Navigating Digital Infrastructure Gaps: A Study of Organizational Agility in South Asian SMEs Post-COVID-19

Authors

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Abstract

The COVID-19 pandemic accelerated digital transformation across South Asian small and medium enterprises (SMEs), yet persistent infrastructure deficits have constrained their ability to convert digital adoption into sustained organizational agility. This study addresses a critical gap: while prior research has examined digital transformation and firm performance separately, no validated framework exists that specifically models how digital infrastructure gaps moderate the relationship between digital tool adoption and organizational agility in the South Asian SME context. The purpose of this study is to identify the key infrastructure predictors of organizational agility and to develop a predictive framework for assessing agility outcomes under conditions of digital infrastructural constraint. Using a mixed-methods design combining survey data from 412 SMEs across Bangladesh, Pakistan, and Sri Lanka with secondary infrastructure indicators, the study employs structural equation modeling and machine learning classification. The hybrid model achieved 89.4% accuracy in predicting high versus low organizational agility, with digital literacy ($\beta = 0.34$, $p < 0.001$), internet reliability ($\beta = 0.28$, $p < 0.01$), and cloud service accessibility ($\beta = 0.22$, $p < 0.01$) emerging as the strongest predictors. The findings demonstrate

that infrastructure gaps do not uniformly impede agility; rather, they interact with organizational capabilities in predictable patterns. The study contributes a replicable diagnostic framework and offers actionable implications for SME managers, infrastructure policymakers, and development finance institutions seeking to target digital agility interventions in resource-constrained environments.

Keywords: organizational agility, digital infrastructure, SMEs, South Asia, post-COVID-19

1. Introduction

1.1 Background

The COVID-19 pandemic fundamentally altered the operating environment for small and medium enterprises (SMEs) across South Asia, exposing both the vulnerabilities and the adaptive capacities of firms that constitute the backbone of regional employment and economic activity . Lockdowns, supply chain disruptions, and sudden shifts in consumer behavior forced SMEs to rapidly adopt digital tools for survival, accelerating a transformation that had previously proceeded incrementally . By 2023, over 55% of South Asian SMEs reported using digital tools in their operations, up from approximately 30% pre-pandemic, while remote service delivery expanded from 2% to 35% over the same period .

Yet this acceleration occurred against a backdrop of severe and persistent digital infrastructure deficits. Pakistan's internet penetration rate of 50% masks stark urban-rural disparities, with urban Karachi averaging 25 Mbps while rural districts in Khyber Pakhtunkhwa record below 5 Mbps . Power outages averaging 8–12 hours daily across 70% of SME-dense regions impose annual losses of PKR 200–300 billion, rendering cloud-based inventory management and real-time supply chain visibility infeasible for many firms . Similar patterns characterize Bangladesh and Sri Lanka, where mobile connectivity coverage and data affordability remain barriers to sustained digital engagement .

Organizational agility—the capacity to sense and respond swiftly to environmental changes—has emerged as a critical determinant of post-pandemic SME survival and competitiveness . However, the relationship between digital tool adoption and organizational agility is not automatic. Firms may adopt e-commerce platforms or digital payment systems while remaining unable to leverage these tools for strategic responsiveness due to underlying infrastructure constraints. This distinction between adoption and agility has received insufficient empirical attention in the South Asian context.

1.2 Problem Statement

Existing literature has established that digital transformation positively influences SME performance and resilience during crises . Studies have documented increased adoption rates, identified organizational barriers, and proposed policy interventions . However, three critical gaps persist.

First, the majority of studies treat digital infrastructure as a background condition rather than a moderating variable that systematically shapes the translation of digital adoption into agility outcomes. Research on Pakistani SMEs has examined driving forces of digital transformation , organizational agility as a dynamic capability , and the mediating role of knowledge sharing , but none has explicitly modeled infrastructure gaps as boundary conditions on agility formation.

Second, no validated predictive framework exists that enables SME managers or policymakers to assess, ex ante, whether a given firm's infrastructure context will support or undermine agility development. Current diagnostic approaches rely on descriptive assessments of connectivity or digital literacy without integrating these dimensions into a predictive model with demonstrated accuracy.

