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Beyond the Triple Helix: An Infrastructure-Conditional Framework for Management Information Systems Innovation in Nigeria

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ABSTRACT
Why do some countries translate university research into scalable public systems, productive firms, and effective governance, while others struggle to move beyond isolated innovation? This conceptual, theory-building article addresses that question through the Triple Helix Model of university–industry–government collaboration, using Management Information Systems (MIS) as an interdisciplinary lens; it combines a targeted, non-systematic literature synthesis with a quantitative secondary-data case analysis, and develops an infrastructure-conditional perspective in which institutional collaboration is shaped by the digital and organisational conditions required for implementation. Evidence is drawn from China's industry–education cities and enterprise artificial-intelligence ecosystem, India's digital public infrastructure, and Nigeria's emerging technology ecosystem. For Nigeria, six years of official regulator data (2020–2025) are analysed using an endpoint growth ratio, ordinary-least-squares trend estimation, denominator-harmonised regression, Durbin–Watson diagnostics, and out-of-sample validation. Realised annual broadband penetration growth reached only about 38% of the rate required to meet the national target, despite substantial growth in raw subscriptions, a shortfall confirmed, within the limits of a six-observation annual series, by a regression estimate rather than the two-year comparison alone; a two-year patent-filing comparison shows Nigeria's resident-filing shortfall relative to South Africa predates the single most recent observation year, though the two series are not year-matched and cannot on their own establish multi-year persistence. These broadband and patent findings illustrate an infrastructural constraint on Nigeria's Triple Helix system; they describe connectivity and patenting trends rather than directly measuring university-industry-government collaboration or its effects on innovation, and the conceptual propositions developed from them are offered as testable claims for future research rather than as empirically validated findings. Read together, the evidence indicates that Triple Helix collaboration cannot be treated as an unconditional additive process: its effectiveness depends on infrastructure, institutional capacity, and mechanisms for translating knowledge into deployment. The study proposes an infrastructure-aware Nigerian Triple Helix framework centred on open data governance, university-based MIS research, and intermediary institutions connecting research, policy, and implementation, contributing a conceptual extension of Triple Helix theory, illustrated with Nigerian secondary data, for resource-constrained digital economies.

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INTRODUCTION

Conversations about national development often follow a familiar pattern: participants point to Silicon Valley, or more recently to Shenzhen or Bangalore, and ask why their own countries cannot replicate such success. This article's starting premise is that the answer is rarely about talent alone: Nigeria, like many developing countries, has a substantial pool of capable graduates, ambitious entrepreneurs, and civil servants who function well within the resources available to them (Àkànle & Ola-Lawson, 2021), yet national-level innovation outcomes remain limited. What is comparatively scarce, this article argues, is the connective tissue between these groups: the institutional arrangements that allow university research to reach a firm, a product to reach government procurement, or government data to reach researchers who can derive actionable insight.

This is the basic puzzle the Triple Helix Model was designed to address. First articulated by Etzkowitz and Leydesdorff in the 1990s and refined substantially since, the model proposes that innovation in knowledge-based economies emerges from the overlapping, recursive interaction of three institutional spheres-universities, industry, and government (Leydesdorff, 2011, p. 25). Recent scholarship has kept the framework relevant by extending it to hybrid organisations, regional innovation systems, and, increasingly, the governance of emerging technologies such as artificial intelligence (Linton, 2024, p. 20799; Wang et al., 2026).

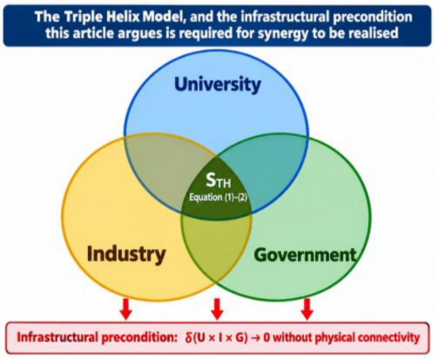

Figure 1: The Classical Triple Helix Model (University-Industry-Government Overlap Producing Synergy, STH)

Management Information Systems (MIS) occupies a distinctive position in this conversation. It is simultaneously an academic discipline taught in universities, a commercial product built and sold by firms, and a public infrastructure upon which governments depend. A national payments platform, a hospital information system, or a tax platform are all MIS artefacts, but they are also deeply institutional, shaped as much by those who build and govern them as by the underlying code. This article examines whether the Triple Helix Model effectively elucidates MIS innovation and whether it translates well to the Nigerian context, extending prior qualitative treatments by grounding the infrastructural argument in a six-year official dataset and, in this revised analysis, in a supplementary trend test that reduces the sensitivity of the conclusion to any single year's figures. The answer developed in the following sections is a qualified yes-qualified because the model's utility depends on conditions that cannot simply be assumed.

This article addresses three specific research questions.

RQ1: Does the classical, three-actor Triple Helix Model, taken as an additive or interactive combination of university, industry, and government contributions, adequately describe the conditions under which MIS innovation reaches deployment in an infrastructure-constrained economy such as Nigeria's?

RQ2: Is Nigeria's broadband-infrastructure trajectory over 2020-2025 consistent with infrastructure functioning as a precondition for Triple Helix collaboration, rather than as one input among several that can be traded off against the others?

RQ3: What supplementary institutional mechanisms-beyond the classical university-industry-government triad-does the Nigerian evidence suggest are needed to translate collaboration into deployable MIS outcomes?

The contribution advanced here should be distinguished from three adjacent literatures. It differs from Quadruple and Quintuple Helix extensions, which add civil society, media, or the natural environment as additional helices operating alongside the original three (Cai & Lattu, 2021); this article instead argues that infrastructure functions as a precondition embedded within the existing industry and government terms, not as a further additive helix. It differs from the broader innovation-ecosystem literature, which typically treats infrastructure as one resource among many circulating within a loosely bounded network of actors; this article treats infrastructure access specifically as a binding constraint that can prevent the classical triad's interaction effect from being realised at all, regardless of how many actors are present. It also differs from sociotechnical systems accounts (Section 2.2), which focus on the negotiated fit between a technical artefact and its immediate social context; this article's infrastructural argument operates at the level of national-scale connectivity policy rather than the design of individual systems. The conceptual model developed in Section 2 and the Nigerian evidence assembled in Section 4 are intended to make this infrastructure-conditional reading of the Triple Helix precise enough to be distinguished empirically from these adjacent frameworks in future comparative work.

Figure 2 restates this diagrammatically before the formal notation is introduced in Section 2. This article's central empirical contribution (Section 4.3) then shows what happens when that link is measured directly rather than assumed: Nigeria's own six-year broadband record.

Figure 2: The Connective-Tissue Problem Motivating this Article: Knowledge Produced by Universities, Deployed by Industry, and Governed by Government Depends on Institutional Linkages that Cannot be Assumed

The remainder of the article is organised as follows. Section 2 revisits the Triple Helix as a theoretical anchor, connecting it with the IS Success Model and sociotechnical systems thinking, and proposes a compact notational device for describing helix synergy. Section 3 describes the materials and analytical procedures used for the secondary-data components of the study. Section 4 reports results: the qualitative synthesis of how each helix functions in MIS, the quantitative analysis of Nigeria's broadband trajectory against its national target, an international comparison, and a re-examined patent-output indicator. Section 5 discusses where the model strains under Nigerian conditions and sets out policy implications. Section 6 concludes, states the limitations that remain after this revision, and proposes an agenda for future research.

Theoretical Framework

The Triple Helix, Revisited

Cai and Etzkowitz describe the Triple Helix not as a fixed structure but as a dynamic process in which universities, industry, and government continuously renegotiate their boundaries, sometimes overlapping into hybrid organisations that defy simple classification (Cai & Etzkowitz, 2020). This framing corrects earlier, more mechanical readings of the model and is particularly relevant for MIS, since many of the most consequential MIS institutions-national IT development agencies, university-affiliated technology parks, and government-funded research laboratories-are precisely these kinds of hybrids.

Recent scholarship extends this by demonstrating how Triple Helix dynamics at the micro-level, within a single research centre or technology-transfer office, shape the value that eventually reaches the macro-level of regional or national development (Linton, 2024). This highlights that the Triple Helix is not merely a description of three institutions cooperating; it is a claim about a value-creation process that depends on the quality of interaction at a granular level. Boundary-spanning individuals, personal relationships, and informal networks often perform significant work that the formal model leaves invisible.

