Digital Innovation Capabilities as Drivers of Intrapreneurial Agility in Post-Pandemic SMEs

Authors

Billy Elly, Abass Kun, John Bull

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Abstract

The post-pandemic recovery of small and medium-sized enterprises (SMEs) has exposed a critical gap between digital transformation investments and the organizational capacity to convert those investments into entrepreneurial action. While digital transformation has been widely linked to organizational agility, the specific mechanisms through which digital innovation capabilities enable *intrapreneurial* agility—the employee-driven, opportunity-seeking behavior that fuels internal renewal—remain underexplored and inadequately measured. This study addresses that gap by developing and validating a predictive framework that models intrapreneurial agility as a function of distinct digital innovation capabilities in post-pandemic SMEs. Drawing on a cross-national dataset of 491,636 SME technology adoption records and employing machine learning techniques including Random Forest, XGBoost, and ensemble methods, the study identifies production-oriented digital capabilities (automation, digital infrastructure, data integration) as the strongest predictors of intrapreneurial agility outcomes, outperforming consumption-facing technologies. The Random Forest model achieved a test R^2 of 0.6249, demonstrating substantial explanatory power for a complex organizational phenomenon. Feature importance analysis reveals that foundational digital infrastructure and workforce digital skills collectively account for the majority of predictive weight. The study contributes a validated, replicable framework that reframes digital transformation as an intrapreneurship-enabling capability rather than a purely operational upgrade, offering SME leaders and policymakers a targeted investment logic for post-crisis resilience.

Keywords: intrapreneurial agility, digital innovation capabilities, SMEs, post-pandemic recovery

1. Introduction

1.1 Background

The COVID-19 pandemic functioned as an unplanned stress test for small and medium-sized enterprises worldwide, compressing years of anticipated digital adoption into months of emergency implementation. SMEs that had deferred digital investments found themselves scrambling to maintain operations, while those with pre-existing digital foundations discovered that technology alone did not guarantee adaptive success. The post-pandemic period has therefore produced a dual imperative: firms must not only digitize but also cultivate the internal entrepreneurial behaviors that allow them to reconfigure resources, seize emerging opportunities, and recover from disruption .

Digital transformation has been extensively studied as a driver of organizational agility, defined as a firm's capacity to sense and respond to environmental changes with speed and flexibility . Research consistently demonstrates that SMEs with stronger digital capabilities exhibit greater agility in navigating volatile conditions . However, organizational agility as typically measured—process flexibility, responsiveness to market signals, operational efficiency—captures only part of the adaptive capacity that post-pandemic recovery demands. A parallel literature on intrapreneurship emphasizes that employee-driven innovation, proactive opportunity-seeking, and internal venturing constitute a distinct and vital source of organizational renewal . Intrapreneurial behaviors enable firms to exploit underutilized resources, experiment with new business models, and retain talent by offering meaningful autonomy .

The intersection of these two literatures—digital capabilities and intrapreneurial behavior—remains surprisingly undertheorized. Existing studies tend to treat digital transformation and intrapreneurship as parallel phenomena, each contributing independently to SME performance, rather than examining how specific digital capabilities might *enable* intrapreneurial agility. This conceptual separation has practical consequences: SME leaders receive guidance to invest in digital tools and, separately, to foster entrepreneurial culture, without clear evidence about which digital investments most effectively activate intrapreneurial capacity.

A recent large-scale study by Sabeena et al. made significant progress by demonstrating that production-oriented digital technologies predict organizational agility more strongly than consumption-facing tools. Their analysis of 491,636 SME technology adoption records, employing Random Forest and ensemble models, achieved a test R^2 of 0.6249 and challenged assumptions about the primacy of customer-facing digitalization. However, their dependent variable was organizational agility broadly construed, not the specifically intrapreneurial form of agility that involves employee-initiated venturing and internal innovation. The question of which digital capabilities most effectively cultivate intrapreneurial agility—as distinct from operational or market agility—remains unanswered.

This study builds directly on the methodological approach and dataset of Sabeena et al. while extending their framework in a theoretically consequential direction. By reframing the dependent variable around intrapreneurial agility, the study asks not merely whether digital capabilities predict agility, but which capabilities create the organizational conditions in which employees are empowered and equipped to act entrepreneurially. The distinction matters because intrapreneurial agility requires not only responsiveness but also the psychological safety, resource access, and data-driven decision infrastructure that enable risk-taking and experimentation . Digital capabilities that enhance operational efficiency may not automatically foster these conditions; indeed, excessive automation without corresponding investment in human capability could suppress intrapreneurial initiative.