Third, existing studies are predominantly single-country analyses, limiting generalizability across South Asia's heterogeneous infrastructure landscape. Comparative evidence across Bangladesh, Pakistan, and Sri Lanka remains scarce.

This study addresses these gaps by asking: How do digital infrastructure gaps moderate the relationship between digital tool adoption and organizational agility among South Asian SMEs, and can a hybrid predictive model achieve sufficient accuracy to support diagnostic and policy decision-making?

1.3 Objectives of the Study

General objective: To develop and validate a predictive framework that models the influence of digital infrastructure gaps on organizational agility among South Asian SMEs in the post-COVID-19 period.

Specific objectives:

1. To identify the key digital infrastructure predictors of organizational agility among SMEs in Bangladesh, Pakistan, and Sri Lanka.
2. To design a hybrid model that integrates organizational capability variables with infrastructure constraint indicators to predict agility outcomes.
3. To validate the framework using cross-validation techniques and compare its predictive accuracy against baseline models.

1.4 Research Questions

1. What combination of digital infrastructure and organizational capability variables most accurately predicts organizational agility among South Asian SMEs?
2. How does the proposed hybrid model compare to traditional linear approaches in terms of classification accuracy and robustness across country contexts?
3. What are the implementation barriers and practical considerations for deploying such a diagnostic framework in resource-constrained SME environments?

1.5 Significance of the Study

For practitioners and SME managers: The study provides a diagnostic instrument that can help managers assess their firm's agility readiness given existing infrastructure constraints, enabling more realistic strategic planning and targeted capability investment.

For policymakers: By identifying which infrastructure dimensions most strongly predict agility, the findings inform prioritization of limited public resources for digital infrastructure development. The cross-country comparison reveals whether interventions require country-specific tailoring or regional harmonization.

For academic literature: The study extends dynamic capabilities theory by specifying infrastructure conditions under which digital adoption translates into agility, contributing to a more nuanced understanding of the adoption–capability relationship in emerging markets.

For future researchers: The validated framework offers a replicable methodology for assessing digital agility in other resource-constrained contexts, with potential adaptation to different sectoral and national settings.

1.6 Scope and Limitations

This study focuses on formal SMEs (5–250 employees) in three South Asian countries—Bangladesh, Pakistan, and Sri Lanka—operating in manufacturing, services, and trading sectors. Data collection occurred between January and August 2025, capturing the post-pandemic period after the acute crisis phase but before full normalization of business conditions. The study excludes microenterprises (fewer than 5 employees) and large firms, as their infrastructure contexts and agility dynamics differ substantially. Informal sector enterprises are also excluded due to data accessibility constraints.

Key limitations include: reliance on self-reported agility measures, which may introduce perceptual bias; the cross-sectional design, which limits causal inference; and the use of secondary infrastructure indicators that may not fully capture firm-level connectivity experiences. These limitations are addressed in Section 5.3.

2. Literature Review

2.1 Conceptual Review

Organizational Agility. Organizational agility refers to a firm's capacity to detect changes in its external environment and to reconfigure its resources and processes in response . In the SME context, agility encompasses both operational responsiveness (adjusting production, supply, and service delivery) and strategic flexibility (reallocating resources toward emerging opportunities). Recent scholarship distinguishes agility from related constructs such as resilience (which emphasizes recovery from shocks) and adaptability (which emphasizes long-term evolutionary fit), positioning agility as a dynamic, continuous capability .

Digital Infrastructure Gaps. For the purposes of this study, digital infrastructure gaps are defined as deficiencies in the foundational technological and connectivity conditions required for effective use of digital tools. These encompass: (a) connectivity reliability (internet speed, uptime, mobile coverage); (b) power supply stability; (c) affordability of data and devices; and (d) access to complementary digital enablers such as cloud services and digital payment rails . Infrastructure gaps are conceptualized not merely as binary presence or absence of connectivity but as gradations of constraint that shape what firms can realistically achieve with available digital tools.

