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Economic Impacts of Smart City Initiatives and Industrial Corridor Development on Urban Transformation in Developing Countries: A Meta-analysis

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Abstract

This study analyzed the economic impact of smart city initiatives and industrial corridor development on urban transformation and local economic diversification in developing countries. In developing countries such as Ethiopia, Smart City projects and industry corridors on urban transformation have been systematically under-researched, despite the occurrence of many Smart City and industrial corridor projects. This analysis applies endogenous growth theory and new economic geography, and the integration of the findings from 47 published peer-reviewed studies across Asia, Africa, and Latin America was completed using meta-analysis techniques, resulting in the inclusion of 312 elasticity estimates between 2015 and 2026. Moreover, a random-effects model using restricted maximum likelihood estimation and robust variance estimates was applied to control for the variance and heterogeneity between the different outcomes. The analyses revealed that the digital infrastructure provided a corrected output elasticity of 0.071, which was larger than the expected value for developed economies, and the transport infrastructure produced an output elasticity of 0.053. The use of quasi-experimental approaches produced output elasticity estimates that were 0.024 lower than those reported from the production function models. Additionally, publication bias existed in the sample, resulting in an inflated effect of 13–15%. The analysis concluded that infrastructure investments and corridors have a strong return on investment. Finally, it is recommended that rural infrastructure targeting be prioritized, institutional capacity be invested in before technology procurement, blended finance with local content requirements be adopted, corridor investments be combined with skills development, and rigorous quasi-experimental evaluation be mandated.

JEL Classification: H54, O14, O18

1. Introduction

Urbanization as a key driver of development in developing nations cannot be overstated and is one of the primary demographic trends of the 21st century (United Nations Department of Economic and Social Affairs, 2019). By 2050, an estimated 68% of the global population will reside in urban environments, and nearly nine out of ten (90%) urban populations will be located in Africa and Asia. These rapid transformations in the built environment due to urbanization provide both great potential for developing viable economic enterprises and significant challenges regarding the development of infrastructure systems, providing adequate services, and developing a sustainable economy. Developing countries will face the greatest challenge with urbanization: the establishment of sound infrastructure systems to support a diversified economy through the creation of jobs and the elimination of poverty during their current periods of rapid urbanization.

It is estimated that the annual infrastructure financing deficit for developing countries will exceed $1 trillion (World Bank, 2022), significantly restricting the ability of these nations to provide, develop, or build adequate transportation, energy, water, and digital connectivity systems for their citizens. The lack of adequate infrastructure between urban and rural populations creates greater spatial inequalities and

limits the potential for productivity and job growth in the future, while creating barriers to the restructuring of national economies from historically agricultural and primary commodity-based economies.

To respond to these issues, countries from all 3 continents of Asia, Africa, and Latin America are utilizing two infrastructure approaches: smart city initiatives and industrial corridor development. Smart cities are characterized as urban centers where urbanization combines the use of advanced digital technologies, information and communication systems, data-based governance, and technology-enhanced infrastructure networks to maximize urban efficiency, deliver services better, and promote greater economic growth (Caragliu et al., 2011). Industrial corridors are large-scale, integrated networks of infrastructure that allow the interconnection of industrial clusters, transportation systems, logistics hubs, and urban centers to enhance trade and attract investment, thereby driving industrial development (Asian Development Bank, 2021).

Investment in the public and private sectors will greatly support different types of initiatives. The African Development Bank (2023). stated that between 2018 and 2023, over 100 billion dollars were invested in infrastructure in Africa annually, with a large portion of that going towards Transportation and Digital Infrastructure investments. Asia's infrastructure will require approximately $1.7 trillion per year to support continued growth, while Industrial Corridors are key elements of National Development Strategies across all countries, from India to Indonesia. (Asian Development Bank, 2024).

Nonetheless, despite significant investments in infrastructure by multiple organizations, many questions remain regarding the economic effects of these strategies and how those effects differ regionally, demographically, and based on the outcome being evaluated. Empirical research finds much heterogeneity in the available evidence and even conflicting results. Research published has employed a variety of methodological approaches, measuring infrastructure effects differently at different times in their history, using geographic areas of different sizes, and finding different numbers of elasticities. This adds a level of complication to creating evidence-based policies and determining the circumstances under which infrastructure investment is successful or unsuccessful. As such, it is not entirely inconsistent with the existing literature; in their thorough review of 87 countries, they find that, overall, there is a positive long-term effect from infrastructure investment on Gross Domestic Product (GDP) with smaller short-run positive effects (Timilsina et al., 2024).

However, while measuring the overall increase due to infrastructure investments, there is disagreement between empirical studies concerning these increases because of differences in methodological approaches, how researchers define infrastructure, the development of countries at varying stages of development, and what rural versus urban regions are defined as (within countries). The meta-analysis of approximately 1,000 estimates covering 201 articles between 1983 and 2022 found that the average effect of infrastructure investment on economic development was modest once the effects of publication bias were accounted for within their research. The elasticity for individual sectors ranged from 0.00 to 0.06, depending on the sector (World Bank, 2023).

There is an urgent need to systematically synthesize the available evidence related to the economic impact of smart city initiatives and industrial corridor development (ICD). Smart cities and ICD are both relatively new concepts in urban planning, and most research on these topics has been conducted since 2015.

Additionally, much of the current literature is based on case studies or qualitative research, and the quantity of available quantitative analyses is limited. While the ICD is supported by a long-standing tradition of research, there is wide variability in terms of geographic coverage, methodological rigor, and outcome measurement. To date, there is no existing and comprehensive meta-analysis of either ICD or smart city initiatives conducted in developing countries. This study aims to address this issue through a comprehensive meta-analysis of the economic impacts of smart cities and ICD projects in developing countries. To do so, we systematically synthesize 312 elasticity estimates from the existing literature, which comprise 47 papers published between 2015 and 2026, and are obtained exclusively from Scopus-indexed journals and the Web of Science database.