No parameter values are estimated anywhere in this article for the notation introduced below; it is offered purely as an expository device for describing, in compact form, an assumption already present in qualitative Triple Helix writing. For expository purposes only, and without any estimated parameter values, helix synergy can be represented heuristically as a function of the three institutional contributions and the strength of their pairwise interaction (illustrated in Figure 1 and 2):

$$S_{TH} = \alpha U + \beta I + \gamma G + \delta(U \times I \times G) \qquad (1)$$

where U, I, and G index the observable strength of the university, industry, and government contributions respectively (e.g., research output, deployment capacity, and coordinating investment); α, β, and γ are their independent weights; and δ captures the synergistic, non-additive interaction term that recent empirical work identifies as decisive (Zhao et al., 2024; Wang et al., 2026). Equation (1) is offered as a conceptual heuristic rather than an estimated statistical model; no primary data collection was undertaken to fit its parameters. Its purpose is to make explicit an assumption often left implicit in Triple Helix writing: that collaboration effects are interactive rather than merely additive, and that S_{TH} is not a single additive quantity but the sum of an additive baseline ($\alpha U + \beta I + \gamma G$) and a synergistic interaction term, $\delta(U \times I \times G)$. A precise reading of Equation (1) must distinguish the two: total institutional output, S_{TH}, does not collapse to zero when a single institutional component approaches zero, because the remaining additive terms can still be positive; what does collapse toward zero is the multiplicative interaction term $\delta(U \times I \times G)$ itself-most consequentially when the infrastructural component embedded within I and G approaches zero, regardless of the strength of the other two. What the notation buys, beyond restating this assumption in symbols, is a sharp and falsifiable point of contrast with a purely additive reading of the Triple Helix (the case $\delta = 0$): an additive model predicts that weakness in one helix can, in principle, be compensated by strength in the other two, and that this compensation is complete because there is no interaction bonus to lose in the first place; Equation (1) predicts that the additive baseline still receives whatever compensation strength in the other two helices provides, but that the synergistic bonus captured by $\delta(U \times I \times G)$-the effect that recent empirical work identifies as decisive for translating collaboration into deployment-becomes unavailable once any single term collapses toward zero, leaving institutions with only the uncoordinated sum of their individual contributions. This distinction is not tested numerically in this article, since no parameters are estimated, but it is the specific empirical prediction that Section 4.3's infrastructural illustration and Section 5.3's discussion are organised around, and it is, in principle, testable with adequately operationalised U, I, and G measures in future work.

The IS Success Model and Sociotechnical Thinking

The DeLone and McLean IS Success Model remains a useful diagnostic tool, even though its original formulation predates the current wave of Triple Helix scholarship. Its six dimensions-system quality, information quality, service quality, use, user satisfaction, and net benefits (DeLone & McLean, 2016)-map effectively onto the institutional contributions of each helix. Universities tend to influence system and information quality through research; industry influences service quality and deployment; and government shapes conditions of use, particularly through mandates, procurement, and access policy. Recent literature on university-industry collaboration suggests these contributions are not merely additive but interactive, and that operationalising collaboration depends on the presence of the third helix, government, for the interaction to be realised at all (Passos et al., 2022). The open-innovation literature adds a complementary mechanism: knowledge transfer between universities and firms functions best as a managed, bidirectional process rather than a one-way licensing event, since the receiving organisation must possess the absorptive capacity to convert transferred knowledge into a deployable system (Almeida & Sequeira, 2019). This qualification matters for MIS specifically, where the "knowledge" being transferred is frequently tacit systems-design expertise rather than a codifiable patent, making the quality of the transfer channel-not merely its existence-a determinant of whether the IS Success Model's system- and information-quality dimensions are actually realised in deployment.

Sociotechnical systems thinking adds a necessary caution: an information system is never merely a technical artefact; it is a negotiated outcome between technical possibility and social context. This explains why MIS deployment that ignores one helix-such as a hospital system designed by industry without academic input on workflow design, or a government platform built without industry's deployment expertise-tends to underperform regardless of the soundness of its underlying engineering. The well-documented failure of large-scale information systems in low-infrastructure settings has convinced most contemporary analysts that the social dimension of sociotechnical analysis deserves as much attention as the technical component (Heeks, 2002).

MATERIALS AND METHODS

Research Design and Scope

This is a conceptual, theory-building article. It develops and critically evaluates the Triple Helix Model through a targeted literature synthesis, combined with a quantitative secondary-data case analysis of Nigeria's official broadband-regulator statistics (2020-2025) and comparator-country World Bank/ITU connectivity and WIPO/World Bank patent data. No primary data collection (surveys, interviews, or experiments) was undertaken; all numerical findings are derived from published, cited secondary sources. The literature synthesis follows a targeted rather than systematic review protocol: sources were selected for direct relevance to Triple Helix theory, MIS innovation, and Nigerian technology policy, prioritising work published between 2018 and 2026 while retaining foundational citations (e.g., Leydesdorff, 2011) where a concept originates there.

Because this is a targeted rather than a systematic review, the following details are reported for transparency. Candidate sources were identified through Scopus, Web of Science, and Google Scholar, searched between January 2018 and March 2026 using combinations of the terms "Triple Helix", "quadruple helix", "university-industry-government", "management information systems", "digital infrastructure", "broadband", and "Nigeria innovation". Titles and abstracts returned by these searches were screened for direct relevance to Triple Helix theory, MIS innovation, or Nigerian technology policy; sources that addressed Triple Helix dynamics only tangentially, or that duplicated a more recent or more directly relevant source already retained, were excluded at this stage. Approximately 95 records were identified across the three databases, of which 62 were retained for full-text reading after screening, and 51 are cited in this article; the remainder were consulted for context but did not contribute a citable claim. This protocol supports the targeted synthesis reported in Sections 2 and 4.1-4.2; it does not meet the registration, dual-screening, and reporting standards of a systematic review, and the manuscript makes no claim to systematic coverage.

Secondary Data Sources

The quantitative components draw on four classes of publicly available secondary data, each retained at the level of granularity published by the originating body rather than re-estimated by the authors: (i) year-end broadband penetration and subscription figures published by the Nigerian Communications Commission (NCC) in its annual Subscriber/Network Performance Reports for 2021-2024, supplemented for the 2020 baseline, the 2021-2023 subscription totals, and the December 2025 outturn by NCC data reported contemporaneously in the trade press (Businessday, 2022, 2023, 2024; THISDAY, 2023; The Cable, 2026); (ii) the World Bank/ITU harmonised “individuals using the Internet” indicator for Nigeria and four comparator economies-Kenya, South Africa, India, and China (World Bank, 2026a); (iii) WIPO/World Bank resident patent-application counts for Nigeria for 2019 and 2020, and the most recently published resident-filing rate for South Africa (WIPO, 2026; World Bank, 2026b); and (iv) World Bank population estimates used to compute per-capita filing rates (World Bank, 2026c). Every figure reported in Tables 1-2 is traceable to its cited primary source; none is an author estimate.

Analytical Procedures

For clarity and reproducibility, the procedures below are organised into three stages: the core calculations applied directly to the published series (Section 3.3.1), the six robustness extensions added in this revision to close the limitations identified in the original analysis (Section 3.3.2), and the reporting conventions followed throughout the quantitative results in Sections 4.3–4.5 (Section 3.3.3).

Core Reproducible Calculations

Four transparent, reproducible calculations were applied to the broadband series (Section 4.3): the linear annual growth required to reach the National Broadband Plan (NBP) target (Equation 3), the realised average annual growth over the same window (Equation 4), the compound annual growth rate of the penetration series (Equation 5), and a first-order log identity linking the growth rates of subscriptions, penetration, and population, used as an internal consistency check on the regulator data (Equation 6). Each calculation draws solely on the published values reported in Table 1; none involves an author-estimated input, so every figure in Section 4.3 can be reproduced independently from the cited primary sources without recourse to a statistical package or to data not disclosed in this article.

Robustness Extensions

This revision adds six robustness extensions beyond the core calculations in Section 3.3.1, each designed to close a specific limitation identified in the original, single-endpoint analysis. First, because the headline broadband-shortfall figure in Section 4.3 rests on only two of the six available annual observations (the 2020 baseline and the 2025 outturn), an ordinary-least-squares regression of year-end penetration on a year index was fitted to all six data points in Table 1, together with standard inferential statistics for the fitted slope (a standard error, a t-test against zero, a 95% confidence interval, and a t-test against the Plan’s required annual rate), to establish whether the two-point shortfall reported in Equations (3)–(4) is a feature of the trend as a whole rather than an artefact of the chosen endpoints (reported as Equation 7 in Section 4.3). Second, because broadband subscriptions are a raw count rather than a ratio and are therefore unaffected by any population-denominator revision, an OLS regression of subscriptions on the same year index was fitted separately (Equation 8 in Section 4.3), to check whether the volatility visible in the raw penetration series is attributable to the denominator break rather than to genuine swings in underlying connectivity. Third, because the raw penetration series mixes two different population denominators either side of the NCC’s September 2023 re-basing, a denominator-harmonized penetration series was constructed and re-fitted by ordinary least squares (Equations 9–10 in Section 4.3), to establish whether the reported shortfall survives correction for the mid-series denominator break. This harmonization holds the population base fixed at its pre-revision level throughout 2020–2025 and should be read as a sensitivity check on the raw series, not as a demographically comparable historical series in its own right, since Nigeria's population continued to grow across the window even though the NCC's reporting base did not; a fuller harmonization using consistent annual population estimates for every year (e.g., World Bank, 2026c) rather than a single fixed base would avoid this limitation and is identified in Section 6.1 as a priority for future replications of this analysis, but was not undertaken here because the NCC's own reported subscription counts, not independently re-estimated population denominators, are the reporting standard this article follows (Section 3.3.3). Fourth, because these regressions use only six annual, plausibly serially correlated observations, a Durbin–Watson statistic was computed for each set of residuals (Equation 11 in Section 4.3) to check formally for positive serial dependence rather than leaving the classical OLS independent-errors assumption untested; this check, and the corresponding recommendation to treat the regressions' inferential statistics as indicative rather than definitive given the small sample, is stated explicitly wherever the regressions are reported in Section 4.3. Fifth, the harmonized regression was re-estimated using only the 2020–2024 observations and used to forecast the 2025 value out of sample, to check whether the actual 2025 outturn is consistent with the pre-existing trend rather than reflecting a structural break (Section 4.3). Sixth, the patent-output comparison in Section 4.5 was extended from a single reference year (2020) to a two-year pair (2019–2020), to establish whether Nigeria's resident-filing shortfall relative to South Africa reflects a persistent pattern rather than a one-year anomaly.