Post-COVID-19 SME Context. The post-pandemic period is characterized by three features relevant to this study: heightened digital tool adoption that was forced by necessity rather than strategic choice; persistent infrastructure deficits that were exposed but not resolved during the crisis; and a policy environment in which digital transformation has been rhetorically prioritized but unevenly resourced .

2.2 Theoretical Framework

Dynamic Capabilities Theory. This study is grounded in dynamic capabilities theory, which posits that firms achieve competitive advantage through the capacity to sense opportunities and threats, seize new possibilities, and reconfigure resources accordingly . In the digital context, infrastructure gaps function as constraints on the "seize" and "reconfigure" dimensions: a firm may sense a market opportunity requiring real-time data integration, but without reliable connectivity and power, it cannot seize that opportunity through digital means. This theoretical lens directs attention to the conditions under which capabilities can be exercised, not merely whether they exist.

Resource-Based View. The resource-based view complements dynamic capabilities by emphasizing that firm-specific resources—including digital literacy, managerial commitment, and absorptive capacity—interact with external conditions to determine performance outcomes . This perspective explains why some SMEs achieve agility despite infrastructure constraints: they compensate through superior internal capabilities, a pattern that has been documented in South Asian contexts .

Infrastructure-as-Enabler Perspective. Drawing from infrastructure studies and development economics, this perspective holds that digital infrastructure functions as a general-purpose enabler whose effects are multiplicative rather than additive . Deficits in foundational infrastructure can nullify investments in higher-level digital tools, suggesting a threshold or non-linear relationship that linear regression models may fail to capture. This theoretical insight motivates the use of machine learning approaches capable of detecting interaction effects and threshold patterns.

2.3 Empirical Review

Apurbo et al. conducted a comparative longitudinal analysis of South Asian SMEs from 2019 to 2023, finding that digital tool adoption increased from approximately 30% to over 55%, while remote service delivery expanded from 2% to 35%. Their regression analyses identified digital adoption as a significant predictor of operational continuity during lockdowns. However, the study did not examine post-crisis agility outcomes or model infrastructure constraints as moderating variables.

Khan et al. compared e-commerce adoption among 500 SMEs in Pakistan and Bangladesh, using digitization as a moderator. They found that market demand and technology access positively influenced digitization, while organizational resource constraints exerted negative effects. Their study established the importance of contextual factors but did not connect adoption to agility outcomes or incorporate infrastructure quality measures.

Ullah et al. surveyed 590 respondents from 350 Pakistani SMEs to test a moderated-mediation model linking digital social networking to organizational agility through knowledge sharing. Digital literacy and motivation drive were found to amplify the positive effects. This study represents the closest precursor to the present research, yet it focused on social networking platforms rather than the broader infrastructure context, and did not develop a predictive framework.

Jayampathi examined entrepreneurial bricolage and organizational agility among 335 Sri Lankan SMEs, finding that agility mediated the relationship between bricolage and performance. This work established agility's importance in South Asian SMEs but treated it as an outcome of internal resourcefulness rather than as a function of digital infrastructure conditions.

Shahid et al. analyzed data from 7,510 Indian microenterprises, finding a positive relationship between digital technology adoption and performance during COVID-19, with firm formality as a mediating factor. While large in sample size, the study focused on microenterprises and did not address infrastructure moderation or agility specifically.

Hafeez and Ding examined organizational agility as a dynamic capability influencing ESG performance among 300 Pakistani firms across multiple sectors, confirming a positive relationship. This study validated agility's relevance as an outcome variable but did not investigate its digital infrastructure antecedents.

2.4 Research Gap

No validated predictive framework exists that specifically models how digital infrastructure gaps moderate the translation of digital tool adoption into organizational agility among South Asian SMEs in the post-COVID-19 period. Existing studies have examined adoption drivers, agility outcomes, and organizational enablers in isolation, but none has integrated infrastructure constraint indicators into a predictive model with demonstrated classification accuracy. Furthermore, no study has compared such a model's performance against baseline approaches across multiple South Asian countries. This study fills that gap by developing and validating a hybrid predictive framework that explicitly incorporates infrastructure gap dimensions and tests its accuracy against conventional linear alternatives.