The meta-analysis will focus on answering three distinct but interrelated research questions.

- What are the average economic impacts of smart cities and ICD projects in developing countries compared to the estimated impacts in developed economies?
- How does the estimated impact vary by infrastructure type (digital vs. transport), geographic focus (urban vs. rural), outcome measure (output vs. employment vs. poverty vs. trade), and methodological approach (production function vs. quasi-experimental designs)?
- What are the policy-relevant factors, including institutional quality, financial development, human capital, and complementary investments, that explain the variation in project success?

The paper is organized as follows: next to the first section discussed above, the second section develops the theoretical framework by blending information from endogenous economic growth theory, new economic geography, and coordination failure theory to produce testable hypotheses for future research. The third section describes the methodology adopted; the fourth section provides the results and discussions of the study, while the left part of the paper consists of conclusions and policy implications, as well as limitations of the study.

2. Theoretical Framework

2.1 Endogenous Growth Theory and Infrastructure Productivity

The endogenous growth theory provides an essential foundation for understanding the relationship between infrastructure investment and long-term economic development. Endogenous models differ from neoclassical models by demonstrating that the effects of investments in physical capital, human capital, and knowledge creation will continue to provide a source of productivity improvement with

increasing returns, knowledge spillovers, and innovation externalities (Romer, 1986; Lucas, 1988; Barro, 1990).

Infrastructure plays many roles in the growth process, consistent with the mechanisms provided by endogenous growth theory. First, infrastructure provides a public (or quasi-public) input into production processes, lowering the costs of private production and increasing the marginal product of private capital. The government-provided infrastructure services complement private investments to produce endogenously generated growth via the non-rival/non-excludable characteristics of infrastructure (Barro, 1990).

The second role of infrastructure in supporting the growth process is by fostering knowledge spillovers through the connection between economic actors and facilitating information exchange. Transportation infrastructure brings together firms, researchers, and entrepreneurs who would otherwise be separated from each other into close physical proximity, through which face-to-face interactions of economic actors facilitate the diffusion of innovations(Audretsch & Feldman, 1996). Digital infrastructure facilitates virtual connections that lower the cost of accessing knowledge and help accelerate the adoption of technology across institutions and industries (Czernich et al., 2011).

Furthermore, infrastructure complements private investment and has been identified as an important contributor to the amplification of growth effects. For example, improved transport connectivity associated with new rail lines can enhance the returns associated with locating production facilities in previously isolated regions, thereby generating additional private capital investment. The availability of reliable electricity allows firms to implement productivity-enhancing technologies that would be difficult to implement if there are frequent interruptions in the provision of power(Roller and Waverman, 2001). On the other hand, the growth impacts of electrical and communication infrastructure are much more significant than the growth impacts of transportation infrastructure in developing countries as opposed to developed countries (Timilsina et al., 2024).

H1

The output elasticities associated with infrastructure investments in developing countries will be greater than the estimates of output elasticities associated with infrastructure investments in developed countries.

2.2 New Economic Geography and Spatial Concentration

The primary mechanism driving the new economic geography is the trade-off between agglomeration forces that drive the clustering of economic activities and dispersion forces that drive the dispersion of those activities. Firms benefit from co-locating with one another because of shared access to specialized suppliers, pooled labor markets, and knowledge spillovers (Marshall, 1920), which give rise to agglomeration economies and result in increased returns that encourage concentrated economic activity. Conversely, the reduction in transport costs associated with infrastructure investments also

enables firms in the center of urban areas to serve the periphery of urban areas from central locations, ultimately resulting in continued industrial development in the center of urban areas (Puga, 2002).

Corridors create an environment conducive to the development of agglomeration economies around corridor nodes by minimizing transportation costs along designated routes. The proximity of firms to the intersection of a corridor enables them to take advantage of enhanced connectivity, resulting in the formation of industrial clusters that attract more firms, employees, and supporting industries. The cumulative causation process associated with industrial clusters can lead to self-reinforcing growth dynamics, whereby initial investments in infrastructure lead to ongoing growth (Krugman, 1991).

On the other hand, the new economic geography suggests that infrastructure can create unequal spatial development patterns. As transport costs decline, clustered activity will likely occur near already established nodes to the detriment of remote locations, which would lose business as they become easier to access for core producers. The net result depends on whether agglomeration or dispersion forces dominate and the nature of the spatial configuration of the infrastructure network (Fujita et al., 1999).

H2

The impact of infrastructure investment on the economy varies across geographical locations; specifically, rural areas will realize more pronounced marginal impacts owing to less connectivity before investment and a greater degree of infrastructure constraints limiting capacity.

2.3 Coordination Failure Theory and the Big Push

The theory of coordination failure derived from) “Big push” model highlights the crucial role of infrastructure in development. The main point here is that investments in infrastructure may not occur because they depend on complementary investments occurring simultaneously; none of the individual investors can coordinate their investments well enough to lead them to invest together in complementary inputs (Rosenstein-Rodan’s, 1943).

Nchofoung et al. (2023 studied the moderating influences of financial development and human capital on the impact of infrastructure on industrialization across thirty-three African nations. They showed that infrastructure investments directly promote industrialization, while indirect effects vary across studies based on the interaction of financial development or human capital with infrastructure. Their empirical findings demonstrate that the presence of required complementary investments in both financial development and human capital served as minimum thresholds to nullify the conditional (negative) impact of infrastructure on industrialization.

H3

Complementary investments in human capital and financial development produce larger returns on investments in infrastructure.

2.4 Institutional Conditionality

Various theoretical and empirical studies have pointed to the importance of institutional quality as a determining factor in understanding how infrastructure impacts development (North, 1990; Rodrik, 2000; Acemoglu et al., 2005).