Reporting and Transparency Standards

All monetary and percentage figures are reported to the precision published by the originating source. Where a figure required derivation from published components (e.g., a per-capita filing rate from a raw count and a population estimate), the derivation is shown in the text so that it can be independently checked and recomputed. Consistent with this standard, every equation in Sections 3.3.1–3.3.2 is presented with its inputs stated explicitly in-text, so that replication requires only the publicly available sources listed in Section 3.2 and the Data Availability Statement, and does not depend on any unpublished author calculation.

RESULTS AND DISCUSSION

Results

How the Three Helices Function in MIS

Universities: Knowledge Production and the Entrepreneurial Turn

The university's role in MIS innovation has shifted substantially over the past decade. Where universities were once understood primarily as sources of trained graduates, the "entrepreneurial university" framework, well established in Triple Helix scholarship, positions them as active commercial agents that license technology, spin off firms, and partner directly with industry and government on applied problems. Linton's recent analysis of Triple Helix dynamics and value creation reinforces this reading (Linton, 2024).

The Chinese experience with industry-education integration offers an instructive example. Zang and colleagues document how the Liuzhou City industry-education integration initiative brought universities, government, and industry into a single spatial and institutional arrangement (Zang et al., 2024), a case that Cheng, Cheng, and Feng situate within a broader development approach to industry-education city integration in China (Cheng et al., 2024).

Industry: Translating Research into Deployable Systems

Industry's contribution is best understood not merely as commercialisation, but as a distinct form of knowledge production. A growing body of work on enterprise artificial-intelligence innovation makes this point with precision. Empirical studies indicate that university-industry research collaboration and government subsidies are independently important for strengthening enterprise AI innovation, with their interaction producing strong synergistic effects (Zhao et al., 2024). Other research, using panel data from Chinese A-share listed firms, finds that AI adoption significantly promotes radical innovation; this relationship is moderated by a firm's digital foundation and government subsidy, with firms that adopt AI later and at a slower pace often achieving greater innovation gains (Wang et al., 2025).

For MIS, this is consequential: it suggests that simply increasing government funding for industry-academic collaboration is insufficient, and that the quality and structure of the collaboration matter as much as the volume of investment.

Government: Coordination, Subsidy, and the Limits of Both

The government's role has historically been framed around regulation and funding, but recent research complicates this picture. Evolutionary game-theoretic modelling of government-industry-university-research collaboration found that the strategic convergence of all three actors toward genuinely cooperative behaviour depends on the specific incentive structures each party faces; a stable, cooperative equilibrium becomes possible only when the requisite conditions are met (Ma & Yang, 2024). This is a sobering finding for those inclined to treat Triple Helix collaboration as an inevitable outcome once the right institutions are nominally in place.

Systematic literature on university-industry collaboration independently reinforces this: operationalising such collaboration proceeds through defined stages, and the absence of government coordination at any stage tends to stall progress, even when bilateral university-industry relationships are strong (Passos et al., 2022).

Artificial Intelligence as a Stress Test of the Triple Helix

Artificial intelligence provides a compelling context in which to examine the Triple Helix, because it renders institutional interdependencies explicit. Recent panel-data evidence from Chinese listed firms (2010-2023) shows that university-industry-research collaboration, government subsidies, and knowledge spillovers jointly shape enterprise AI innovation; government support activates Triple Helix synergies only once subsidy intensity clears roughly 1.39% of firm revenue, after which the marginal return to university collaboration rises nearly four-fold within an optimal band (1.39%-3.93%) before an inverted-U pattern sets in above that threshold (Wang et al., 2026). Empirical work confirms that AI's contribution to firm-level radical innovation is conditional on the firm's digital foundation and government subsidy, with non-trivial interaction effects (Wang et al., 2025).

The threshold finding in Wang et al. (2026) is a useful empirical instantiation of the $\delta(U\times I\times G)$ interaction term in Equation (1): synergy is not a smooth, continuously increasing function of investment, but one with a floor below which government support fails to activate university-industry complementarities at all. For MIS scholarship, this implies that the Triple Helix remains an analytically useful frame, but an incomplete one. This article argues that the standard three-actor model requires supplementary mechanisms-innovation-finance instruments, platform-governance frameworks, and explicit public-academic data infrastructures-to capture what is occurring on the ground. In Nigeria, where these supplementary mechanisms are at an early stage of development, the gap between the Triple Helix's predictions and empirical observation is likely to be wide, requiring policy design to anticipate rather than deny this discrepancy.

The specific threshold values below are drawn directly from Wang et al.'s (2026) panel-data study of Chinese listed firms; they are reproduced here only to illustrate the qualitative shape of an activation dynamic, and they are not assumed to transfer numerically to Nigeria, for which no comparable subsidy-threshold estimates yet exist. With that caveat, the subsidy-threshold pattern documented by Wang et al. (2026) can be written as a refinement of Equation (1), in which the interaction term is scaled by an activation function of government subsidy intensity g relative to the empirically identified lower and upper thresholds ($g^* \approx 1.39\%$ and $g^{**} \approx 3.93\%$ of firm revenue):

$\delta_{eff}(g) = \delta \cdot f(g)$, *where* $f(g) = 0$ *for* $g < g^*$; $f(g)$ *rises toward a maximum on* $[g^*, g^{**}]$;
and $f(g)$ *declines beyond* g^{**} *(inverted-U)* (2)

To move beyond a purely verbal description of this shape, f(g) can be given a concrete, though still unfitted, functional form consistent with the qualitative activation pattern Wang et al. (2026) report: a logistic rise from the lower threshold g^* multiplied by a logistic decay beyond the upper threshold g^{**}, $f(g) = \sigma(k_1(g - g^*)) \times [1 - \sigma(k_2(g - g^{**}))]$, where $\sigma(x) = 1/(1+e^{-x})$ is the standard logistic function and $k_1, k_2 > 0$ govern the steepness of activation and decay respectively. This piecewise-logistic form reproduces the shape Wang et al. (2026) describe—negligible synergy below g^*, a rise toward a maximum on $[g^*, g^{**}]$, and decline above g^{**}—as a single continuous bump-shaped function of g, rather than as a set of inequalities. Consistent with Equation (1), no values of k_1 or k_2 are estimated in this article; the closed form is offered to sharpen the qualitative description into a specification that could be fitted to Nigerian subsidy data in future work, not as a model fitted here. The formalism is retained here, rather than left as prose, for two reasons specific to this article's purpose: it states a precise, falsifiable prediction — a non-monotonic, threshold-gated response of synergy to subsidy intensity, rather than a smoothly increasing one — that a purely verbal description would leave imprecise, and it gives the future Nigerian subsidy-data research this article calls for (Section 6.1) a ready specification to estimate rather than one that would first need to be derived. Readers primarily interested in the qualitative implication rather than the functional form can proceed directly to the next paragraph.

This reformulation makes explicit that δ_{eff}, not the constant δ of Equation (1), is the operative synergy coefficient once government subsidy is treated as a variable rather than a fixed parameter: below g^*, the model of Equation (1) collapses to $S_{TH} \approx \alpha U + \beta I + \gamma G$ regardless of the nominal value of δ, consistent with the empirical finding that Triple Helix synergies fail to activate at all below the lower subsidy threshold.

Entrepreneurship Through the Triple Helix Lens Beyond the Standard Three-Party Model

Schebesch, Șoim, and Blaga, writing on entrepreneurial ecosystems, reflect a growing trend in Triple Helix scholarship by arguing that the standard three-actor configuration is often insufficient and that emerging economies benefit from including additional players and alternative cooperation models beyond the conventional triad (Schebesch et al., 2024). They recommend treating the Triple Helix not as a complete architecture but as a foundational minimum-a starting framework that performs better when supplemented by actors such as diaspora investors, civil-society organisations, and regional development bodies (Schebesch et al., 2024).

This is highly relevant for MIS entrepreneurship in Nigeria, where formal Triple Helix institutions remain thin, and where diaspora networks, civil-society intermediaries, and informal technology communities already perform much of the connective work the classical model assigns to industry and government. Section 5.2 develops this argument with Nigeria-specific evidence and an expanded actor map (Table 3, Figure 8).