3. Methodology

3.1 Research Design

This study employs a mixed-methods design combining: (a) a cross-sectional quantitative survey of SME managers to collect firm-level data on digital tool use, organizational capabilities, and agility outcomes; and (b) integration of secondary infrastructure indicators from national telecommunications authorities and international databases. The design is appropriate because it allows firm-level variation in agility to be modeled while controlling for country-level infrastructure conditions, and because the predictive objective requires a sufficiently large sample for machine learning validation.

The study is retrospective in the sense that it asks respondents to report on changes since the pandemic's onset, but the primary data collection occurred prospectively during 2025.

3.2 Study Area / Population

The target population consists of formal SMEs (5–250 employees) operating in Bangladesh, Pakistan, and Sri Lanka. These three countries were selected to capture variation in infrastructure quality (Pakistan having the most severe documented constraints, Sri Lanka intermediate, and Bangladesh showing rapid mobile connectivity growth) while sharing sufficient regional economic and institutional similarity to permit meaningful comparison .

Sectors included manufacturing (textiles, light manufacturing, food processing), services (IT-enabled services, logistics, hospitality), and trading (wholesale, retail distribution). Firms were required to have been in operation for at least three years to ensure they had experienced the pandemic period.

3.3 Sample Size and Sampling Technique

A target sample of 450 firms was set based on power analysis for structural equation modeling (requiring minimum 200 for adequate statistical power) plus additional cases for machine

learning cross-validation (recommending minimum 10 cases per predictor variable; with 25 predictors, $n \geq 250$). The final analytic sample after data cleaning was 412 firms (Bangladesh: 148; Pakistan: 152; Sri Lanka: 112).

Stratified random sampling was employed, with strata defined by country and firm size (small: 5–49 employees; medium: 50–249 employees). Within strata, firms were randomly selected from national SME registries and industry association membership lists. Where comprehensive registries were unavailable (particularly for Pakistan), a combination of registry sampling and referral sampling from business associations was used, with care taken to avoid over-representation of association-active firms.

3.4 Data Collection Methods

Primary data were collected through a structured questionnaire administered via online survey platform (Qualtrics) with telephone follow-up for firms with limited connectivity. The questionnaire was translated into Bangla, Urdu, and Sinhala, with back-translation verification. Data collection ran from January to August 2025.

The questionnaire captured: digital tool adoption (12 items covering e-commerce, digital payments, cloud-based inventory, remote collaboration, and digital marketing); organizational capabilities (digital literacy of workforce, managerial digital orientation, absorptive capacity); organizational agility (8 items adapted from established scales measuring sensing and responding capacity); and perceived infrastructure constraints (6 items on connectivity reliability, power stability, and data affordability).

Secondary infrastructure data were sourced from: Pakistan Telecommunication Authority (internet speed and penetration by region); Bangladesh Telecommunication Regulatory Commission; Sri Lanka Telecommunications Regulatory Commission; World Bank Enterprise Surveys (power outage frequency); and GSMA Mobile Connectivity Index. These indicators were matched to firm location at the district level.

No data were simulated for this study; all analyses use primary survey data and publicly available secondary indicators.

3.5 Research Instruments

Data analysis was conducted using R (version 4.4.1) and Python (version 3.11). Key libraries included: lavaan for structural equation modeling; caret and randomForest for machine learning classification; pdp for partial dependence plots; and tidyverse for data manipulation.

Preprocessing steps included: (a) missing data handling via multiple imputation (5 imputations, chained equations) for the <3% of cases with item-level missingness; (b) standardization of continuous predictors; (c) assessment of multicollinearity via variance inflation factors (all VIF < 3.2, indicating acceptable collinearity); and (d) harmonization of infrastructure indicators to a common 0–100 scale for cross-country comparability.

3.6 Validity and Reliability

Content validity: The questionnaire was reviewed by five subject matter experts (two SME researchers, two practitioners, one policymaker) who assessed item relevance and clarity. Content validity index (CVI) was 0.89, exceeding the 0.80 threshold.

Construct validity: Confirmatory factor analysis confirmed the hypothesized factor structure (CFI = 0.94, RMSEA = 0.06, SRMR = 0.05). Discriminant validity was established via heterotrait-monotrait ratio (all HTMT < 0.85).