The existence of strong institutions, such as secure property rights, contract enforcement, regulatory quality, and effective government, enables infrastructure to deliver development benefits through various channels. First, institutions determine the quality of infrastructure and maintenance. Weak governance can lead to inadequately constructed projects, cost overruns, and poor maintenance, which reduce the effective flow of infrastructure services from what would otherwise be expected from an investment in infrastructure (Kenny, 2007).

Transparent processes and meritocratic bureaucratic structures with safeguards to prevent corruption help ensure that government spending on infrastructure is transformed into productive assets rather than being misappropriated. Second, institutions affect how the benefits of infrastructure are distributed. The manner in which the regulatory framework defines who can access and use infrastructure services and under what conditions dictates how the benefits of infrastructure are distributed (World Bank, 2023).

Institutions significantly impact private sector investment behavior regarding infrastructure. When a company feels confident that contractual agreements will be enforced, there is regulatory stability, and there is a predictable policy environment, it is more likely to invest in response to infrastructure improvement. Poor institutional quality may decrease the private sector's response, leading to a lower multiplier effect associated with government (public) infrastructure investment. Estache et al. (2015) examine the informational and operational implications of whether developing countries should pursue private or public financing for infrastructure (depending on their type of government)

The authors indicate that if a country has a limited ability to make credible commitments to maintain fiscal and policy discipline, it will likely have difficulty attracting large amounts of private infrastructure.

H4

The quality of a country's institutions positively affects the development impact of the improvements made to infrastructure.

2.5 Financial Development and Human Capital as Thresholds

New studies have shown that the development of financial services and education, along with the presence of an adequately skilled labor force, are both critical to the attainment of infrastructure benefits. This finding builds on coordination failure theory through its identification of specific complementary variables that must reach certain minimum levels before infrastructure can produce

positive rates of return. The development of financial services allows for a more efficient use of financial resources in an economy, as they help direct savings towards productive investments with minimal asymmetries in information risk between lenders and borrowers.

The increasing returns can be obtained when knowledge flows from one firm to another, indicating that when there is an investment in knowledge and materials that contribute to the success of a particular business, the success of that business will, in turn, encourage further investment in both knowledge and infrastructure. Therefore, workers must be able to read, write, perform basic mathematics, and use basic technical skills to function in today's industrialized and service economy (Romer, 1990).

In a recent publication, Nchofoung et al. (2023) found that the empirical evidence of threshold effects exists in African countries. The authors analyzed infrastructure development and its relationship with industrialization across 33 African countries from 2000 to 2019. The findings suggest that infrastructure development is associated with industrialization; however, the extent to which the net positive effect of this association exists depends on achieving specific levels of financial development and human capital. Therefore, if either of these two conditions is not met, the infrastructure does not produce a positive return on investment. The study further indicated that in a subset of the models employed, the interaction effects between infrastructure and industrialization are negative until each threshold is crossed.

The positive impact on poverty alleviation from infrastructure will vary depending on the specific characteristics of the emerging market. Analysis of a sample of nine emerging markets from 2000 to 2018 revealed that infrastructure has a significant impact on poverty reduction; however, both education and employment will act as important channels through which the effects of infrastructure will be transmitted to poverty reduction. Based on these findings and evidence from prior research (Tsaurai, 2024).

H5

The financial development and human capital serve as thresholds for infrastructure's impact on industrialization.

2.6 Methodological Considerations and Publication Bias

Infrastructure is a heterogeneous area of research with respect to method, which has significant implications for meta-analysis. Infrastructure research has primarily used a production function approach using aggregate and sectoral data (Aschauer 1989; Munnell, 1992).

Through the use of production functions, researchers typically estimate output elasticities with respect to infrastructure capital stocks, and production function estimates are likely to be plagued by endogeneity bias due to: (1) an embedding, where infrastructure investment is part of the economic condition; (2) a common cause that affects both infrastructure and economic output; and (3)

measurement error that reduces the strength of the coefficients measured (Gramlich 1994). Quasi-experimental methods include difference-in-differences, instrumental variables, regression discontinuity designs, and synthetic control, which are all methods commonly applied to the evaluation of infrastructure (Baum-Snow 2007; Donaldson 2018).

As shown by Doucouliagos and Stanley (2013), as well as Stanley (2005), the presence of publication biases, the tendency for journals to predominantly accept statistically significant results for publication, poses a serious challenge for both evidence-based policy and meta-analytic validity. Publication bias in the field of infrastructure research is evidenced by an over-representation of statistically significant positive estimates in the literature, as well as an under-representation of null or negative effects.) documents the existence of publication bias in infrastructure studies and presents estimates of infrastructure effects that are much smaller than had been originally calculated following an adjustment for publication bias, using almost 1,000 estimates from 201 empirical studies published between 1983 and 2022. In the World Bank meta-analysis, correction for publication bias produced elasticities for individual sectors that ranged from 0 to 0.06 (World Bank, 2023).

H6

Quasi-experimental designs produce smaller estimates of infrastructure effects that are more credible than those produced using production function methods.

3. Methodology and Data

3.1 Meta-Analytic Framework

In this paper, the author used the meta-analyses method because it has more advantages over the method of study: (i) the studies have a large degree of heterogeneity due to true context, differences in methodologies, and error due to sampling. The method of meta-analysis is a way of estimating averages that have less variation than an individual study, as well as to quantify the degree to which there really are differences between studies. (ii) the method calculates how study characteristics moderate effect sizes and model heterogeneity in the meta-regression analysis of the data collected; and (iii) the evidence of publication bias can be checked and adjusted for when conducting a meta-analysis.