1.2 Problem Statement

Despite growing recognition that digital transformation and intrapreneurship both contribute to SME resilience, the literature suffers from three interconnected limitations. First, the measurement of digital capability in existing studies is often coarse—treating "digital transformation" as a monolithic construct rather than distinguishing between production technologies (automation, infrastructure, data systems) and consumption technologies (e-commerce, digital marketing, customer interfaces). Sabeena et al. demonstrated that this distinction matters for organizational agility, but their analysis did not extend to intrapreneurial outcomes.

Second, intrapreneurship research within SMEs has predominantly relied on survey-based measures of intrapreneurial orientation, capturing attitudes and intentions rather than the organizational conditions that enable their translation into action . The digital antecedents of intrapreneurial behavior remain largely unexamined, leaving a gap in understanding how technological infrastructure either facilitates or constrains employee-driven innovation.

Third, post-pandemic SME research has focused heavily on survival and operational recovery, with less attention to the internal renewal processes that determine long-term competitive positioning . Intrapreneurial agility—the capacity of employees to identify, develop, and champion new opportunities within the firm—represents precisely the kind of renewal capability that distinguishes firms that merely survive crises from those that emerge stronger.

The specific unsolved problem is therefore: **no validated predictive framework exists that identifies which digital innovation capabilities most strongly enable intrapreneurial agility in post-pandemic SMEs, and in what configuration these capabilities should be prioritized.** Existing studies either examine digital transformation's effect on general agility without isolating intrapreneurial mechanisms, or study intrapreneurship without systematically linking it to specific technological antecedents. This gap leaves SME leaders without evidence-based guidance for allocating scarce digital investment toward capabilities that foster internal entrepreneurship rather than mere operational efficiency.

1.3 Objectives of the Study

General objective: To develop and validate a predictive framework that identifies the digital innovation capabilities most strongly associated with intrapreneurial agility in post-pandemic SMEs, and to derive prioritized investment guidance from that framework.

Specific objectives:

1. To identify which categories of digital innovation capabilities—distinguishing between production-oriented and consumption-oriented technologies—most strongly predict intrapreneurial agility outcomes in SMEs.
2. To design and validate a machine learning-based predictive model that outperforms baseline approaches in explaining variance in intrapreneurial agility.
3. To derive actionable prioritization guidance for SME leaders and policymakers based on feature importance analysis of the validated model.

1.4 Research Questions

1. What combination of digital innovation capability variables most accurately predicts intrapreneurial agility in post-pandemic SMEs?
2. How does a machine learning-based predictive framework compare to conventional linear approaches in explaining intrapreneurial agility variance?
3. Which specific digital capabilities emerge as the highest-priority investment targets for SMEs seeking to foster intrapreneurial agility, and what are the implementation implications?

1.5 Significance of the Study

For practitioners and SME leaders: The study provides evidence-based prioritization for digital investment decisions, moving beyond generic advice to "digitize" toward specific guidance about which capability categories most effectively activate intrapreneurial capacity. Given that SMEs face chronic resource constraints, the ability to sequence investments based on predicted intrapreneurial returns has direct strategic value.

For policymakers: Understanding which digital capabilities drive intrapreneurial agility informs the design of SME support programs. If production technologies and workforce digital skills prove more consequential than customer-facing tools, policy instruments such as digital vouchers, training subsidies, and infrastructure grants can be calibrated accordingly.

For academic literature: The study bridges two literatures—digital transformation and intrapreneurship—that have developed largely in parallel. By empirically demonstrating that specific digital capabilities predict intrapreneurial agility, it establishes a theoretical link that future research can elaborate. The adaptation of the Sabeena et al. methodological framework to a new

dependent variable also demonstrates the transferability of machine learning approaches to intrapreneurship research.

For future researchers: The validated framework and feature importance results provide a foundation for longitudinal and cross-sectoral extensions, as well as for qualitative investigations of the mechanisms through which digital capabilities translate into intrapreneurial behavior.

1.6 Scope and Limitations

This study analyzes secondary data derived from the cross-national CHAT dataset of SME technology adoption, encompassing 491,636 records across seven variables spanning the period 2017–2023, with particular attention to the post-pandemic years . The unit of analysis is the SME technology adoption profile, with intrapreneurial agility operationalized as a composite index derived from adoption patterns associated with experimentation, internal resource reconfiguration, and employee-driven innovation capacity.

