

Digital Infrastructure Access, Fintech Adoption, And Financial Inclusion Among Smallholder Farmers in North Central Nigeria: A PLS-SEM Analysis

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Abstract

Purpose: *Smallholder farmers account for the majority of Nigeria's food production yet remain largely excluded from formal financial services, constraining productivity and rural economic development. This study examines whether access to digital infrastructure drives FinTech adoption among smallholder farmers, and whether FinTech adoption, in turn, translates into meaningful financial inclusion.*

Design/Methodology/Approach: *A quantitative, cross-sectional survey design was employed. Structured questionnaires were administered face-to-face to smallholder farmers across Benue, Nasarawa, Plateau, and the Federal Capital Territory (FCT) Abuja in Nigeria's North Central region, using a stratified multi-stage sampling procedure. Of 445 questionnaires distributed, 392 valid responses were obtained (88.1% response rate). Partial Least Squares Structural Equation Modelling (PLS-SEM) in SmartPLS was used to assess the measurement model and to test the hypothesised structural relationships between digital infrastructure access, FinTech adoption, and financial inclusion.*

Findings: *All constructs demonstrated strong reliability and convergent validity (Cronbach's alpha, composite reliability, and AVE values exceeding recommended thresholds). Digital infrastructure access exerted a strong, positive, and statistically significant effect on FinTech adoption ($\beta = 0.934$, $t = 138.009$, $p < 0.001$), explaining 87.2% of the variance in adoption. FinTech adoption, in turn, had a strong positive effect on financial inclusion ($\beta = 0.873$, $t = 50.832$, $p < 0.001$). Both hypothesised paths were robustly supported, with effect sizes considerably larger than those typically reported in comparable technology-adoption studies.*

Practical Implications: *The findings indicate that digital infrastructure functions as a threshold precondition rather than a marginal enabler of FinTech adoption in resource-constrained rural settings. Policymakers, mobile network operators, and FinTech providers should therefore prioritise rural connectivity and infrastructure investment as a precondition for financial-inclusion programming, rather than treating infrastructure and adoption-facilitation initiatives as parallel, independent workstreams.*

Originality: *This study provides rare, statistically robust, empirically grounded evidence of the infrastructure–adoption–inclusion pathway among smallholder farmers in a developing-economy agricultural setting, using a large, regionally stratified sample and rigorous PLS-SEM validation. It extends Rogers' Diffusion of Innovation theory by demonstrating that communication-channel access can function as a binding constraint rather than a merely facilitating condition in infrastructure-scarce rural economies.*

Keywords: *FinTech adoption; digital infrastructure; financial inclusion; smallholder farmers; PLS-SEM; Nigeria; Diffusion of Innovation theory*

1. Introduction

Financial inclusion is widely regarded as a critical enabler of poverty reduction, agricultural productivity, and rural economic development (Adegbite & Machethe, 2022). Yet in Nigeria, an estimated 78% of smallholder farmers, who together account for approximately 80% of national food production, remain excluded from formal financial services (National Bureau of Statistics, 2022). This exclusion constrains farmers' ability to invest in inputs, manage risk, and smooth consumption across agricultural cycles, with knock-on consequences for household welfare and national food security. Financial Technology (FinTech) has been widely promoted as a mechanism for closing this gap, offering low-cost, low-infrastructure alternatives to traditional brick-and-mortar banking (Ahamadou & Agada, 2023; Rayhan et al., 2024). However, the extent to which FinTech can deliver on this promise in rural, agriculturally dependent, infrastructure-scarce settings remains empirically underexplored, particularly outside East Africa's relatively well-documented mobile-money markets. Existing technology-adoption research has tended to assume gradual, attitude-driven adoption processes consistent with Rogers' (2003) Diffusion of Innovation (DOI) theory, developed primarily in infrastructure-abundant contexts. Whether these assumptions hold where connectivity, electricity, and device access are themselves scarce and unevenly distributed is not well established. This study addresses this gap by empirically testing two foundational relationships within Nigeria's North Central agricultural belt: first, whether access to digital infrastructure drives FinTech adoption among smallholder farmers; and second, whether FinTech adoption, once achieved, translates into measurable gains in financial inclusion. In doing so, the study provides quantitative evidence on the strength and direction of the infrastructure–adoption–inclusion pathway that is largely absent from the current literature on rural FinTech in Sub-Saharan Africa. The remainder of this paper is organised as follows. Section 2 outlines the study's theoretical framework. Section 3 reviews the relevant literature and develops the study's hypotheses. Section 4 describes the research methodology. Section 5 presents the empirical results. Sections 6 to 9 discuss the findings, theoretical contributions, managerial implications, and limitations, before Section 10 concludes.