3.2 Study Selection and Inclusion Criteria

Analyses were obtained by conducting systematic searches within the Scopus and Web of Science online databases. These databases span all areas of peer-reviewed academic work regarding economics, urbanization, regional science, and economic development. The reason for selecting these specific databases was due to their broad amount of peer-reviewed research and their strict standards for indexing to include only journals that have undergone the formal peer review process. Boolean operators were used in this study to merge databases. The studies being sought to review include all studies regarding economic development through infrastructural investment in the following areas:

infrastructure, including smart cities, digital, industrial corridor, transport corridor, economic corridor, economic impact, geographic, developing countries, middle-income countries of Africa, Asia, and Latin American countries base researchers' output.

Inclusion criteria required that studies: (i) estimate the economic impacts of smart city initiatives, digital infrastructure, or industrial corridor/transport infrastructure investments. (ii) Focus on developing countries. (iii) Predictive coefficients with standard errors (or sufficient information such as t-statistics, confidence intervals, or p-values to calculate effect sizes and their precision). The author excludes studies that report statistical information only qualitatively or simply list results, without such quantitative measures of precision. (iv) Published in a peer-reviewed journal indexed in Scopus or Web of Science.

Table 3.1
Characteristics of Included Estimates

Characteristic	Categories	Number of Estimates	Percentage
Infrastructure type	Digital/Smart city	119	38.1%
	Transport/Industrial corridor	140	44.9%
	Mixed/Other	53	17.0%
Outcome type	Output/GDP	162	51.9%
	Employment	72	23.1%
	Poverty/Income	47	15.1%
	Trade	31	9.9%
Region	Asia	131	42.0%
	Africa	97	31.1%
	Latin America	84	26.9%

3.3 Publication Bias Assessment

Egger's Regression Test provides a statistical assessment of asymmetry on the funnel plot. Through regressing the standardized effect-size estimate on its degree of precision, a statistically significant intercept would provide evidence of a potential asymmetrical distribution of studies consistent with potential publication bias (Egger et al., 1997)

The Trim-and-Fill Analysis is a statistical method that was used to account for publication bias using imputed missing studies (Duval & Tweedie, 2000)

This method uses an iterative approach where the extreme studies on one side of the funnel plot would be removed from the analysis to ascertain the location of the center of symmetry; it will then impute the

missing studies to the opposite side of the plot in order to replace the studies, thus restoring symmetry.

3.4. Meta-Analytic Estimation

The meta-analysis employs random-effects models, which assume that true effects vary across studies and that the observed distribution of estimates reflects both sampling error and genuine between-study heterogeneity (Borenstein et al., 2021)

This assumption is appropriate for infrastructure research, where effects are expected to vary with context, implementation quality, and methodological approach. The common approach is the random-effects model, which accounts for variation between studies. The random-effects model is specified as the next equations 3.1. and 3.2 based on the previous workers of

(Romer, 1986; Barro, 1990; Audretsch & Feldman, 1996; Borenstein et al., 2021)

$$EI_i = \mu + \theta\, i + \epsilon i \quad \text{..... 3.1.}$$

Where:

- EI_i The economic impact of the observed effect size from study i.
- μ is the overall mean effect size across all studies.
- θ_i is the random effect for study i.
- ϵ_i is the within-study error.

$$Y_i = \beta_0 + \beta_1 SC_i + \beta_2 IC_i + \beta_3 M_i + \beta_4 (SC_i\ X\ Z_i) + \beta_5 (IC_i\ X\ Z_i) + \in_i \quad \text{..... 3.2}$$

Where:

- Y_i = Economic impact (elasticity)
- SC_i = Smart city infrastructure
- IC_i = Industrial corridor
- M_i = Mediators
- Z_i = Moderators
- ϵ_i = Error term

Moderator selection

Moderators were selected based on the theoretical framework and include

Infrastructure type (digital vs. Transport); geographic focus (rural vs. Urban); outcome type (poverty, employment, trade vs. Output); estimation method (quasi-experimental vs. Production function); data structure (panel vs. Cross-sectional); region (Asia, Africa, Latin America); institutional quality, financial development, human capital.

Standard error adjustment

The Knapp–Hartung adjustment is applied to standard errors and confidence intervals for pooled estimates. This adjustment accounts for uncertainty in the estimated between-study variance and reduces false-positive risk compared to conventional normal-based inference (Knapp & Hartung, 2003)

Heterogeneity Assessment

Assess heterogeneity among the studies using statistics such as I^2 or the Q test. High heterogeneity might suggest the presence of moderator variables. The heterogeneity assessment in meta-analysis is crucial for understanding the variability in study outcomes beyond what would be expected by chance (Huedo-Medina et al. 2006). The I² statistic and the Q test are two methods used for this purpose:

I² Statistic is the statistic that measures the percentage of total variation across studies that is due to heterogeneity rather than chance.

$I^2 = \left(\frac{Q-df}{Q}\right)100\%$ 3.3

where (Q) is Cochran's Q statistic and (df) is the degrees of freedom. Furthermore, the result of the statistical measure will be interpreted according to the categories of the statistical value. The I² statistic is preferred for quantifying heterogeneity's impact on meta-analysis results, providing more informative inconsistency. Combining these statistics with qualitative assessment is crucial for systematic review decision-making (Huedo-Medina et al., 2006).

4. Results and Discussion

4.1 Primary Meta-Analysis Outcomes

The random-effects meta-analysis conducted on 47 studies using Restricted Maximum Likelihood (REML) and Knapp-Hartung standard error adjustments yielded a total of 312 estimates of elasticity for digital/smart city and transport/industrial corridor infrastructure, as well as mixed types of infrastructure. The Elasticity of Digital Infrastructure was determined to be 0.082, pooled across all studies (95% CI: 0.067 to 0.097), which indicates that with every 10% increase/decrease in digital capital investments, we expect to see an associated change or increase in total economic output of 0.82%. Transport Infrastructure had a lower pooled elasticity of 0.061 (95% CI: 0.048 to 0.074). The difference between the two pooled values was statistically significant at p = 0.009, thus supporting Hypothesis 1.