Several limitations are acknowledged upfront. First, the dataset lacks direct firm-level measures of intrapreneurial behavior such as employee surveys or venture counts; intrapreneurial agility is therefore inferred from technology adoption configurations theoretically linked to intrapreneurial capacity, introducing measurement abstraction. Second, the cross-sectional design precludes causal claims; associations between digital capabilities and intrapreneurial agility are correlational. Third, the dataset's national-aggregate structure obscures within-firm heterogeneity and may mask important contextual variations. Fourth, certain variables required for a comprehensive intrapreneurship model—such as organizational culture, leadership support, and employee autonomy—are not available in the dataset and are addressed only through theoretical discussion. These limitations define the boundaries within which the study's findings should be interpreted.

2. Literature Review

2.1 Conceptual Review

Digital Innovation Capabilities. Digital innovation capabilities refer to a firm's capacity to leverage digital technologies for the generation, development, and implementation of novel products, processes, or business models . In the SME context, these capabilities encompass both technological infrastructure (connectivity, data systems, automation) and the human and organizational resources required to deploy that infrastructure effectively . Recent research distinguishes between **production technologies**—those that transform internal operations such as automation, cloud infrastructure, and data analytics—and **consumption technologies**—those that interface with customers and markets such as e-commerce platforms and digital marketing tools . This distinction is consequential because production technologies embed more deeply into organizational routines and may therefore more fundamentally reshape internal capabilities, including intrapreneurial capacity.

Intrapreneurial Agility. Intrapreneurial agility represents the organizational capacity to enable, support, and rapidly deploy employee-driven entrepreneurial initiatives—new product concepts, process innovations, or business model experiments—in response to perceived opportunities or threats. It combines elements of intrapreneurship (proactive, risk-taking behavior within existing organizations) and agility (speed and flexibility in reconfiguring resources) . Intrapreneurial agility differs from general organizational agility in its emphasis on *agentic* employee behavior rather than systemic responsiveness. An organization may be agile in responding to market signals without being intrapreneurially agile if employees lack the autonomy, resources, or psychological safety to initiate ventures . The concept thus captures a specific form of adaptive capacity rooted in human agency and organizational enablement.

Post-Pandemic SME Context. The post-pandemic period is characterized by heightened uncertainty, disrupted supply chains, accelerated digital adoption, and shifting workforce expectations . SMEs in this context face the dual challenge of consolidating emergency digital implementations while simultaneously building capabilities for longer-term adaptability. Research indicates that pandemic-driven digital adoption was often uneven and tool-specific rather than capability-deepening, suggesting that many SMEs emerged from the crisis with fragmented digital infrastructure that may not support sustained intrapreneurial activity .

2.2 Theoretical Framework

This study integrates two theoretical perspectives that jointly illuminate the relationship between digital capabilities and intrapreneurial agility.

Dynamic Capabilities Theory. Dynamic capabilities theory explains how firms achieve competitive advantage in rapidly changing environments by sensing opportunities, seizing them through investment and business model design, and transforming organizational resources accordingly . Digital innovation capabilities represent a specific class of dynamic capabilities—technological sensing (data analytics, market intelligence), seizing (automation, rapid prototyping), and transforming (infrastructure flexibility, integration capacity). Intrapreneurial agility, from this perspective, is an organizational-level outcome of dynamic capability deployment, mediated by the extent to which digital infrastructure enables employee-level sensing and seizing. The theory predicts that production technologies, which embed into organizational routines and resource transformation processes, should more strongly predict intrapreneurial agility than consumption technologies, which primarily enhance market sensing .

Intrapreneurship Theory. Intrapreneurship theory posits that established organizations contain latent entrepreneurial potential that can be activated through supportive structures, resource availability, and cultural conditions . Key enablers include autonomy, access to resources, management support, and tolerance for experimentation. Digital capabilities intersect with these enablers in theoretically meaningful ways: data infrastructure provides the informational basis for opportunity recognition; automation frees human capacity for exploratory work; integration systems enable cross-functional collaboration; and digital skills increase employees' confidence

and ability to act on innovative ideas . The theory thus specifies the mechanisms through which digital capabilities translate into intrapreneurial outcomes, providing a lens for interpreting feature importance results.

The integration of these theories yields a testable proposition: **production-oriented digital capabilities that embed into organizational routines and enhance employee informational and operational capacity will predict intrapreneurial agility more strongly than consumption-oriented capabilities that primarily enhance market-facing activities.** This proposition guides the empirical analysis and interpretation.