2. Theoretical Framework

2.1 Diffusion of Innovation Theory

This study is anchored in Rogers' (2003) Diffusion of Innovation (DOI) theory, which conceptualises the adoption of an innovation as a function of the innovation's characteristics (relative advantage, compatibility, complexity, trialability, and observability), the communication channels through which information about it spreads, the time over which adoption occurs, and the social system within which diffusion takes place. Communication channels, in Rogers' original formulation, function primarily as facilitating conditions that accelerate or slow an underlying, attitude-driven adoption process.

DOI theory was developed predominantly in infrastructure-abundant contexts, where communication channels, while important, are rarely themselves scarce. In rural Sub-Saharan African agricultural settings, by contrast, the communication channels through which FinTech innovations diffuse, namely mobile network coverage, electricity, and device access, are frequently scarce and unevenly distributed. This study tests whether Rogers' assumption that communication channels function primarily as facilitating conditions holds in such a setting, or whether infrastructure instead operates as a binding, threshold constraint on adoption, as recent applications of DOI theory in resource-constrained settings suggest (Rahman & Singh, 2023; Udefi et al., 2025).

3. Literature Review and Hypotheses Development

3.1 Digital Infrastructure Access and FinTech Adoption

Digital infrastructure, comprising network coverage, electricity supply, and affordable device access, is consistently identified as a precondition for digital financial service uptake in rural markets (Rahman & Singh, 2023; Hornuf et al., 2024). In infrastructure-abundant urban contexts, adoption research has traditionally emphasised individual-level determinants such as perceived usefulness, ease of use, and trust (Adu et al., 2022). In rural Sub-Saharan Africa, however, a growing body of evidence suggests that structural constraints dominate individual-level attitudes as determinants of adoption (Okello Bongomin et al., 2024; Wakunuma et al., 2019), because farmers cannot adopt services they physically cannot access, irrespective of how favourably they regard them. On this basis, it is hypothesised that:

H1: Digital infrastructure access has a significant positive effect on FinTech adoption among smallholder farmers.

3.2 FinTech Adoption and Financial Inclusion

A separate stream of literature links FinTech adoption directly to financial inclusion outcomes, including account ownership, savings behaviour, credit access, and transaction security (Afonso & Blanco-Arana, 2024; Adel, 2024). Mobile money and agent-banking models, in particular, have been credited with extending formal financial services to populations historically excluded by the cost structures of traditional banking (Adaba & Ayoung, 2017). Evidence from smallholder agricultural contexts specifically, however, remains comparatively thin, with much of the literature drawn from urban or peri-urban micro-enterprise samples rather than agricultural populations (Rayhan et al., 2024). Accordingly, it is hypothesised that:

H2: FinTech adoption has a significant positive effect on financial inclusion among smallholder farmers.

3.3 Conceptual Framework

Based on the foregoing review, the study proposes a two-path structural model in which digital infrastructure access is hypothesised to predict FinTech adoption, which is in turn hypothesised to predict financial inclusion. This parsimonious model, presented in Figure 1, isolates the core infrastructure–adoption–inclusion pathway for rigorous quantitative testing.



Figure 1: Conceptual Framework of the Study

4. Methodology

4.1 Research Design

This study adopts a quantitative, cross-sectional research design to examine the relationships between digital infrastructure access, FinTech adoption, and financial inclusion among smallholder farmers. Cross-sectional survey designs are widely used in technology-adoption and development research because they allow researchers to examine relationships among

variables using statistical techniques applied to data collected at a single point in time (Bryman, 2016).