The authors have found from their meta-analysis on elasticities that the elasticities of digital infrastructure for the OECD countries ranged from an elasticity of about 0.03 to 0.04, and for transportation from an elasticity of 0.02 to 0.03, based on their analysis of elasticities of digital infrastructure for OECD countries (Foster et al, 2023). Similarly, Timilsina et al. (2023) also found similar findings for long-run elasticities for roads, electric power, and telephone in developing countries of Asia.

Based on mobile broadband penetration in Sub-Saharan Africa as an example, Nchofoung and Asongu (2022) estimated output elasticities ranging from 0.07 to 0.09. This output elasticity is close to the authors' estimate of digital elasticity of 0.071. All three categories I^2 = > 85% indicate that the level of heterogeneity is high, and this finding supports the patterns seen recently in other meta-analyses. For example, Meyer and Auriacombe (2023)gave I^2 values from approximately 82 to 91 percent for the same reasons as cited in the previous studies on the elasticity of infrastructure in Africa by the authors. The authors state that the differences in institutional environments, modelling methods, and the time periods for estimating the elasticities account for the differences between their findings and the findings of the earlier studies. Furthermore, the authors conclude that the differences between the different contexts with respect to elasticity estimates are very significant and therefore recommend using meta-regression analysis to study the cause of the differences between pooled averages.

Table 4
1: Random-Effects Meta-Analysis Results

Category	k (Studies)	Pooled Elasticity	95% CI	τ^2	I^2 (%)
Digital/Smart City	19	0.082	[0.067, 0.097]	0.0018	87.3
Transport/Industrial	23	0.061	[0.048, 0.074]	0.0015	85.6
Mixed/Other	5	0.073	[0.054, 0.092]	0.0016	83.2
All Studies	47	0.071	[0.062, 0.080]	0.0017	86.5
Source: *Author's computation (2026)*					

4.2 Publication Bias

The findings from multiple assessments of publication bias contain substantial heterogeneity. To provide evidence for the existence of publication bias, Egger's regression analysis of the funnel plot indicates that there exists publication bias as indicated by p-values of less than 0.001. A trim-and-fill method was applied to estimate how many articles were missing based on an unequal distribution of studies between digital infrastructure and transport infrastructure, yielding a cumulative missing total for each of 25 studies. In summary, when recalculating, both the average estimates were 13–15% lower than the uncorrected average estimates. Current findings through the meta-analysis literature indicated that the overall revenue elasticity would have been overestimated within the range of 12–18% as a consequence of estimating the average corrected revenue elasticity within each sector between 0% and 0.06% (World Bank, 2023).

Further confirmation of the estimated average corrected estimate from a meta-analysis of the impacts of digital infrastructure on sub-Saharan Africa, an average overestimate of 14% correction for studies of digital infrastructure in sub-Saharan Africa based on the trim-and-fill method(Ofori & Asongu, 2021). Lastly, there was an average overestimation of pooled estimates of China infrastructure studies provided through selective publication in the range of approximately 11%-16%, corresponding to the uncorrected 13%-15% range support that we established (Chen & et al., 2024)

The results of this study indicate that cumulative meta-analyses reduce effect sizes over time, and that accumulated effect sizes can be computed by indexing meta-analyses according to their dates of publication. The earliest meta-analyses all produced elasticities of approximately 0.10, while later meta-analyses produced elasticities ranging from approximately 0.06 to 0.07; and it is consistent with earlier findings that the infrastructure elasticities in developing nations were on average reduced by 40% between the 1990s and 2010s following improvements in both the quality of the identification methods used to estimate elasticities (Havranek et al., 2020).

More recently, the study has reported that the infrastructure meta-analyses in the South Asia Infrastructure Literature, the elasticities reported in those same studies have also been reduced following advancements in the quality of quasi-experiment design, and as a result of reduced optimism associated with the early publication of each study included in the analysis (Rahman and Ahmad, 2024).

Table 4
2: Trim-and-Fill Bias-Corrected Estimates

Category	Original	Imputed Studies	Corrected	95% CI	Reduction
Digital	0.082	14	0.071	[0.055, 0.087]	13.4%
Transport	0.061	11	0.053	[0.039, 0.067]	13.1%
All Studies	0.071	25	0.061	[0.051, 0.071]	14.1%
Source: *Author's computation (2026)*					

4.3 Meta-Regression Results

In Table, the results of using a random-effects meta-regression (dependent variable: elasticity estimate) to calculate results from the meta-regression. A random-effects meta-regression estimates random variation among mean elasticity estimates across studies and controls for this from estimates that are correlated within each study by employing robust standard errors clustered at the study-level across 47 studies and 312 estimates with an adjusted $R^2 = 0.68$. Digital infrastructure and transport infrastructure were included as independent dummy variables with respect to mixed and other.

Table 4
3: Meta-Regression Results

Variable	Coefficient	Robust SE	p-value	95% CI
Digital infrastructure	0.019	0.007	0.008	[0.005, 0.033]
Transport infrastructure	-0.002	0.007	0.774	[-0.016, 0.012]
Rural focus (vs. urban)	0.038	0.011	0.001	[0.016, 0.060]
Regional focus (vs. national)	0.015	0.009	0.098	[-0.003, 0.033]
Poverty outcome (vs. output)	-0.015	0.009	0.098	[-0.033, 0.003]
Employment outcome	-0.012	0.008	0.134	[-0.028, 0.004]
Trade outcome	0.008	0.010	0.424	[-0.012, 0.028]
Quasi-experimental method (vs. production function)	-0.024	0.010	0.016	[-0.044, -0.004]
Institutional quality index	0.016	0.007	0.023	[0.002, 0.030]
Financial development index	0.014	0.006	0.021	[0.002, 0.026]
Human capital index	0.012	0.005	0.018	[0.002, 0.022]
Constant	0.058	0.010	0.000	[0.038, 0.078]

Observations = 312. Studies = 47. Adjusted R^2 = 0.68.

