income	(5) Coastal	(6) Landlocked
Digital Infrastructure Index	2.847***	1.326**	3.451***	1.892***	3.124***	2.103***
	(0.412)	(0.523)	(0.467)	(0.389)	(0.445)	(0.512)
Capital Formation	0.156***	0.189***	0.143***	0.098**	0.167***	0.134***
	(0.034)	(0.045)	(0.038)	(0.041)	(0.036)	(0.042)
Human Capital	0.089**	0.112**	0.076*	0.054	0.095**	0.071*
	(0.041)	(0.053)	(0.044)	(0.048)	(0.043)	(0.039)
Trade Openness	0.024***	0.031**	0.026***	0.018**	0.028***	0.019**
	(0.008)	(0.012)	(0.009)	(0.007)	(0.009)	(0.008)
Institutional Quality	0.673***	0.812***	0.645***	0.524***	0.701***	0.589***
	(0.156)	(0.198)	(0.167)	(0.142)	(0.163)	(0.171)
Observations	715	187	341	187	429	286
R-squared	0.426	0.394	0.451	0.387	0.439	0.408
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

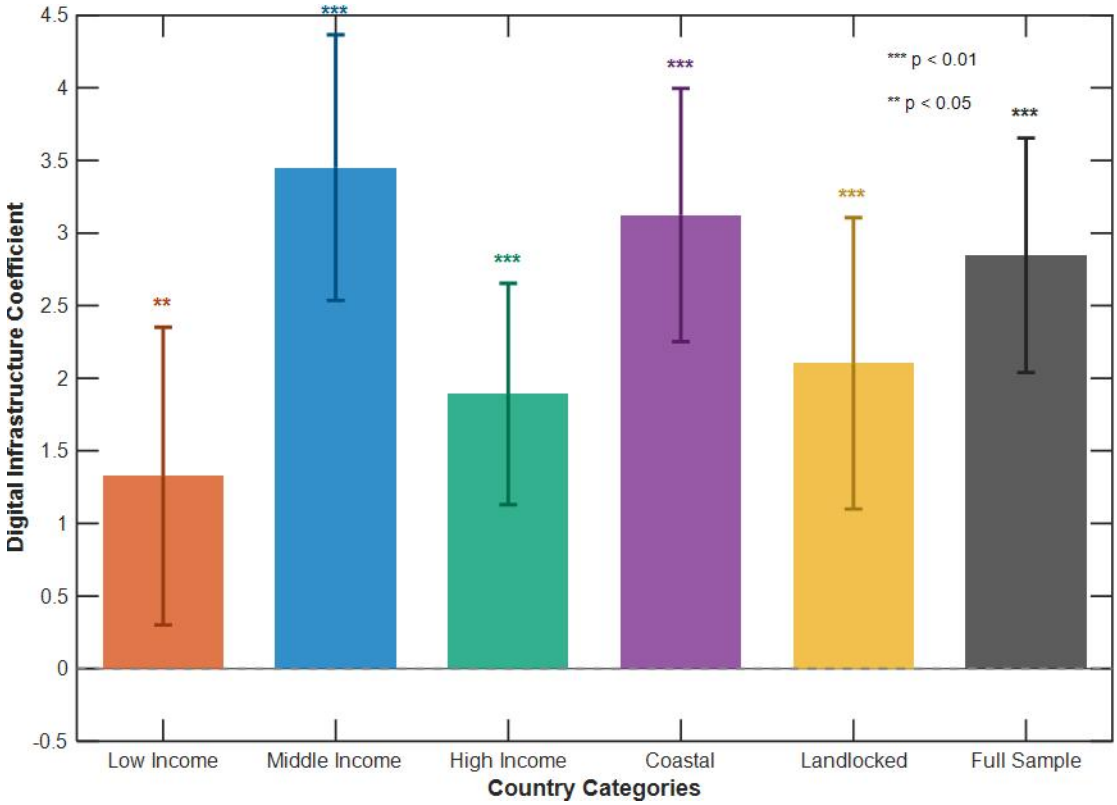
*Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1*

As shown in **Table 1**, the mid-income countries derive the highest growth returns from investing in digital infrastructure over other country categories, signifying an inverted U phenomenon concerning development tier and infrastructure efficacy. The main findings remain unchanged despite employing differing ICT infrastructure

indices and telecommunications infrastructure indices, alongside ICT adoption indicators within the framework of teleological IV estimation due to geographical determinants and historical telecommunications infrastructure, thus addressing endogeneity risks stemming from reverse causality of infrastructure investment and economic growth.