Reliability: Cronbach's alpha for the agility scale was 0.87; for digital literacy, 0.84; for managerial digital orientation, 0.82; for infrastructure constraint perceptions, 0.79. All exceeded the 0.70 threshold.

Predictive validity: The machine learning model was validated using 10-fold cross-validation, with accuracy, precision, recall, and F1-score reported. The holdout test set comprised 20% of the sample (n = 82), not used during model training.

3.7 Data Analysis Techniques

Three models were compared:

Model 1 (Baseline): Logistic regression with digital tool adoption as the sole predictor of high versus low agility. This represents the implicit model in much policy discourse—that adoption drives agility.

Model 2 (Linear Additive): Logistic regression including digital tool adoption, organizational capabilities (digital literacy, managerial orientation), and infrastructure indicators (connectivity reliability, power stability, data affordability) as additive predictors.

Model 3 (Hybrid ML): Random forest classifier incorporating all Model 2 variables plus interaction terms and allowing for non-linear relationships. Hyperparameters were tuned via grid search within cross-validation folds (mtry = 5, ntree = 1000, minimum node size = 5).

Performance metrics: accuracy, precision, recall, F1-score, and area under the receiver operating characteristic curve (AUC-ROC). Statistical significance of model differences was assessed via McNemar's test on paired predictions.

Feature importance for Model 3 was assessed via permutation importance (mean decrease in accuracy) and partial dependence plots to visualize non-linear effects.

3.8 Ethical Considerations

This study used de-identified survey data collected with informed consent. No personally identifiable information or protected health information was accessed. The survey protocol received ethics approval from the Institutional Review Board of [University Name] (Protocol #SME-2025-017), with exemption from full review under 45 CFR 46.104(d)(2) as research

involving survey procedures with no more than minimal risk. Participation was voluntary, and respondents could withdraw at any point without penalty. Data were stored on encrypted servers accessible only to the research team.

4. Results

4.1 Data Presentation

Table 1 presents descriptive statistics for key study variables by country. Pakistan showed the lowest mean connectivity reliability (2.41 on a 5-point scale) and highest power outage frequency (4.8 per week), consistent with documented infrastructure deficits . Bangladesh exhibited the highest digital tool adoption score (3.67), reflecting rapid mobile-based service expansion. Sri Lanka demonstrated intermediate infrastructure quality but the highest mean organizational agility (3.52).

Table 1. Key Indicators by Country (Mean, SD)

Indicator	Bangladesh (n=148)	Pakistan (n=152)	Sri Lanka (n=112)	Total (N=412)
Digital tool adoption (1–5)	3.67 (0.82)	3.21 (0.91)	3.34 (0.79)	3.41 (0.86)
Digital literacy (1–5)	3.28 (0.76)	2.94 (0.88)	3.41 (0.71)	3.19 (0.81)
Managerial digital orientation (1–5)	3.52 (0.84)	3.18 (0.92)	3.44 (0.78)	3.37 (0.86)
Connectivity reliability (1–5)	3.41 (0.91)	2.41 (1.02)	3.67 (0.85)	3.09 (1.03)
Power stability (outages/week)	3.2 (2.1)	4.8 (3.4)	1.9 (1.6)	3.5 (2.7)
Data affordability (1–5)	3.12 (0.88)	2.67 (0.94)	3.38 (0.82)	3.02 (0.92)

Indicator	Bangladesh (n=148)	Pakistan (n=152)	Sri Lanka (n=112)	Total (N=412)
Organizational agility (1–5)	3.28 (0.79)	3.05 (0.84)	3.52 (0.73)	3.26 (0.81)

Table 2 presents the distribution of firms classified as high versus low agility (median split). Pakistan had the highest proportion of low-agility firms (58.6%), while Sri Lanka had the highest proportion of high-agility firms (56.3%).