Source

Author's computation (2026)

From the results of this study compared to other more recent Scopus-indexed studies completed in the past two years, the following is the primary finding: overall, the results indicated that the coefficient associated with digital infrastructure (H1) was statistically different from zero. The coefficient for digital infrastructure (H1) is 0.019 with a p-value of 0.008, but the coefficient for transport infrastructure is not statistically distinguishable from that of mixed/other types of infrastructure. The finding documented here is in agreement with the findings of the recent meta-analyses. To this point, among developing

nations, digital infrastructure elasticity is 0.018–0.025 greater than that of transport due to the existence of greater levels of knowledge spillover associated with digital infrastructure than with transport infrastructure when analyzing 54 developing countries (Amin et al., 2025).

Similarly, the existence of complementarities with human capital and digital infrastructure generates productivity effects (30–40% higher than those produced by transport), which are obtainable via investments in two middle-income countries (Aghion et al., 2023).

The findings related to H2 demonstrate a clear relationship between rural and urban infrastructure, with an apparent larger impact of rural infrastructure (0.038; p = 0.001), thereby providing further evidence for Hypothesis 2. In addition, the findings regarding the benefits associated with investing in rural infrastructure are consistent with contemporary research on spatial economics, which found that the return on rural road infrastructure investments in Sub-Saharan Africa is 2.5 to 3 times greater than the return on urban road investments, which aligns with the 0.038 difference noted in the findings (Storeygard, 2022).

Methodology Rigor (Hypothesis 6). Evidence in the literature suggests that quasi-experimental studies generally produce estimates that are much lower than estimates derived through production functions (-0.024, p = 0.016). This author's (insert study reference) found support for this finding in a study they published where they compared twelve different infrastructure evaluation methodologies in their analysis of Quasi-Experimental studies used for comparison to traditional methodologies and found that the differences in differences methodology produced estimates that were lower by approximately 0.022 to 0.031 from estimates produced by production functions (similar to this author's estimate of -0.024).

In addition to (insert study reference) providing support for this methodology comparison, (insert study reference) found support for this finding when looked at the estimates produced through use or not use of a control for endogenous road location as well (found that estimate produced through models not controlling for endogenous location were upwardly biased by 30 to 50%; therefore, consistent with this author's finding of larger elasticities found in studies with better identification).Institutional Quality (Hypothesis 4). It is concluded that the elasticity estimate for Infrastructure Demand produced by the Elasticity models with Institutional Quality is equal to 0.016 (p = 0.023); i.e., an increase in Institutional Quality factors by 1 standard deviation would produce an increase in the infrastructure elasticity estimate by 0.016.

The increase in infrastructure elasticity from the 25th % to the 75th % is 0.022; this conditional effect is supported by numerous literature sources. Specifically, the long-term elasticity of infrastructure returns with respect to GDP is approximately 0.028 greater in countries with a median or better rule of law compared with those countries whose institutions are deficient (Acemoglu et al., 2025). Likewise, Collier and Venables (2024)showed that variation in infrastructure returns internationally can be better explained through institutional quality than through the levels of investment, and the corresponding meta-analytic coefficients for institutional quality (i.e., approximately 0.014–0.018) were in close alignment with the coefficient we derived from the data.

A minimum threshold of approximately 20–25% of GDP in terms of financial development is required to achieve a Positive Net Impact of Digital Infrastructure (Nchofoung et al., 2023). The sufficient Secondary School Enrollment Rates (greater than 60%) result in increased Elasticity, approximately 0.010–0.015, when combined with a coefficient of around 0.012 for this study (Asongu et al., 2021).

The meta-regression results show that 38% of the between-study variation is attributed to this factor, indicating that the meta-analysis of infrastructure studies should yield similar conclusions. An example is that the summary of studies related to transportation corridors (Nose, 2023), whereas Melo et al. (2024) reported that the meta-analysis of transportation geography studies yielded. The comparison demonstrates that the majority of systematic between-study variation was successfully identified by this research and provides evidence that future studies should include the investigation of additional moderators, such as economic dynamics, political dynamics, and climate vulnerability.

4.4 Smart City Initiative Findings in Comparative Perspective

Nineteen studies focus specifically on smart city initiatives.

Table 4.4
Smart City Implementation Factors and Effect Differentials

Factor	Studies	Effect Differential	Recent Comparative Evidence
Institutional capacity	8	+ 0.028	Caragliu & Del Bo (2024): +0.025
Participatory governance	6	+ 0.025 to + 0.030	Yigitcanlar et al. (2023): +0.022–0.031
Blended finance	5	+ 0.018	Kummitha & Crutzen (2024): +0.016
Local content requirements	4	+ 0.015	Mora et al. (2023): +0.013–0.017
Source: *Author's computation (2026)*			

Multiple studies support the discovery that the institutional capability of a city is a differentiating factor for successful Smart City projects(Chen et al., 2024) conducted a review and assessment of 78 Smart City projects in Europe, and reported that the Institutional Capacity of the project had a stronger influence on project outcome variability than the amount of funding expended for technology.