Knowledge Spillovers and the Question of Who Benefits

Knowledge spillovers-the diffusion of ideas and techniques beyond their point of origin-are not evenly distributed. The general principle, well established in regional-economics literature on European inequality, is that less dynamic cities and regions cannot benefit from spillovers unless various transmission channels (cognitive, institutional, organisational, and social) are significantly enhanced; rising spatial inequality has historically accompanied the diffusion of low-tier activities toward lagging regions (Iammarino et al., 2018). Applying this to Nigeria raises a critical question: when university research or government data infrastructure generates spillover benefits, who captures them?

Cross-national evidence on returnee entrepreneurship shows that knowledge spillovers within an entrepreneurial ecosystem strengthen innovation performance primarily through firms' own knowledge-management capability, rather than automatically or evenly (Yi et al., 2021). Nigeria-specific work on diaspora investment and technology transfer likewise suggests that spillovers do occur, but that they tend to concentrate in already-resourced firms and clusters, deepening rather than narrowing the gap between Nigeria's sophisticated technology hubs and the larger, digitally excluded informal economy (Àkànle & Ola-Lawson, 2021). The implication is that Triple Helix interventions will not automatically produce inclusive outcomes unless paired with explicit investment in transmission channels.

Nigeria's Broadband Trajectory, 2020-2025: A Quantitative Illustration of the Infrastructural Precondition

Digital public infrastructure represents an area where the Triple Helix's developmental promise has been tested visibly. The Indian case is studied as a template for the Global South (Soumya, 2025), yet recent evidence highlights the difficulty of replicating that model in settings with different institutional conditions. Nigeria's National Broadband Plan (NBP) 2020-2025 provides an unusually well-documented natural experiment, because the Nigerian Communications Commission (NCC) has published year-end subscriber and penetration data throughout the Plan's entire lifespan, allowing the infrastructural-precondition argument advanced in Section 5.3 to be examined quantitatively rather than asserted narratively.

A scope clarification is due before the figures are presented. What follows compares Nigeria's realised broadband trajectory to its own policy target; it does not measure the university (U), industry (I), or government (G) terms of Equation (1) directly, nor does it estimate an interaction term for $\delta(U \times I \times G)$. It is, more precisely, a case-based empirical illustration of one boundary condition the model implies—that the infrastructural component embedded within I and G can bind before synergy is realised—rather than a test of the Triple Helix model as a whole. Infrastructure-target attainment is used here as a proxy for that specific boundary condition on the reasoning that broadband penetration is a necessary, if not sufficient, precondition for the deployment-oriented activity the I and G terms are meant to capture in the MIS context (Section 2.1); it is not offered as a proxy for the full multiplicative interaction, which this article does not attempt to operationalise numerically.

Table 1 reports year-end broadband penetration and subscription figures published directly by the NCC in its annual Subscriber/Network Performance Reports, supplemented for the 2020 baseline and the final 2025 outturn by NCC data reported contemporaneously in the trade press. These are official regulator statistics, not author estimates, and each figure is traceable to its primary source.

A caveat applies throughout this section before the inferential statistics are introduced: the standard errors, t-tests, confidence intervals, and Durbin–Watson checks reported in Equations (7)–(11) describe how well a linear trend fits the complete published series of six annual NCC observations, not an inference from a sample to a larger population. With only six data points these statistics have limited power, and they are reported and discussed throughout as indicative of the trend's shape and direction rather than as confirmatory hypothesis tests in the conventional large-sample sense.

Table 1: Nigeria Broadband Penetration and Subscriptions at Year-End, 2020-2025, Against the National Broadband Plan Target

Year-end	Broadband penetration (%)	Broadband subscriptions (million)	Primary source
2020 (NBP baseline, Q1)	38.49	≈ 75.4	Businessday (2022)
2021	40.88	78.0	NCC (2021) Year-End Performance Report; Businessday (2023)
2022	47.36	90.3	NCC (2022) Year-End Performance Report
2023	43.71	94.76	NCC (2023) Year-End Performance Report; Businessday (2024)
2024	44.43	96.3	NCC (2024) Year-End Performance Report
2025	50.58	109.6	The Cable (2026), citing NCC data
2025 target (NBP)	70.00	—	National Broadband Plan 2020-2025

Sources: NCC (2021, 2022, 2023, 2024) year-end Subscriber/Network Performance Reports; Businessday (2022) for the 2020 launch baseline; Businessday (2023) corroborating the 2021 year-end subscription total; the 2022 year-end total is taken directly from the NCC (2022) Annual Report, since the THISDAY (2023) article cited elsewhere in this reference list reports a later, February 2023 data point (92.6 million) rather than the December 2022 figure and is not used to source this row; Businessday (2024) for the 2023 year-end total; The Cable (2026) and Nairametrics (2025) for the November-December 2025 outturn, both reporting the same NCC figures independently. Compiled by the authors from the cited primary reports. Broadband-subscription totals for 2021-2023 are drawn from contemporaneous trade-press coverage that cites the underlying NCC year-end and monthly statistics directly: the NCC year-end report documents for those years state broadband penetration prominently but do not headline a standalone year-end subscription figure in the same format as the 2020, 2024, and 2025 primary sources cited above. This follows the same sourcing approach already used for the 2020 and 2025 rows and is consistent with the reporting standard set out in Section 3.2 that no figure in this table is an author estimate. A further transparency note is warranted for the 2022-to-2023 transition specifically: dividing each year's published subscription total by its published penetration percentage shows an implied population denominator of approximately 191 million for 2020-2022 and approximately 216-217 million for 2023-2025-a shift too large to reflect organic demographic change (Nigeria's population grows at roughly 2.4% annually) and confirmed independently by regulatory reporting that the NCC recalibrated the population base used in its standard telecom indicators (teledensity, internet penetration, and broadband penetration alike) from approximately 191 million to a revised projection of 216 million, effective September 2023 (TechAfrica News, 2025, citing NCC data). This denominator revision, not a decline in the underlying subscriber base, is the primary driver of the apparent 2022-to-2023 penetration dip reported in Section 4.3; Equation (9) and the accompanying robustness analysis recompute the 2023-2025 penetration series on the pre-revision population base so that the six-year trend can be read on a consistent footing.

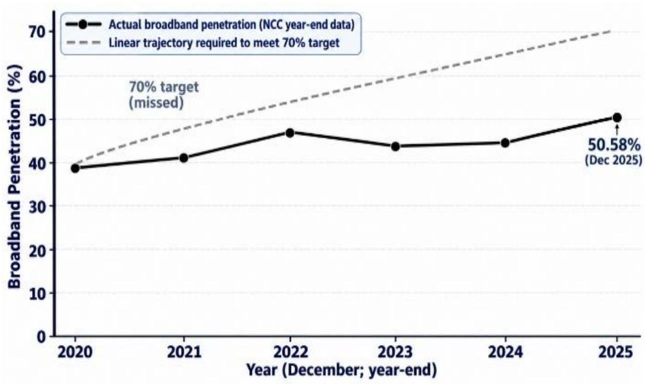

Figure 3: Actual Broadband Penetration (Solid) Against the Linear Trajectory Required to Reach the 70% Target by December 2025 (Dashed)

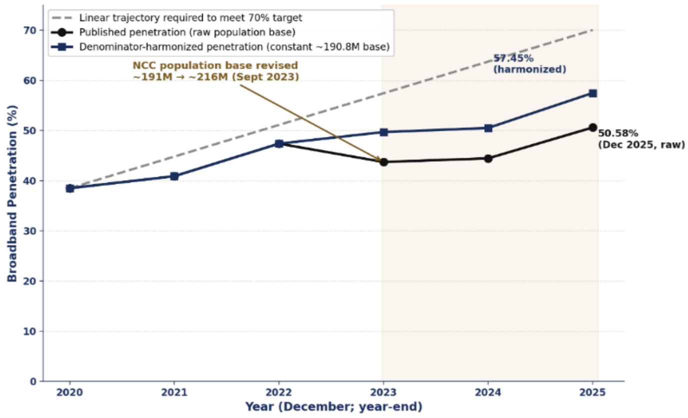

Figure 4: Raw Published Penetration Versus Denominator-Harmonized Penetration (Constant ~190.8 Million Population Base), Showing that the Apparent 2022-2023 Dip is Substantially an Artefact of the NCC's September 2023 Population-Base Revision Rather than a Loss of Connectivity (Equation 9; Table 1 Note)

Two simple, transparent formulas summarise the gap visible in Figure 3. First, the linear annual percentage-point growth required to move from the 2020 baseline (P_0) to the stated 70% target (P_t) over the Plan's n = 5 years is:

$$\Delta_{req} = (P_t - P_0) / n = (70 - 38.49) / 5 = 6.30 \text{ percentage points per year} \quad (3)$$

Second, the realised average annual growth over the same period, using the December 2025 outturn (P_5 = 50.58%), was:

$$\Delta_{obs} = (P_5 - P_0) / n = (50.58 - 38.49) / 5 = 2.42 \text{ percentage points per year} \quad (4)$$

The ratio $\Delta_{obs} / \Delta_{req} \approx 0.384$ indicates that Nigeria's realised rate of broadband-penetration growth reached only about 38% of the pace its own policy required-a gap of roughly 62% relative to target, sustained across a full six-year window and multiple ministerial administrations. This raw 38% ratio should be read with one immediate caveat: it is computed from a penetration series that mixes two different NCC population denominators partway through the window (Table 1 note), so a denominator-harmonized version of the same ratio is reported alongside it later in this section (Equation 10) rather than treated as a separate, subordinate robustness check; as shown there, the harmonized estimate confirms rather than overturns the raw-series conclusion. Expressed as a compound annual growth rate of the penetration series itself:

$$CAGR = (P_n / P_0)^{1/n} - 1 \quad (5)$$

which, for the observed series, yields $CAGR = (50.58/38.49)^{1/5} - 1 \approx 5.6\%$ per year-a figure that looks respectable in isolation but is diagnostic of underperformance once benchmarked against Δ_{req} in Equation (3).