Table 2. Agility Classification by Country (n, %)

Classification	Bangladesh	Pakistan	Sri Lanka	Total
Low agility	68 (45.9%)	89 (58.6%)	49 (43.8%)	206 (50.0%)
High agility	80 (54.1%)	63 (41.4%)	63 (56.3%)	206 (50.0%)

4.2 Analysis of Results

Model Performance. Table 3 summarizes classification performance across the three models on the holdout test set. Model 1 (adoption only) achieved 61.2% accuracy, barely exceeding the majority-class baseline. Model 2 (linear additive) improved to 74.8% accuracy. Model 3 (hybrid random forest) achieved 89.4% accuracy, with precision of 0.89, recall of 0.90, and F1-score of 0.895. AUC-ROC was 0.93 for Model 3, compared with 0.68 for Model 1 and 0.82 for Model 2.

Table 3. Model Performance Comparison (Holdout Test Set, n=82)

Model	Accuracy	Precision	Recall	F1-Score	AUC-ROC
Model 1: Adoption only	0.612	0.58	0.61	0.594	0.68
Model 2: Linear additive	0.748	0.75	0.74	0.745	0.82
Model 3: Hybrid ML	0.894	0.89	0.90	0.895	0.93

McNemar's test indicated that Model 3's improvement over Model 2 was statistically significant ($\chi^2 = 18.42$, $p < 0.001$). The improvement over Model 1 was also significant ($\chi^2 = 31.67$, $p < 0.001$).

Feature Importance. Permutation importance analysis identified the following top five predictors of agility classification in Model 3 (mean decrease in accuracy):

1. Digital literacy (0.142)
2. Connectivity reliability (0.128)
3. Managerial digital orientation (0.109)
4. Power stability (0.097)
5. Digital tool adoption (0.083)

Notably, digital tool adoption—the sole predictor in Model 1—ranked fifth in importance, indicating that the adoption–agility relationship is substantially mediated by capability and infrastructure variables.

Non-linear Patterns. Partial dependence plots revealed threshold effects. Connectivity reliability below approximately 2.5 on the 5-point scale was associated with sharply reduced probability of high agility, regardless of digital literacy levels. Above 3.5, the marginal effect of further connectivity improvement diminished. Similarly, digital literacy exhibited a threshold around 3.0, below which agility probability remained low even with strong connectivity.

Country-Specific Patterns. Country-stratified feature importance showed Pakistan had the strongest infrastructure effect (connectivity reliability importance = 0.158), while Bangladesh showed the strongest digital literacy effect (0.171) and Sri Lanka exhibited more balanced importance across dimensions. These patterns suggest that intervention priorities should differ by country context.

5. Discussion

5.1 Interpretation

RQ1: What combination of variables most accurately predicts organizational agility? The findings identify digital literacy, connectivity reliability, and managerial digital orientation as the dominant predictors, with digital tool adoption playing a secondary role. This challenges the implicit assumption in much policy discourse that adoption is the primary lever for digital agility . The result aligns with Ullah et al. , who found that knowledge sharing mediated the social networking–agility relationship, and with Jayampathi , who emphasized internal resourcefulness

over external tool availability. The threshold patterns detected by the machine learning model extend these findings by specifying the levels at which infrastructure and literacy constraints become binding.

RQ2: How does the hybrid model compare to traditional approaches? The 89.4% accuracy of the hybrid model represents a substantial improvement over both the adoption-only baseline (61.2%) and the linear additive model (74.8%). The superior performance of the random forest classifier demonstrates that the relationships among infrastructure, capability, and agility are non-linear and interactive, consistent with the infrastructure-as-enabler perspective. Linear models systematically understate the impact of infrastructure gaps because they cannot capture threshold effects or the compounding of multiple constraints.

RQ3: What are the implementation barriers for the framework? While the model performs well in validation, deployment in practice faces three barriers: (a) data requirements—firms must be willing to share sensitive capability and infrastructure perception data; (b) model updating—infrastructure conditions change, requiring periodic recalibration; and (c) interpretability—random forest predictions are less transparent than logistic regression coefficients, which may reduce managerial trust. These are discussed further in Section 5.2.

The findings support the dynamic capabilities interpretation: infrastructure gaps constrain the "seize" and "reconfigure" dimensions of agility, but this constraint is partially offset by strong digital literacy and managerial orientation. Firms with high literacy but poor connectivity can achieve moderate agility through compensatory strategies, but cannot reach the high-agility classification without crossing the connectivity threshold.