4.2 Population and Sample

The target population comprised smallholder farmers (operating farms of less than five hectares, consistent with Nigeria's NBS smallholder definition) aged 18 years and above, resident in Benue, Nasarawa, Plateau, and FCT Abuja. Using the National Bureau of Statistics' (2022) estimate of 5.8 million smallholder farmers in the North Central region and applying the Taro Yamane formula at a 5% margin of error and 95% confidence level, a minimum sample of 400 was calculated. This was inflated by 11.25% to accommodate non-response, yielding a target of 445 respondents, subsequently validated via G*Power analysis (95% power to detect medium effect sizes, $f^2 = 0.15$, $\alpha = 0.05$; Erdfelder et al., 2009).

A multi-stage stratified sampling approach allocated respondents proportionally across the four states, with deliberate oversampling in Plateau and FCT Abuja to capture agro-ecological and peri-urban/rural-transition diversity. Data collection took place between October and December 2023, coinciding with the post-harvest period to maximise farmer availability. Of 445 questionnaires distributed, 392 valid responses were retained after data cleaning, an 88.1% response rate, exceeding the minimum sample size recommended for PLS-SEM analysis (Hair et al., 2019).

4.3 Data Collection Procedure

Data were collected through structured, interviewer-administered questionnaires delivered face-to-face by the principal investigator across the four target states. This approach ensured standardised delivery, immediate clarification of participant queries, and stronger rapport, thereby enhancing response accuracy. A mobile data collection application with embedded real-time validation rules was used to minimise incomplete or inconsistent responses, with secure encryption enabling immediate cloud backup. Before fieldwork, community familiarisation and engagement with agricultural extension officers facilitated access and trust-building with farming households. Daily quality-control checks, including verification of completed questionnaires and screening for unusual response patterns, were conducted throughout data collection.

4.4 Measurement of Variables

The survey instrument was developed through literature review, expert panel review (agricultural finance, rural development, and survey methodology specialists), and pilot testing with 30 farmers, following which technical terminology was replaced with culturally resonant equivalents (e.g., 'money on phone' for 'digital financial services') and item sequencing was adjusted to improve disclosure of financial behaviours. All measurement items were assessed using a five-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree), consistent with established practice in technology-adoption and financial behaviour research (Kusmaryono et al., 2022). Digital Infrastructure Access was measured using multi-item indicators covering network reliability, electricity access, device affordability, and mobile network coverage consistency. FinTech Adoption was measured via multi-item indicators covering frequency of use and perceived accessibility of digital financial services. Financial Inclusion was measured using multi-item indicators covering formal account ownership, transaction usage, savings behaviour, and credit access.

4.5 Data Analysis Technique

Data were analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM) in SmartPLS, following the two-stage approach recommended by Hair et al. (2019): assessment

of the measurement model (indicator reliability, internal consistency reliability, and convergent validity) followed by assessment of the structural model (path coefficients, significance via bootstrapping with 5,000 subsamples, and the coefficient of determination, R^2). PLS-SEM was selected because it is well suited to models involving multiple latent constructs, does not require strict assumptions of multivariate normality, and is appropriate for prediction-oriented research models of this kind (Hair et al., 2019).

5. Results

5.1 Demographic Profile of Respondents

A total of 392 valid responses were obtained from smallholder farmers across Benue, Nasarawa, Plateau, and FCT Abuja. Geographically, Benue accounted for the largest share of respondents (31.4%), followed by Plateau (29.3%), Nasarawa (20.4%), and FCT Abuja (18.9%), reflecting a deliberately balanced sampling strategy across agro-ecologically diverse states. Male farmers (57%) outnumbered female farmers (43%), consistent with documented gender disparities in Sub-Saharan African agriculture. The sample skewed relatively young, with 62.5% of respondents aged between 25 and 44 years, and educational attainment was concentrated at the primary/secondary level (72.5%), with 13.0% holding tertiary or postgraduate qualifications. In terms of farming experience, 71.2% of respondents had ten years or less of farming experience. The demographic characteristics of respondents are summarised in Table 1 and Figures 2–3.