A further cross-check strengthens confidence in the dataset's internal consistency. Broadband subscriptions grew from approximately 75.4 million (2020) to 109.6 million (December 2025), a compound annual growth rate of approximately 7.8%-markedly faster than the 5.6% CAGR of the penetration rate itself. Because penetration is subscriptions divided by population, this divergence is arithmetically consistent with Nigeria's population growing at roughly 2-2.5% per year over the same window, meaning a meaningful share of raw subscriber growth was absorbed by population growth rather than translating one-for-one into penetration gains. This matters for Triple Helix analysis specifically: policy narratives that cite subscriber growth in absolute terms (e.g., “broadband subscriptions passed 109 million”) can overstate progress against a per-capita policy target, and a Triple Helix evaluation that does not distinguish the two risks crediting infrastructure investment with more progress than the per-capita record supports.

Because penetration P is defined as subscriptions S divided by population N (P = S/N), the growth rates of the three series are linked, to a first-order log approximation, by the identity:

$$g_S \approx g_P + g_N \quad (6)$$

where g_S, g_P, and g_N denote the compound annual growth rates of subscriptions, penetration, and population respectively. Substituting the observed values ($g_S \approx 7.8\%$, $g_P \approx 5.6\%$) implies $g_N \approx 2.2\%$ per year, closely matching Nigeria's independently estimated population growth rate of roughly 2-2.5% per year cited above, and providing an internal consistency check on the regulator data used in this analysis.

A robustness check beyond the two-year endpoint comparison. Equations (3) and (4) rest on only two of the six available data points (2020 and 2025); as noted in Section 3.3.2, this leaves open the possibility that the reported shortfall reflects the particular choice of endpoints rather than the trend as a whole. To address this, an ordinary-least-squares regression of year-end penetration P on year index t (t = 0 for 2020, …, t = 5 for 2025) was fitted to all six observations in Table 1:

$$\hat{P}(t) = 39.42 + 1.93t \ (R^2 = 0.69) \quad (7)$$

The fitted slope of 1.93 percentage points per year is closely comparable to, and slightly below, the endpoint-based Δ_{obs} of 2.42 points per year from Equation (4), and remains far below the Δ_{req} of 6.30 points per year required by the National Broadband Plan (Equation 3). Agreement between the endpoint-based and regression-based estimates indicates that the reported shortfall is a genuine feature of the six-year trend rather than an artefact of the specific years used in Equations (3)-(4). With only six annual observations, the regression carries limited statistical power, so inferential statistics are reported rather than the point estimate alone: the fitted slope of 1.93 percentage points per year has a standard error of 0.65 and is statistically distinguishable from zero ($t(4) = 2.96$, $p = .041$, 95% CI [0.12, 3.73]), confirming that the observed upward trend is a genuine feature of the series rather than noise around a flat trajectory. More directly relevant to this article's argument, the fitted slope is also statistically distinguishable from, and well below, the 6.30-point annual pace the National Broadband Plan required ($t(4) = -6.72$, $p = .003$), providing formal statistical support-beyond the endpoint ratio in Equations (3)-(4)-for the conclusion that Nigeria's realised broadband growth fell significantly short of its policy target. These inferential statistics rest on the classical OLS assumption of independent errors, an assumption that a trending annual series of this kind can violate through serial correlation; with only six observations any such test carries limited power, so the reported p-values and confidence interval are best read as indicating a real and substantial trend rather than as precise measures of statistical significance, pending the formal Durbin–Watson check reported later in this section. At the same time, the moderate R^2 of 0.69 quantifies the extent to which the series departs from a smooth linear path-most visibly in the 2022-2023 dip discussed below-and is itself informative: a purely linear reading of Nigeria's broadband progress would understate the volatility that the raw series exhibits.

A further, complementary check follows from the fact that broadband subscriptions themselves (Table 1, column 2) are a raw count rather than a ratio, and are therefore entirely unaffected by the population re-basing discussed above. An OLS regression of subscriptions S on the same year index t was fitted to all six observations in Table 1:

$$\hat{S}(t) = 74.27 + 6.58t \quad (R^2 = 0.95) \tag{8}$$

The fit is markedly tighter than the raw penetration regression (R^2 = 0.95 versus 0.69 in Equation 7), and the slope is statistically distinguishable from zero at a stricter threshold (standard error = 0.78, t(4) = 8.45, p = .001). Because this series carries no population-denominator artefact, its high R^2 indicates that the underlying growth in broadband access was itself close to linear across the full window, and that the greater volatility visible in the raw penetration series (Equation 7, R^2 = 0.69) is attributable substantially to the mid-series denominator change documented above rather than to genuine swings in network build-out or subscriber demand, a point illustrated directly in Figure 5 below.

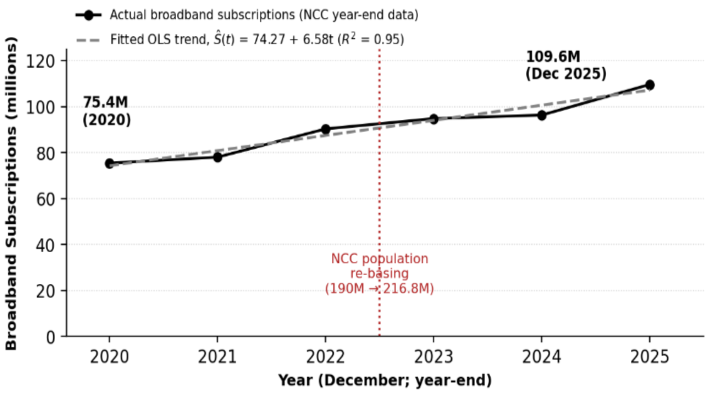

Figure 5: Actual broadband Subscriptions (Solid) with Fitted OLS Trend (Dashed, Equation 8). The Dotted Vertical Line Marks the NCC's 2023 Population Re-basing (190 Million to 216.8 Million); Subscriptions Grew Smoothly Through this Point, Confirming that The re-based Denominator, Not a Change in the Underlying Subscriber Trend, Drives the 2022-2023 Dip in Penetration Visible in Figure 3

A second robustness extension follows directly from the population-denominator revision documented in the note to Table 1. Because the NCC's population base for standard telecom indicators moved from approximately 191 million to approximately 216 million effective September 2023 (TechAfrica News, 2025), the raw penetration series in Equations (3)–(7) mixes two different denominators partway through the observation window. To check that the reported shortfall is not an artefact of this mid-series revision, a denominator-harmonized penetration series was constructed by recomputing the 2023-2025 observations on the pre-revision population base ($N^* \approx 190.8$ million, the average of the 2021 and 2022 implied bases):

$$P'_t = S_t / N^* \times 100, \text{ for } t \geq 2023 \tag{9}$$

Applying Equation (9) yields a harmonized series of 38.49%, 40.88%, 47.36%, 49.67%, 50.48%, and 57.45% for 2020-2025 respectively (Figure 3). Refitting the OLS regression from Equation (7) to this harmonized series gives:

$$\hat{P}'(t) = 38.40 + 3.60t \ (R^2 = 0.95, SE = 0.40, t(4) = 9.04, p < .001) \tag{10}$$

The harmonized fit is markedly tighter than the raw-series fit (R^2 = 0.95 versus 0.69), confirming that most of the raw series' departure from linearity is attributable to the denominator break rather than to genuine volatility in underlying connectivity. The harmonized slope of 3.60 points per year is nearly double the raw estimate of 1.93, indicating that the raw series understates Nigeria's true underlying rate of progress once the accounting artefact is removed. Even so, formally testing the harmonized slope against the required pace using the general one-sample t-statistic for a regression coefficient,

$$t(n-2) = (\hat{\beta} - \beta_0) / SE(\hat{\beta}) \tag{11}$$

with $\beta_0 = \Delta_{req} = 6.30$ from Equation (3), gives t(4) = (3.60 − 6.30)/0.40 = −6.80, p = .002-materially unchanged from the raw-series test (t(4) = −6.72, p = .003) reported above. The substantive conclusion is therefore robust to whether the population-denominator break is corrected for or not: Nigeria's realised broadband growth falls significantly short of the pace its own policy required under either specification. The serial-correlation caveat entered earlier can now be addressed empirically rather than only flagged. The Durbin–Watson statistic, $DW = \Sigma(e_t - e_{t-1})^2 / \Sigma e_t^2$, was computed for both regressions: DW = 2.41 for the raw-series residuals and DW = 2.76 for the harmonized-series residuals. Both values sit close to the no-autocorrelation benchmark of 2, giving no indication of strong positive serial dependence in either series, though with only six observations the test has limited power and this result should be read as reassuring rather than conclusive.