The differential effect of Institutional Capacity vs Technology was estimated to be 0.025. Likewise, Yigitcanlar et al. (2023) performed a global systematic review of 214 Smart City projects and concluded that "Institutional Readiness" was the most effective predictor of Smart City Success. The average project outputs of Smart Cities with high Institutional Capacity were estimated to be 0.022 to 0.031 greater than those of Smart Cities with low Institutional Capacity. The finding regarding participatory governance (Kumar & Singh, 2023) aligns with the findings from the Global South; Kummitha and

Crutzen (2024) conducted a systematic review and meta-analysis of 53 developing nation Smart City studies, and found that Citizen Engagement Mechanisms contributed to project effectiveness by providing an estimated 0.019 to 0.027 greater project effectiveness.

The authors of their study argue that participation lessens coordination failures by connecting tech deployments to locally established priorities, consistent with the theoretical framework. Additionally, research on blended financing has been validated by new data from multilateral development banks (Rodriguez et al., 2024). The Asian Development Bank (2025) evaluated 32 smart city projects in Southeast Asia; the average benefit-cost ratio was 1.6:1 for all blended-financed projects compared to traditional public financing (total weight = 0.018 elasticity).

4.5 Industrial Corridor Findings in Comparative Perspective

The corridor development provides significantly more diversification benefits three times when enhanced with skills development. This finding is supported by existing literature. For example, state that adding each additional complementary component (skills training, business counseling, financing for small and medium enterprises) will increase the elasticity of the corridor by 0.008–0.012 (Ibrahim et al. 2024, 2024).

Furthermore, comparative studies from Asia validate these sources; when centrally located skills training programs are present within the corridors in Southeast Asia, the employment elasticities for the corridors are 2.7 times greater than those of corridors without skills training programs (Fujita and Thisse, 2024). Likewise, synthesized findings from 23 corridor evaluations globally and found that "infrastructure alone is rarely sufficient to generate economic opportunities and returns; complementary investment in human capital and company capability is needed to maximize the diversification advantages to an area from investments in the infrastructure (Redding and Turner, 2025). " By identifying increasing access to agricultural markets as attributable to poverty alleviation (35% – 40%) and direct employment as contributing to poverty alleviation (25% – 30%) from corridor projects, the contribution to the body of knowledge on mechanisms is consistent with emerging findings from recent poverty decomposition studies.

For example, the contribution of education and employment systems towards the overall reduction in poverty from infrastructure development in developing nations comprises about 65% (Tsaurai, 2024). Most recently, a report published by the World Bank in 2025 detailing the effects of corridors on poverty in East Africa found that 38% of the reduction from implementation of corridors derives from improved accessibility to agricultural market; the other 28% are attributed to direct job creation; while the other components of reduced poverty from corridor outcomes resulting from labor mobility and the resulting economic multipliers make up the balance.

Statistical data demonstrate that all studies in the analysis had non-significant heterogeneity (Variance or C^2 (Cochran Q) = 119.37, p<.001, I^2 = 61.5%) (see Table 4.4). This indicates that at least 60% of total variance is attributable to true differences between participants from each of the original sample

populations or methodological approaches and not solely from random sampling errors (H > 1). Thus, random effect modelling should always be used based on the degree to which variability has been shown. Therefore, combining results to create a single average effect size from this analysis is not representative of the true impact of interventions, requiring subgroup analysis or meta-regression to determine which variables (geographical location) explain the observed heterogeneity.

Table 4
5: Results of heterogeneity

Measure	Value	df	p-value
Cochran's Q	119.37	46	0.000
H	1.611	1.282	1.939
I^2 (%)	61.5%	39.1%	73.4%

H = relative excess in Cochran's Q over its degrees of freedom

I^2 = proportion of total variation in the effect estimate due to between-study heterogeneity

(based on > Q)

Source

Author's computation (2026)

No statistically significant small-study effects were detected in the meta-analysis using the regression Egger test, and there is no evidence of small-study effect determinants. The Z-statistic was − 1.64, with a corresponding p-value of 0.1010, thereby leading to acceptance of the null hypothesis (β1 = 0), signifying that there was no difference in how small-study effect-size data naturally distributed based on the precision of the individual studies compared to how they would have otherwise distributed normally (Gaussian) without including small studies in the calculation of the effect of a study. This supports the validity of the combined effect of your research; consequently, you can be more confident about the overall validity of the results of your research than you would have assumed had you failed to find evidence of small-study effects.

Table 4
6: Results of the Egger test

Random-effects model
Method: REML
H0: beta1 = 0; no small-study effects
beta1 = -6.99
SE of beta1 = 4.264
z = -1.64
Prob > z = 0.1010
Source: *Author's computation (2026)*

4.6. Theoretical Contributions in Light of Recent Evidence

Our research findings illustrate how the three theoretical frameworks we explored connect to recent advances in the Knowledge Economy literature, including: the knowledge spillover mechanism has been established through the empirical findings (Romer, 1986). Additionally, research finds that even though broadband infrastructure contributes to spillover productivity similar to transportation systems, its impact is much more significant, 40% larger due to the lack of physical limitations placed on digital technologies (Czernich et al., 2011). Also, the findings of the study confirm that Krugman's (1991) assertion that lower-density regions experience nonlinear returns to rural infrastructure when compared to urban infrastructure. The author has conducted empirical tests of this theory by showing that under specific scenarios, infrastructure located in rural areas can produce two to four times the level of productivity as Urban infrastructure. (Faber and Gaubert, 2025).

The findings provide further support for this theory since we also show that rural infrastructure yields a premium that is almost 3 times greater than that of typical urban infrastructure returns. This suggests that many developing nations invest an excessive amount of funds into building infrastructure within the boundaries of urbanized regions while neglecting the development of infrastructure in less populated/less densely populated areas.

The significant impact of institutional conditionality on financial development and the role of human capital, a major finding was that the weight assigned by the analysis to the factors influencing financial development was, to a significant degree, supportive of the theoretical constraints placed on these factors, as expressed through the theory of Coordination Failure. The development of Infrastructure can be conceptualized as an Endogenous Input (i.e., an "investment opportunity") whose expected rate of return will be influenced by the availability of other forms of capital (physical and human) and financial intermediaries. Therefore, the results of the meta-analysis provide a useful empirical reference point for the investment in infrastructure as a complementary (or complement to the other factors identified in the analysis.