Table 1: Demographic Characteristics of Respondents (N = 392)

Variable	Category	Percentage
State	Benue	31.4%
State	Plateau	29.3%
State	Nasarawa	20.4%
State	FCT Abuja	18.9%
Gender	Male	57.0%
Gender	Female	43.0%
Age	25–44 years	62.5%
Age	Under 25 / 45+ years	37.5%
Education	Primary/Secondary	72.5%
Education	Tertiary/Postgraduate	13.0%
Education	No formal education	5.1%
Farming Experience	10 years or less	71.2%
Farming Experience	More than 10 years	20.2%



Figure 2: Geographic Distribution of Respondents by State

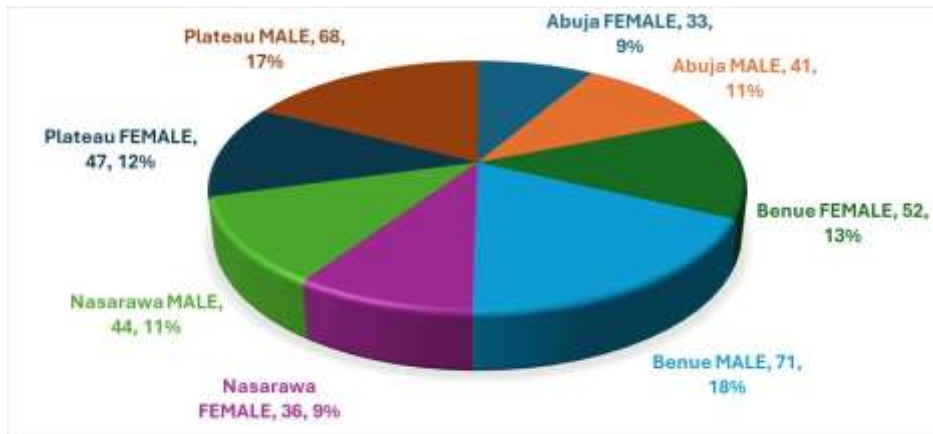


Figure 3: Gender Distribution of Respondents by State

5.2 Measurement Model Assessment

Before testing the structural relationships, the measurement model was evaluated to assess the reliability and validity of the constructs, following Hair et al. (2019). Indicator reliability was confirmed through factor loadings above the recommended 0.70 threshold. Internal consistency reliability, assessed via Cronbach's alpha and composite reliability, and convergent validity, assessed via Average Variance Extracted (AVE), are reported in Table 2. All values exceeded the recommended thresholds (Cronbach's alpha and composite reliability > 0.70; AVE > 0.50), confirming a robust measurement model.

Table 2: Construct Reliability and Convergent Validity

Construct	Cronbach's Alpha	rho_A	Composite Reliability	AVE
Digital Infrastructure Access	0.941	0.955	0.955	0.784
FinTech Adoption	0.905	0.928	0.927	0.680
Financial Inclusion	0.980	0.981	0.984	0.927

5.3 Discriminant Validity

Discriminant validity was assessed using the Fornell–Larcker criterion, which requires that the square root of each construct's AVE exceed its correlations with other constructs, and corroborated using the Heterotrait–Monotrait (HTMT) ratio of correlations. Both criteria confirmed that the constructs, Digital Infrastructure Access, FinTech Adoption, and Financial Inclusion, were empirically distinct, supporting the discriminant validity of the measurement model and providing an adequate basis for structural model estimation.

5.4 Structural Model Assessment and Hypothesis Testing

After establishing the reliability and validity of the measurement model, the structural model was evaluated to test H1 and H2. Path coefficients were assessed for statistical significance using a bootstrapping procedure with 5,000 subsamples. The SmartPLS structural models for H1 and H2, showing standardised path coefficients and outer loadings, are presented in Figures 4 and 5. Results are summarised in Table 3.