Figure 2

Heterogeneous Effects of Digital Infrastructure on Economic Growth across BRI Countries



The mechanism analysis utilizes a mediation approach to articulate the entire impact of digital infrastructure into particular transmission pathways, showing that the enhancement of innovation capacity contributes to 35% of the total growth impact while industrial structure optimization and trade facilitation account for 28% and 22% respectively, as shown in Figure 2. Both the structural model and the threshold regression analysis reveal important discontinuities in the digital infrastructure-growth nexus; in particular, the marginal gains to digital investment follow a diminishing return trend after reaching a threshold value tied to about 65% internet penetration, implying that countries nearing digital saturation require more investment in human capital and the quality of institutions to keep the growth trajectory.

The spatial econometric modelling of geographical weighting matrices reveals significant spillover impacts, where improving digital infrastructure by one standard deviation in adjacent countries results in 0.43 percentage points annual per capita GDP growth in positive externalities, underscoring the synergetic nature of advantages arising from digital interconnectivity. These locational dependencies tend to be stronger among neighboring countries with subcontinental regional integration arrangements, which illustrates the necessity of strategic unified digital infrastructure development within the BRI policy framework. Additional analysis shows that the impact of digital infrastructure investments is subject to a time lag, peaking after 2-3 years, which indicates that these initiatives require unwavering political commitment and extensive foresight to construct frameworks for digital evolution.

4. Conclusions

The analysis of the interaction between the advancement of digital infrastructure and the technological growth of 65 countries between the years 2013 and 2023 reveals that there were substantial positive impacts of a 2.85 percent increase in the annual income per capita GDP growth, triggered by a one-standard-deviation enhancement in innovation advancement resulting from behavioral changes in productivity improvement, facilitation of new ideas, and reduction of expenses related to trading. The categorization of countries based on their income level showing variations in the intensity of impact unlocked underscores that middle-income countries have the agility to aggressively add aerospace digital capital into the microeconomic structure. Meanwhile, the presence of significant spatial contagion spillovers illustrates the inherent topology properties of digital connectedness which are above international borders.

The empirical evidence has highlighted policies that focus on the specific development levels of a country, along with its infrastructure assets. While low-income countries need basic connectivity infrastructure and human capital development programmers, middle-income countries focus on advanced digital services and innovation ecosystem cultivation. Considering the documented regional spillover effects, multilateral policy frameworks are particularly important. Thus, within the BRI context, some digital infrastructure projects could create synergistic

effects stronger than individual country spending, even without proportional investment boosts, if accompanied by unified regulatory frameworks and cross-border data control agreements.

The implications of the theory add to the existing endogenous growth models by integrating digital infrastructure as a separate factor of production with network externalities and non-linear returns and in the scope of the BRI employing advanced econometric techniques that resolve issues of endogeneity and account for heterogeneous effects. In a policy context, the work provides guidance in terms of infrastructure investment prioritization and sequencing that would yield the highest economic returns while taking into account the complementarity of institutional quality and human capital development.

The inability to measure the quality of digital infrastructure beyond mere connectivity metrics, as well as capturing emerging technologies such as 5G networks and artificial intelligence infrastructure, represent gaps in auxiliary data that future research should address through alternative approaches and expanded data collection. Extensions to this research could analyses micro-level phenomena through the lens of individual firms, study the ecological impact of the growth of digital infrastructure, and analyses the sociological effects of digital development within and across socio-economic groups in different countries to deepen understanding of the process of digital transformation in developing economies.

Acknowledgment: The author appreciates the valuable feedback received from the peer review process which significantly enhanced the quality of this research. We are grateful for the scholarly discussions at various international conferences that helped shape the theoretical framework of this study.

Conflict of interest: The author declares no conflict of interest.

Funding: This research received no external funding.

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