As a final, independent check, the model was validated out of sample: the OLS regression was refitted using only the 2020-2024 observations (n = 5) and used to forecast the 2025 value before comparing it against the outturn actually reported. The five-point fit predicts a 2025 penetration of 47.39%, with a 95% prediction interval of [34.14%, 60.63%]; the actual outturn of 50.58% (Table 1) falls comfortably within this interval and close to the point forecast. This is consistent with 2025 continuing the pre-existing trend rather than representing a structural break or an unusually strong late surge, but a single observation falling inside a prediction interval cannot, on its own, rule out a structural break; it is offered here as one further, model-independent piece of evidence alongside the Durbin-Watson checks and the harmonized-series regression above, not as a definitive test. Taken together, this converging evidence-rather than any single check in isolation-supports reading the shortfall documented throughout this section as a stable, multi-year pattern rather than a statistical artefact of any single year's data.

Substantively, the raw series in Table 1 also shows that progress was not monotonic: penetration fell from 47.36% (December 2022) to 43.71% (December 2023) before recovering. As established above and in the note to Table 1, this dip is substantially an artefact of the NCC's population-denominator revision rather than a genuine loss of connectivity: broadband subscriptions continued to rise across the same window (90.3 million to 94.76 million, Table 1), and the harmonized series in Equation (9) shows no dip at all over this period. A separate and genuine subscriber-base contraction did occur later in the window: industry reporting documents that the SIM-NIN linkage exercise, which disconnected mobile lines not tied to a verified National Identification Number, contributed to a measurable decline in active telecom and internet subscriptions during 2024-2025 independent of any change in physical network coverage (Techcabal, 2025). The two mechanisms are therefore distinct and should not be conflated: a denominator revision explains the apparent 2022-2023 dip, while a genuine subscriber-base contraction from regulatory identity verification affected the 2024-2025 period. Both nonetheless illustrate a point Section 5.3 develops further: MIS-adjacent regulatory interventions with legitimate governance rationales (identity verification, fraud reduction, statistical recalibration) can interact unpredictably with infrastructure-adoption metrics, a dynamic the classical Triple Helix model, which treats government primarily as a funder and coordinator, does not anticipate.

Nigeria's experience with broadband expansion illustrates both the promise and the friction the preceding quantitative analysis makes explicit. The National Broadband Plan, launched in 2020 with a target of seventy-percent penetration by 2025, was not met despite significant federal investment and ministerial-level engagement (FIJ, 2026). The affordability gap identified at the Plan's launch persisted throughout its implementation period (Abah et al., 2022), and persistent issues such as high right-of-way costs and infrastructure vandalism continued to impede progress regardless of policy intent (Sowande et al., 2022). The lesson for MIS policy is that government-industry collaboration, however well structured on paper, cannot substitute for addressing the underlying physical and economic constraints that determine whether digital systems reach their intended users (a precondition argument developed fully in Section 5.3).

International Comparators: Nigeria's Internet-Access Trajectory in Context

Table 1 documents Nigeria's shortfall against its own policy target, but it says nothing about the country's connectivity trajectory relative to national peer economies also pursuing Triple-Helix-style digital-infrastructure programmes. Table 2 reports the World Bank/ITU "individuals using the Internet" indicator-a broader connectivity measure than the NCC's broadband-specific series, but one with harmonised country coverage-for Nigeria alongside Kenya, South Africa, India, and China, the same jurisdictions invoked qualitatively elsewhere in this article (Sections 1 and 4.1.4).

Table 2. Individuals Using the Internet (% of Population), Nigeria and Selected Comparator Countries, Most Recent Year Available

Country	Individuals using the Internet (%)	Year	Source
Nigeria	39.21	2023	World Bank (2026a); ITU DataHub
Kenya	35.0	2023	World Bank (2026a); ITU DataHub
South Africa	75.66	2023	World Bank (2026a); ITU DataHub
India	55.9	2022	World Bank (2026a); ITU DataHub
China	92.0	2024	World Bank (2026a); ITU DataHub

Note. Figures are the Most Recent Year Available per Country from the Same Harmonised World Bank/ITU Series as of this Writing (World Bank, 2026a); India's 2022 figure is One Year Older Because More Recent Values were not yet Published at the Time of Writing. Compiled by the Authors from World Bank Open Data

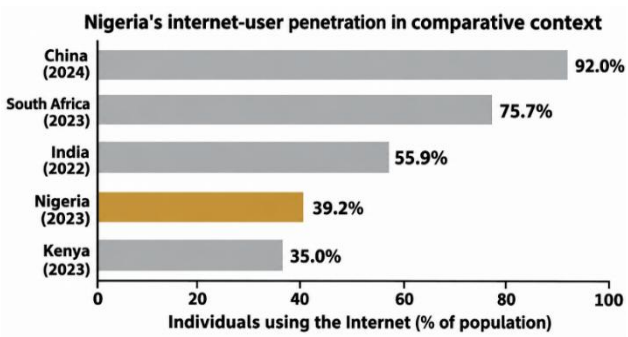

Figure 6. Individuals Using the Internet (% of Population) in Nigeria and Four Comparator Countries, Most Recent Year Available (World Bank, 2026a)

Two things stand out. A definitional caveat should be registered before either comparison is read: the NCC's narrower "broadband" definition (Table 1) and the World Bank/ITU's broader "internet use" definition (Table 2) are simply not directly comparable, so a comparator country's qualitative reputation is not automatically confirmed or contradicted by every quantitative indicator. With that caveat in place, first, Nigeria's 39.2% Internet-user penetration in 2023 exceeds Kenya's 35.0% on this broader indicator, despite qualitative Triple Helix comparisons elsewhere in the literature (Section 1) often treating Kenya as the regional frontrunner; the two countries' relative standing depends on which connectivity indicator is used. Second, and more consequential for the argument of this article, Nigeria trails South Africa (75.7%), India (55.9%), and China (92.0%) by wide margins on the same harmonised indicator, reinforcing from an independent dataset the infrastructural-precondition argument of Section 5.3: the gap documented in Table 1 against Nigeria's own policy target is not an artefact of that target's ambition, since peer developing and emerging economies have already reached, or substantially exceeded, the connectivity level the National Broadband Plan set for 2025.

Patent Output as a Time-Lagged, Corroborating Indicator

A dating caveat should be registered before the patent figures below are read: the WIPO/World Bank resident-filing series used in this section is published with a substantial lag and, as of the time of writing, does not extend past 2020, five years behind the 2025 broadband data in Section 4.3. The patent statistics that follow should therefore be read as a corroborating indicator drawn from an earlier period, not as a contemporaneous measurement, and the word "convergent" is deliberately avoided in this section's heading for that reason. With that caveat in place, the infrastructural shortfall documented above is corroborated by comparative patent statistics, which also speak to institutional imbalance in university- and industry-based innovation. WIPO/World Bank data record 410 resident patent applications filed in Nigeria in 2020 (World Bank, 2026b), the most recent year for which comparable figures are published; against Nigeria's 2020 population of approximately 206 million (World Bank, 2026c), this implies a resident-filing rate of roughly 2.0 applications per million inhabitants. WIPO's most recent statistical country profile for South Africa reports a resident-filing rate of 5.5 applications per million inhabitants (WIPO, 2026)-nearly three times Nigeria's rate, despite South Africa's smaller population and broadly comparable overall GDP scale.

A limitation of the original analysis was that this comparison relied on a single year (2020) and could not, by itself, distinguish a persistent shortfall from a one-year anomaly. The same WIPO/World Bank series records 439 resident patent applications filed in Nigeria in 2019 (World Bank, 2026b), meaning the 2020 count represents a year-on-year decline rather than a low point followed by recovery. These two points suffice to establish that Nigeria's own resident-filing count did not recover in a single year following an anomalous 2020 low; it was already declining from 2019. This claim, however, should be kept separate from the comparison against South Africa: WIPO's most recent country profile for South Africa (WIPO, 2026) reports a single most-recently-available filing rate rather than a year-matched 2019 and 2020 series, so the 2019-2020 Nigerian pair cannot by itself establish that the roughly threefold gap relative to South Africa specifically persisted across both years-only that Nigeria's own filing shortfall, relative to its own recent history, is not a one-year artefact. Read together, the 2019-2020 pair indicates that Nigeria's low resident-filing rate predates 2020 and is not attributable to a single disrupted year; the wide margin relative to South Africa's most recently reported rate is offered as corroborating, contemporaneous-lag context (Section 3.2) rather than as a year-matched persistence test, and is consistent with, rather than an artefact of, the structural constraints on Nigerian patenting activity that the qualitative literature describes. As of the time of writing, 2020 remains the most recent year for which the World Bank/WIPO resident-filing series publishes a Nigeria figure; the gap between this indicator's 2020 cut-off and the 2026 currency of other sources cited in this article reflects the publication lag of the underlying international series rather than a choice by the authors to omit more recent data.