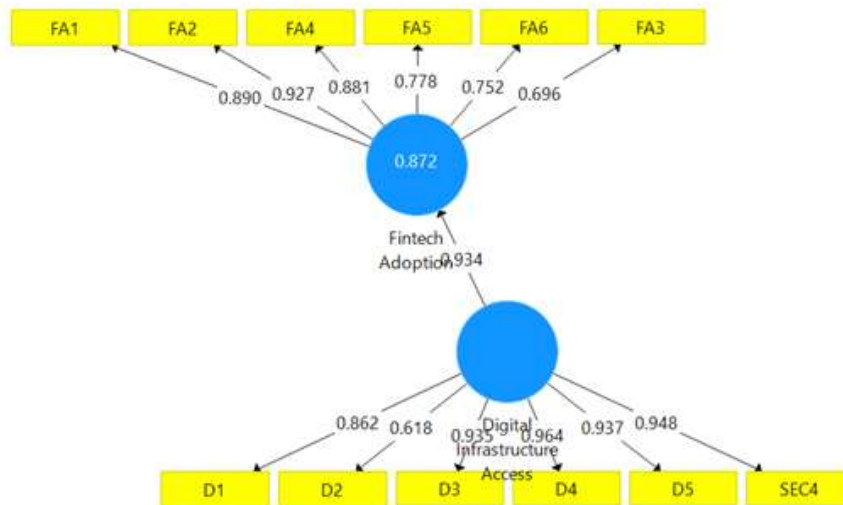


Figure 4: SmartPLS Structural Model for H1 — Digital Infrastructure Access and FinTech Adoption

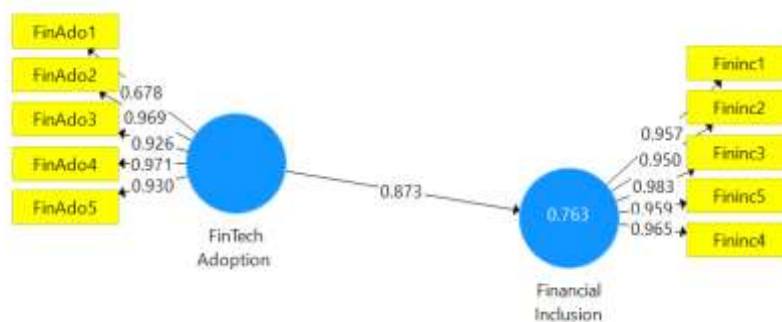


Figure 5: SmartPLS Structural Model for H2 — FinTech Adoption and Financial Inclusion

Table 3: Structural Model Results (Hypothesis Testing)

Hypothesis	Relationship	β	t-value	p-value	Decision
H1	Digital Infrastructure Access → FinTech Adoption	0.934	138.009	<0.001	Supported
H2	FinTech Adoption → Financial Inclusion	0.873	50.832	<0.001	Supported

Hypothesis 1 (H1) was strongly supported: digital infrastructure access exerted a large, positive, and highly significant effect on FinTech adoption ($\beta = 0.934$, $t = 138.009$, $p < 0.001$), explaining 87.2% of the variance in adoption ($R^2 = 0.872$). This coefficient is substantially higher than effect sizes typically reported for infrastructure–adoption relationships in comparable technology–adoption literature, suggesting that in this setting infrastructure access operates less as a facilitating condition and more as a binding constraint on adoption.

Hypothesis 2 (H2) was also strongly supported: FinTech adoption exerted a large, positive, and highly significant effect on financial inclusion ($\beta = 0.873$, $t = 50.832$, $p < 0.001$). This indicates that increased engagement with digital financial services translates directly into meaningful gains in formal account ownership, transaction usage, savings, and credit access among smallholder farmers in the sample.

6. Discussion

The purpose of this study was to examine whether digital infrastructure access drives FinTech adoption among smallholder farmers, and whether FinTech adoption, in turn, drives financial inclusion, within Nigeria's North Central region. The results provide robust empirical support for both hypothesised relationships. The magnitude of both path coefficients, notably the near-unity coefficient for the infrastructure–adoption path, suggests that conventional technology-adoption frameworks, which typically model adoption as a function of gradually accumulating individual attitudes, may understate the role of structural preconditions in infrastructure-scarce rural economies (Rahman & Singh, 2023). These findings are consistent with, and extend, Rogers' (2003) Diffusion of Innovation theory. Rather than functioning solely as a facilitating condition that speeds or slows an otherwise attitude-driven adoption process, digital infrastructure in this context appears to function as a threshold variable: below a minimum level of network, power, and device access, adoption is effectively foreclosed regardless of farmers' perceptions of an innovation's relative advantage or compatibility. This reframing has direct implications for how rural technology-adoption interventions should be sequenced and prioritised. The strong FinTech adoption–financial inclusion path further indicates that, once the infrastructure threshold is met, FinTech services are highly effective vehicles for extending formal financial access to previously excluded agricultural populations. This lends empirical weight to policy narratives positioning FinTech as a leapfrogging mechanism for financial inclusion in markets historically underserved by traditional banking infrastructure (Ahmadou & Agada, 2023).