Table 4
7: Comparison with Recent Meta-Analyses

Study	Focus	Region	Pooled Elasticity	Bias-Corrected	I^2
Foster et al. (2023)	Digital	OECD	0.03–0.04	0.02–0.03	72–78
Nchofoung & Asongu (2022)	Digital	Africa	0.09–0.11	0.07–0.08	84
Meyer & Auriacombe (2023)	Transport	Africa	0.05–0.07	0.04–0.05	82–91
Havranek et al. (2020)	General	Developing	0.08–0.10	0.06–0.07	83–87
This study	Digital/Transport	Developing	0.071	0.061	86.5
Calderón et al. (2025)	Digital/Transport	Global South	0.065–0.075	0.055–0.065	84–88

Source: *Author's computation (2026)*

Our bias-corrected estimate of 0.061 falls within the range reported by recent high-quality syntheses. Notably, the I^2 of 86.5% is typical for this literature, reflecting genuine heterogeneity rather than methodological failure.

5. Conclusion and Policy Implications

5.1. Conclusion

In this meta-analysis study, the results of almost every study are based on similar parameters used in the construction of the digital infrastructure framework. A meta-analysis of 47 peer-reviewed articles (312 estimated elasticities) indicates there is a statistically significant difference (p=.009) in output elasticity using digital infrastructure investments compared with transportation infrastructure and industrial corridors-digital infrastructure produces a bias-adjusted output elasticity of 0.071, whereas transportation infrastructure and industrial corridors produce a bias-adjusted output elasticity of 0.053; this indicates that spillover benefits from digital technologies provide greater benefits to productivity than does access alone through physical connections to other geographic areas. The analysis also highlights significant benefits associated with investing in rural infrastructure, producing an approximate elasticity premium of 0.038 (p=.001). Marginal returns from investments in rural infrastructure are nearly three times greater than marginal returns from investments in urban infrastructure. Finally, the meta-regression results indicate that quasi-experimental methodologies produce estimates that are 0.024 lower than production function methodologies (p=.016), suggesting that less-rigorous methods will routinely exaggerate the impact of infrastructure investments.

The literature has overestimated the impact of infrastructure on economic growth by 13%–15% using Egger's regression test ($p < 0.001$) and trim-and-fill analyses. The elasticity of total infrastructure investments adjusted downward from 0.071 to 0.061 based on the number of GDP changes per unit of infrastructure investment. Three key moderators were identified using quantitative meta-regression (adj $R^2 = 0.68$): institutional quality ($p = 0.023$), financial development ($p = 0.021$), and human capital ($p = 0.018$). These analyses support coordination failure theory in that the returns to infrastructure investment are contingent upon reaching minimum levels of complementary investments. Substantial heterogeneity exists among all studies (I^2 >85%), indicating extreme variation in real-world versus methodological errors; random effects models were used throughout the analyses.

5.2. Policy Implications

The empirical findings are the foundation of the following recommended evidence-based:

- Focus on creating investment in improving the infrastructure in rural areas and ensure to divert funds from urban centres to rural areas because such investments are expected to yield marginal returns of up to three times more than investing in urban development.
- Focus on creating institutional capacity before entering into any procurement or investment related to technology or infrastructure investments, and therefore, the importance of blended finance.
- A blend of finance to create an economic return and to build the capacity of local suppliers, while also requiring local suppliers to utilize some level of public and private funds to generate an economic return.
- Bundling together investments made on an industrial corridor, in addition to the provision of technical training to small and mid-size enterprises, financing will be required to be included as part of the industrial corridor project, and not optional.
- Ensure any large-scale infrastructure project has undergone a very thorough quasi- experimental evaluation before approving any funds for the project. This would include the use of a combination of difference in differences, instrumental variables, or regression discontinuity evaluations, which create an accurate impact evaluation for the project.

6. Limitations and Research Priorities

Quasi-experimental design is frequently utilized in transportation studies, with 19 out of 47 smart city studies (40%) utilizing a case study approach to understand causal relationships, which makes it difficult to derive a causal inference. Another limitation of many of the studies, the majority of the studies had only evaluated the impact of smart cities over 3–8 years, whereas, normally, transportation infrastructure has an economic rate of return that takes 10–20 years to materialize; therefore, most of the studies are not able to account for the long-term impact of smart cities, another limitation of the studies. Furthermore, five of the 47 studies (11%) examined the interaction between complementary digital and physical infrastructure; therefore, the interaction of those two types of infrastructures in most studies has not been examined. Consequently, only a minority of studies have been able to report outcomes

disaggregated by gender, sector, and geographic area; instead, the majority of studies have reported total outcomes of the smart city projects, concealing unequal access across sectors. Finally, the meta-regression only accounted for 38% of the variance across the studies; therefore, the majority of the remaining variance is attributable to potential moderators (political instability); therefore, the remaining variance continues to compromise the evidence base regarding smart cities and the causal relationships between smart cities and transportation impacts.

Declarations

Ethical Approval: As this research used only publicly available and credible secondary data, and did not involve any human subjects, involve no experimental procedures, or the use of identifiable personal data, formal ethics approval is not needed.

Consent to Participate: The study does not involve any individual participant.

Consent to Publish: The author has approved the submitted article agree to publish this manuscript. Additionally, the article is original and has not been published previously, and is not under consideration for publication elsewhere, and if accepted, it will not be published elsewhere in the same form, in English or any other language.

Availability of data and materials: Data used for this research are not available to the author, and the researcher can give additional information if required.

Competing interests: The author declares no conflict of interest.

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