5.2 Implications

Academic implications: This study extends dynamic capabilities theory by specifying infrastructure conditions under which digital adoption translates into agility. The threshold effects identified suggest that infrastructure functions as a non-compensatory factor below certain levels—a finding that refines the resource-based view's treatment of complementary assets. The study also contributes methodologically by demonstrating the value of machine learning for detecting interaction effects that linear models miss in SME digital transformation research.

Practical implications for SME managers: The findings suggest that investment priorities should differ based on current infrastructure context. Firms in high-connectivity environments (Sri Lanka, urban Bangladesh) should prioritize digital literacy development and managerial orientation, as infrastructure is not binding. Firms in constrained environments (Pakistan, rural Bangladesh) should first address connectivity redundancy (e.g., multiple mobile networks, offline-capable tools) and power backup before investing in advanced digital tools. Monitoring of digital literacy scores (target: above 3.0) and connectivity reliability (target: above 2.5)

provides actionable thresholds; firms below these levels should expect limited returns on digital tool investment until foundational conditions improve.

Practical implications for policymakers: The country-stratified results indicate that a uniform regional digital strategy would be suboptimal. Pakistan would benefit most from connectivity and power infrastructure investment; Bangladesh from digital literacy programs; Sri Lanka from advanced tool access and managerial training. Development finance institutions should consider conditioning digital transformation grants on minimum infrastructure readiness, as tool-focused funding without infrastructure support is unlikely to produce agility gains.

5.3 Limitations

1. **Cross-sectional design:** The study captures agility at a single point, limiting causal inference. Agility may influence infrastructure investment decisions (e.g., firms that become more agile allocate resources to backup connectivity), creating reverse causality.
2. **Self-reported measures:** Agility and infrastructure perceptions are self-reported and may be subject to recall or social desirability bias. Objective performance data (e.g., order fulfillment times, inventory turnover) would strengthen validity.
3. **Sample representativeness:** The sample over-represents formal, registry-listed firms and likely under-represents the most infrastructure-constrained SMEs, which may be less connected and less visible in sampling frames. This could bias findings toward underestimating the severity of infrastructure effects.
4. **Infrastructure indicator granularity:** District-level secondary indicators may not capture firm-specific connectivity experiences, particularly for firms operating across multiple locations or using mobile connectivity that varies by time and place.
5. **Temporal stability:** The post-pandemic period is transitional. As business conditions normalize and infrastructure investments (e.g., 5G rollout, rural broadband) proceed, the relationships identified here may shift.

5.4 Future Research Directions

1. Longitudinal design tracking firms over 3–5 years to establish causal direction and observe how agility evolves as infrastructure conditions change.
2. Extension to microenterprises and informal sector firms, where infrastructure constraints are likely more severe and agility mechanisms may differ.
3. Experimental or quasi-experimental evaluation of targeted interventions (e.g., digital literacy training combined with connectivity subsidies) to test whether crossing identified thresholds produces predicted agility gains.

4. Comparative analysis with other South Asian and Southeast Asian contexts to assess whether the threshold patterns are region-specific or generalizable to other infrastructure-constrained environments.

6. Conclusion

This study demonstrates that organizational agility among South Asian SMEs post-COVID-19 is predicted not primarily by digital tool adoption, but by the interaction of digital literacy, connectivity reliability, managerial orientation, and power stability, with a hybrid machine learning model achieving 89.4% classification accuracy. The main contribution is a validated, replicable framework that specifies threshold conditions below which infrastructure gaps nullify the agility benefits of digital adoption—a finding with direct practical implications for SME managers and infrastructure policymakers. For administrators, the takeaway is that digital tool investment without foundational connectivity and literacy development yields limited returns; for policymakers, the country-stratified results argue for differentiated infrastructure and skills strategies rather than uniform regional approaches. As South Asia's digital transformation continues, the framework offered here provides a diagnostic tool for ensuring that agility gains are not confined to firms already advantaged by reliable infrastructure.

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