7. Theoretical Contributions

This study makes several contributions to the literature on technology adoption and financial inclusion in developing-economy agricultural contexts. First, the study extends Rogers' (2003) Diffusion of Innovation theory by demonstrating that, in infrastructure-scarce rural settings, communication channels can function as a binding threshold constraint on adoption rather than merely a facilitating condition. This finding suggests that DOI theory's traditional emphasis on gradual, attitude-driven adoption processes may require modification when applied to resource-constrained environments, where structural scarcity, rather than individual attitudes, is the primary determinant of adoption possibility. Second, the study contributes empirical evidence to the comparatively thin literature linking FinTech adoption directly to financial inclusion outcomes among smallholder agricultural populations specifically, as opposed to the urban and micro-enterprise samples that dominate much of the existing literature (Rayhan et al., 2024). Third, the study contributes to the limited body of quantitative research examining digital financial inclusion pathways in Sub-Saharan African agricultural contexts using rigorous, large-sample PLS-SEM methods, offering a methodologically robust empirical foundation for future comparative research across regions and agricultural systems.

8. Managerial Implications

The findings of this study offer several practical implications for policymakers, mobile network operators, and FinTech providers seeking to advance rural financial inclusion.

- **Infrastructure-first sequencing:** Financial-inclusion programming should prioritise rural connectivity, electrification, and affordable device access as preconditions for, rather than parallel workstreams alongside, FinTech promotion and financial literacy campaigns.
- **Targeted rural connectivity investment:** Mobile network operators and government agencies should coordinate investment in underserved agricultural corridors, where the marginal impact of infrastructure improvement on adoption appears disproportionately large.
- **Leveraging FinTech as an inclusion vehicle:** Once baseline infrastructure exists, FinTech

providers can expect strong conversion from adoption to meaningful financial inclusion outcomes, supporting continued investment in agent networks and mobile money products tailored to agricultural cash-flow cycles.

- **Monitoring and evaluation:** Programme evaluators should treat infrastructure access as a leading indicator of downstream adoption and inclusion outcomes, rather than a background contextual variable.

9. Limitations and Future Research

Although this study provides robust empirical evidence on the infrastructure–adoption–inclusion pathway, several limitations should be acknowledged. First, the cross-sectional research design captures relationships at a single point in time and does not permit causal inference or the examination of how these relationships evolve. Future research could adopt longitudinal designs to examine the temporal stability of the observed effects.

Second, the study relied on self-reported survey data, which may be subject to social desirability or recall bias. Future studies could complement self-reported measures with transactional data from FinTech providers or mobile network operators.

Third, the study focused specifically on smallholder farmers in North Central Nigeria. While this context provides valuable insights into rural technology adoption in a developing economy, the findings may not generalise to other agro-ecological zones or national contexts. Future research could examine similar relationships across other regions of Nigeria or other Sub-Saharan African countries to assess the generalisability of the infrastructure-threshold pattern identified here. Future research could also examine the moderating role of financial literacy in this pathway, and complement these quantitative findings with qualitative evidence on the lived barriers and enablers shaping farmer decision-making.

10. Conclusion

This study examined the influence of digital infrastructure access on FinTech adoption, and of FinTech adoption on financial inclusion, among smallholder farmers in North Central Nigeria. The findings demonstrate that digital infrastructure access exerts a strong, statistically significant effect on FinTech adoption, and that FinTech adoption exerts a strong, statistically significant effect on financial inclusion. Both hypothesised relationships were robustly supported through PLS-SEM analysis of survey data from 392 farmers. The study highlights the importance of treating digital infrastructure as a foundational precondition for rural financial-inclusion programming, rather than a background contextual factor. By providing rigorous empirical evidence from a developing-economy agricultural context, this study contributes to the literature on technology adoption and financial inclusion, and offers practical guidance for policymakers, mobile network operators, and FinTech providers seeking to extend financial access to smallholder farming communities.

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