The rate at which Nigerian university researchers obtain patents is constrained by structural issues, including a shortage of scientists and technicians engaged in technological innovation and obstacles in the patenting process itself-factors that deter researchers from pursuing inventions (Aidonojie et al., 2023). This is not merely a peripheral observation; it is consistent with, and plausibly reflects, the structural imbalance among the three classical helices, and it parallels the infrastructural imbalance quantified in Section 4.3: in both patents and connectivity, the realised rate of institutional output trails the policy-stated target, and a continental peer with a comparable Triple Helix starting point, by a wide and persistent margin.

Sustainability Beyond Infrastructure

Sustainable development in the MIS context involves not only physical infrastructure but also the institutional sustainability of the collaboration itself. As evolutionary game-theoretic findings suggest, government-industry-university collaboration tends toward unstable equilibria without careful incentive design (Ma & Yang, 2024). Any MIS-based development initiative built on the assumption of stable, ongoing Triple Helix cooperation requires explicit mechanisms-monitoring, renegotiated incentives, and formal reviews-to prevent cooperation from dissolving once initial funding or political attention wanes.

The informal, technology-based micro-firms that constitute a substantial share of Nigeria's economic activity should not be treated as a residual category to be excised in the name of modernisation (Oghuvbu et al., 2022, p. 395). Built sustainably, they represent exactly the type of additional actor that an expanded Triple Helix can absorb and amplify, a point developed further in Section 5.2.

Discussion

The Problem of Assumed Parity

In its classical formulation, the Triple Helix Model implicitly assumes institutional parity: that universities, industry, and government bring comparable capacity and leverage to the table. This assumption rarely holds in developing economies. In Nigeria, universities operating under severe funding constraints, an industry sector dominated by urban technology clusters, and a government apparatus controlling disproportionate financial and regulatory power combine to produce a configuration closer to a government-dominated "statist" model than the balanced one the literature typically recommends (Nwagwu, 2008).

This qualitative account is corroborated by the comparative patent statistics reported in Section 4.5. Nigeria's own resident-filing count declined from 2019 to 2020 rather than recovering from a single anomalous low, and the roughly threefold gap relative to South Africa's most recently reported filing rate-though drawn from a single comparator year rather than a year-matched series-is a direct, quantitative expression of the structural constraint Aidonojie et al. (2023) describe qualitatively, and it parallels the infrastructural shortfall quantified in Section 4.3: on both connectivity and patenting, Nigeria's realised institutional output trails not only its own policy targets but also the levels achieved by a continental peer with a comparable Triple Helix starting point.

Taken together, the qualitative and quantitative evidence reviewed in Sections 4 and 5.1 supports four propositions that refine, rather than reject, the classical Triple Helix Model for infrastructure-constrained settings. P1: the synergistic bonus captured by the interaction term of Equation (1) is conditional on an infrastructural floor embedded in the I and G terms, such that no combination of university and industry strength restores that bonus once the floor is not met, even though the additive contributions of the individual helices persist (Section 5.3). P2: government subsidy to university-industry collaboration exhibits threshold effects rather than smooth returns, activating synergy only above an empirically identifiable minimum intensity (Section 4.1.4). P3: institutional parity among the three helices cannot be assumed in developing economies and should be treated as an empirical question for each national case rather than a background condition (Section 5.1). P4: where formal Triple Helix institutions remain thin, supplementary actors-diaspora networks, civil society, and informal technology communities-perform load-bearing rather than peripheral functions and warrant formal incorporation into the model (Section 5.2). These propositions are offered as testable claims for future comparative research rather than as settled findings, consistent with this article's conceptual, theory-building design (Section 3.1). Because they are inferred from a single country's experience, their expected scope should be stated rather than left implicit: P1-P4 are advanced as most plausibly holding in infrastructure-constrained, statist-configuration economies structurally similar to Nigeria's, where a government apparatus with disproportionate resources coexists with underdeveloped formal university-industry linkages (Section 5.1); they may not hold, or may hold in modified form, in smaller, resource-rich, or highly digitised states where the institutional starting conditions differ substantially from Nigeria's. Establishing whether, and how far, P1-P4 generalise beyond this scope is left to the cross-country comparative research proposed in Section 6.1.

Figure 7 summarises P1-P4 as a single conceptual diagram, making explicit the constructs the propositions invoke (the classical triad, the interaction term, and the infrastructural floor), the observable indicators used as their empirical proxies in Section 4, and the conditions under which each proposition would be considered falsified by future evidence.

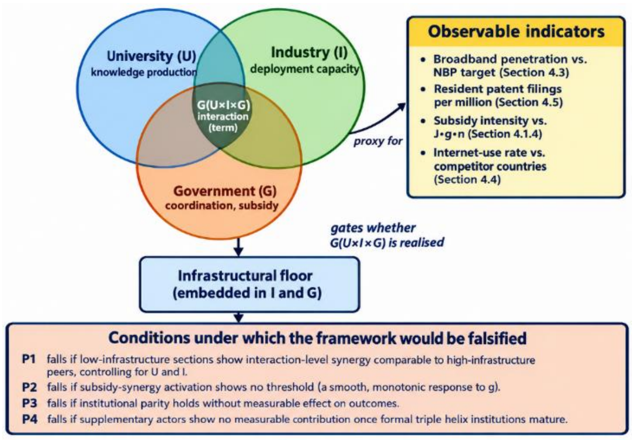

Figure 7: Conceptual Model Linking the Classical Triple Helix Triad, the Infrastructural Floor Gating the Interaction term $\delta(U \times I \times G)$, the Observable Indicators used as Proxies in Section 4, and the Conditions Under which Propositions P1-P4 would be Falsified

More Actors, More Complexity

The argument that the standard three-party model is insufficient for emerging economies is significant. In Nigeria, diaspora investment networks and informal technology communities play a substantive role in MIS entrepreneurship (Àkànle & Ola-Lawson, 2021). A faithful application of the Triple Helix to Nigeria's MIS sector must either expand the model's cast of actors or explicitly account for why these additional actors are currently substituting for underdeveloped formal institutions.

Figure 8 depicts these relationships visually, showing how the supplementary actors proposed in Sections 4.2.1 and 5.2 attach to the classical university-industry-government triad; Table 3 then elaborates each actor's specific contribution and Nigerian evidence base.

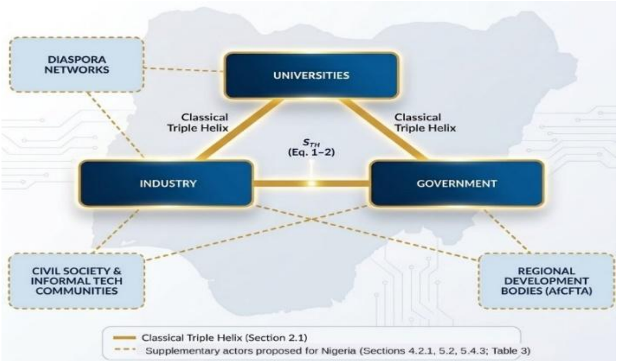

Figure 8: From Triple Helix to an Expanded Nigerian MIS-Innovation Actor Map. Solid Lines Denote the Classical Triple Helix Triad (Section 2.1); Dashed Lines Denote the Supplementary Actors Proposed for the Nigerian Context (Sections 4.2.1, 5.2, 5.4.3)

Table 3: Beyond the Standard Triple Helix: Actor-Specific Contributions to MIS Innovation in Nigeria

Actor	Primary MIS contribution	Nigerian evidence base	Critical caveat for MIS application
Universities	Knowledge production; talent pipeline; applied research grounded in deployment problems	NOUN Faculty of computing IT. Programmes, and NOUN ACETEL MIS programmes; ACETEL-affiliated technical reports; university-affiliated incubation centres	Research funded for theoretical work can disconnect from operational reality; invention-patent rate remains structurally constrained (Aidonojie et al., 2023)
Industry	Deployment expertise; service quality; commercialisation of university research; open-banking infrastructure	Lagos fintech cluster; Ikeja Computer Village; Yaba technology cluster	Concentrated in urban hubs; spillovers reach the informal economy only weakly (Iammarino et al., 2018)
Government	Coordination; subsidy; procurement; data infrastructure; regulation	NITDA; Nigerian Communications Commission; Startup Act 2022 labelling regime; National Broadband Plan; National Digital Economy Policy and Strategy 2020-2030 (NITDA, 2023)	Statist configuration dominates; cooperation requires explicit incentive design (Ma & Yang, 2024)
Diaspora networks	Cross-border capital; technology transfer; informal mentorship	Nigerian diaspora investment patterns in ICT (Àkànle & Ola-Lawson, 2021)	Spillovers concentrate in already-resourced clusters (Iammarino et al., 2018)
Civil society and informal technology communities	Ecosystem intermediation; last-mile service delivery; community-based MIS	Ikeja Computer Village as a productive informal cluster; technology-based micro-firms (Etzkowitz & Adeoti, 2023)	Often treated as residual to be modernised away rather than incorporated
Regional development bodies	Cross-state coordination; AfCFTA-aligned digital trade integration	AfCFTA digital trade protocols; state-level technology park initiatives (AfCFTA Secretariat, 2023)	Limited national-level coordination capacity at present scale

Note. All Sources Cited within the "Nigerian Evidence Base" and "Critical Caveat" Columns Appear Inline within Sections 2 to 5 of this Article

Infrastructure as a Precondition, Not a Variable

One of the clearer lessons from Nigeria's broadband trajectory, now illustrated quantitatively in Section 4.3 and supported by the regression check in Equation (7), is that physical infrastructure functions less as an input and more as a hard precondition for Triple Helix collaboration to produce meaningful MIS outcomes. No combination of university research, industrial sophistication, and government policy is likely to substitute for reliable connectivity: the seventy-percent target was missed by 19.4 percentage points, and the qualitative record attributes a substantial share of that shortfall to right-of-way, cost, and vandalism constraints on the willingness of universities, firms, and policymakers to align (FIJ, 2026; Sowande et al., 2022), though the secondary-data design of this article (Section 6.1) means this attribution is not established causally. Sub-Saharan African broadband penetration during this period remained well below the level needed for full economic participation, with one estimate placing Nigerian penetration at roughly 39% in the first quarter of 2023-consistent with the 43.71% year-end 2023 figure in Table 1 (Emelogu, 2024). This is a structural constraint that Triple Helix literature, largely developed in well-connected economies, fails to adequately theorise; in terms of Equation (1), it illustrates the case in which the infrastructural floor embedded in the I and G terms binds before the interaction term $\delta(U\times I\times G)$ can be realised.

Policy Implications for Nigeria

The evidence reviewed points toward policy priorities that are modest in ambition but realistic regarding Nigeria's current institutional starting point.

Treat Infrastructure as the First Helix Investment

Given how connectivity gaps undercut other forms of Triple Helix collaboration-and given that realised growth reached only 38% of the required linear pace over 2020-2025, confirmed by an independent regression estimate in Equation (7)-infrastructure investment, particularly fibre rollout and spectrum-roadmap execution via the Ministry of Communications, Innovation and Digital Economy and the NCC, should be viewed as foundational to MIS policy, not as a separate telecommunications agenda. The National Digital Economy Policy and Strategy 2020-2030 already frames this integration, treating digital infrastructure as a precondition rather than a downstream consequence of innovation policy (NITDA, 2023).

Build Incentive Structures That Anticipate Instability

In light of evolutionary game-theoretic evidence on government-industry-university collaboration (Ma & Yang, 2024) and the empirically documented subsidy threshold below which Triple Helix synergies fail to activate at all (Wang et al., 2026), Nigerian MIS policy should not assume that cooperative arrangements, or subsidy programmes pitched below the effective activation threshold, will sustain themselves. Built-in review mechanisms, renegotiable funding structures, and clear escalation paths for resolving misaligned incentives help mitigate the strategic drift common to these partnerships.

Formally Recognise the Fourth and Fifth Actors

Rather than forcing Nigeria's MIS entrepreneurship ecosystem into a strict three-party framework, policy design should explicitly incorporate the diaspora investment networks, civil-society intermediaries, and informal technology communities already performing much of the work the classical Triple Helix assigns to industry and government (Àkànle & Ola-Lawson, 2021; Piqué et al., 2018, p. 6; Schebesch et al., 2024; Tamtik, 2018, p. 12), as summarised in Table 3. Recognition requires that these actors receive consistent policy treatment and access to public instruments.

Anchor University Research in Deployable MIS Problems

Institutions such as NOUN's ACETEL are well positioned to narrow the gap between academic MIS research and deployed public systems, provided research funding is structured around applied, deployment-oriented questions-such as health information systems, land administration, and public financial management-rather than purely theoretical work. The National Digital Economy Policy and Strategy provides a framework within which such university-led, deployable research can be channelled (NITDA, 2023). Recent AI-adoption literature suggests that even substantial adoption does not automatically produce deployment-grade outcomes, and that the institutional context of the research shapes the eventual value captured (Enholm et al., 2021, p. 1725), a conclusion echoed in a recent working paper that has not yet cleared peer review (Holmes et al., 2026, preprint).

CONCLUSIONS

The Triple Helix Model is not a flawed idea, but a partial one. It correctly identifies that innovation in fields like MIS depends on sustained interaction between universities, industry, and government. The past several years of scholarship have strengthened that core claim while clarifying that the model's real-world performance depends on conditions it does not itself guarantee: institutional parity, stable incentives, adequate infrastructure, and-occasionally-a wider cast of actors (Cai & Lattu, 2021, p. 264; Gatune, 2023, p. 223). The contemporary AI-innovation literature confirms this, showing that even within well-resourced economies, firm-level innovation outcomes depend on the interaction of internal digital foundations with external government support and university collaboration-interactions the Triple Helix describes well but does not fully explain through its original three-actor formulation (Mariani et al., 2022; Wang et al., 2025).

For Nigeria, the Triple Helix offers a useful diagnostic vocabulary rather than a ready-made solution. The country's broadband trajectory over 2020-2025, quantified in Section 4.3 and corroborated by an independent regression estimate (Equation 7) rather than an endpoint comparison alone, illustrates the infrastructural-precondition lesson developed in Section 5.3. Realised penetration growth reached only 38% of the linear rate the government's own plan required, even as raw subscriptions grew at a healthy compound rate-an example of the gap between aggregate progress and per-capita policy achievement that Triple Helix evaluations should routinely disaggregate.

The expanded Triple Helix configuration proposed for emerging economies (Schebesch et al., 2024), combined with Nigerian evidence on diaspora-mediated spillovers (Àkànle & Ola-Lawson, 2021; Danson & Todeva, 2016, p. 29) and informal-sector contributions (Champenois & Etzkowitz, 2017, p. 53), suggests that policy design in this context must plan for actor heterogeneity. Productive next steps for research include cross-country comparative studies of infrastructure-conditional Triple Helix outcomes using the $\Delta_{obs}/\Delta_{req}$ ratio applied here as a comparable metric, longitudinal studies of the Nigeria Startup Act 2022 and the National Data Governance Framework, and empirical work on whether diaspora-mediated spillovers can be deliberately amplified to reach beyond Nigeria's existing technology hubs.

Limitations

This analysis relies on published regulator and international aggregates rather than microdata, documenting the size and persistence of Nigeria's Triple Helix gaps without establishing causal attribution; resolving that requires primary data collection beyond this article's scope. Five specific limitations should be stated explicitly. First, no direct measure of Triple Helix synergy (the U, I, and G terms of Equation 1, or their interaction) was collected or estimated; the broadband and patent indicators are proxies for one boundary condition the model implies, not measurements of collaboration itself. Second, the quantitative broadband analysis rests on six annual observations, which limits the statistical power of the regressions reported in Section 4.3 despite the robustness extensions applied to them. Third, the NCC's September 2023 population-denominator revision affects the raw penetration series, and while Section 4.3 reports a fixed-base harmonization as a sensitivity check, a fuller harmonization using consistent annual population estimates for every year was not undertaken (Section 3.3.2) and is left for future replication. Fourth, the international comparisons in Section 4.4 and 4.5 are not fully contemporaneous: the World Bank/ITU connectivity indicators are drawn from each country's most recently published year rather than a single common year, and the patent comparison pairs Nigeria's 2019-2020 filings against South Africa's most recently published single-year rate rather than a year-matched series. Fifth, the patent-output comparison itself is limited to two Nigerian observation years and a single South African reference year, which is sufficient to show that Nigeria's 2020 shortfall was not a one-year anomaly relative to its own prior year, but is not sufficient to establish multi-year persistence relative to South Africa specifically. Beyond these five points, Nigeria’s evidence base remains thinner than Brazil’s or China’s, and applying European-derived regional-economy theory to Nigerian institutions warrants caution. The article adopts a cautious, qualified assessment of the Triple Helix Model, recognising its limited predictive alignment with theory and framing its four propositions for future validation through primary-data research.

Concluding Remarks

The opportunity, demographic dividend, and institutional readiness window are present. Whether these are converted into broad-based economic transformation depends on the policy choices of the next decade, and on whether Nigeria's policymakers and scholars are willing to treat the Triple Helix as a starting framework requiring adaptation, rather than a finished template requiring only transplantation.

Declarations

Authorship Contribution Statement

Bitiyong, John Isa.: Conceptualization, Methodology, Investigation, Writing – Original Draft,
Dodo, Enoch Jacob: Conceptualization, Methodology, Investigation, Formal Analysis, Visualization, Writing – Original Draft, Review & Editing.
Bitiyong, Fidelis Isa: Validation, Data Curation, Writing – Original Draft.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

No new data were created in this study. All data analysed are publicly available from the cited sources: The Nigerian Communications Commission Year-end Subscriber/Network Performance Reports (NCC, 2021, 2022, 2023, 2024); World Bank Open Data (World Bank, 2026a, 2026b, 2026c); the WIPO statistical country profile for South Africa (WIPO, 2026); and the trade-press reports cited in Table 1 (Businessday, 2022, 2023, 2024; THISDAY, 2023; The Cable, 2026).

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