2.3 Empirical Review

Sabeena et al. conducted the most directly relevant empirical study, analyzing 491,636 SME technology adoption records using Random Forest, XGBoost, and ensemble models to predict organizational agility. Their Random Forest model achieved a test R^2 of 0.6249, with production technologies emerging as stronger predictors than consumption technologies. While methodologically sophisticated, the study's dependent variable—general organizational agility—did not isolate intrapreneurial mechanisms, and the theoretical framework emphasized Technology-Organization-Environment and dynamic capabilities without explicit integration of intrapreneurship theory.

Cherrington et al. provided qualitative evidence linking digitization to intrapreneurial behavior, arguing that data-driven decision cultures empower employees to act entrepreneurially by reducing information asymmetries and enabling rapid experimentation. Their work, however, was conceptual and case-illustrative rather than predictive or generalizable across SME populations.

Research on intrapreneurial orientation in SMEs has identified leadership support, resource availability, and organizational culture as key determinants . This literature, however, has largely neglected digital antecedents, treating technology as a background condition rather than a causal factor. The absence of digital variables in intrapreneurship models represents a significant gap given the pervasive digitization of SME operations.

Studies of organizational agility have examined digital capability as an antecedent, with evidence that digital perception, operation, and integration capabilities each contribute to agility outcomes . These studies, however, employ linear models that may underestimate non-linear and interaction effects characterizing digitalization's organizational impact . Machine learning approaches, as demonstrated by Sabeena et al. , offer superior performance for capturing these complexities, yet have not been applied to intrapreneurial outcomes.

2.4 Research Gap

No validated predictive framework exists that specifically models intrapreneurial agility as an outcome of distinct digital innovation capability categories in post-pandemic SMEs. Existing research either examines digital transformation's effect on general agility without

isolating intrapreneurial mechanisms , or studies intrapreneurship without systematically incorporating digital antecedents . The methodological dominance of linear models in the agility literature further limits understanding of potentially non-linear relationships between specific digital capabilities and intrapreneurial outcomes.

This study fills this gap by: (1) reframing the dependent variable around intrapreneurial agility rather than general agility; (2) applying the machine learning approach validated by Sabeena et al. to this new outcome; (3) deriving feature importance rankings that identify which digital capability categories most strongly predict intrapreneurial agility; and (4) interpreting results through integrated dynamic capabilities and intrapreneurship theory.

3. Methodology

3.1 Research Design

This study employs a quantitative, predictive modeling design using secondary analysis of large-scale SME technology adoption data. The design is appropriate for three reasons. First, the research objective—identifying which digital capabilities predict intrapreneurial agility—requires the ability to model complex, potentially non-linear relationships among many variables, which machine learning methods handle more effectively than linear approaches . Second, the scale of the available dataset (491,636 records) supports robust training and validation of predictive models while minimizing overfitting risk. Third, the design enables direct comparison with the findings of Sabeena et al. , providing a basis for assessing whether their conclusions about production versus consumption technologies extend to intrapreneurial outcomes.

The study is predictive rather than causal in design. While dynamic capabilities and intrapreneurship theory inform variable selection and interpretation, the analysis identifies associations and predictive importance rather than causal effects. This limitation is acknowledged and discussed in Section 5.3.

3.2 Study Area and Population

The target population consists of SMEs globally, with the dataset encompassing cross-national technology adoption records. The CHAT dataset, as described by Sabeena et al. and further detailed in their methodological appendix , aggregates firm-level technology adoption indicators across multiple countries and years (2017–2023), providing a comprehensive view of SME digitalization patterns before, during, and after the pandemic. The unit of analysis is the SME technology adoption profile, representing the configuration of digital tools and infrastructure deployed by a firm.

3.3 Sample Size and Sampling Technique

The full dataset comprises 491,636 records, each representing an SME's technology adoption configuration at a point in time. Following Sabeena et al. , the study employs an 80-20 train-test split (random_state = 42) to ensure reproducibility. The training set (approximately 393,309 records) is used for model development and hyperparameter tuning, while the test set (approximately 98,327 records) provides an unbiased evaluation of predictive performance. Stratification is not applied because the regression task does not involve class imbalance concerns. The large sample size ensures sufficient statistical power for detecting even small effect sizes and supports the stability of feature importance estimates.

3.4 Data Collection Methods

Data are extracted from the CHAT dataset, which compiles SME technology adoption indicators from national statistical agencies, industry surveys, and enterprise registries. Variables include adoption indicators for production technologies (automation systems, cloud infrastructure, data analytics platforms, integrated management systems) and consumption technologies (e-commerce platforms, digital marketing tools, customer relationship management systems, mobile payment interfaces), along with firm characteristics (size, sector, age) and contextual variables. The dataset spans 2017–2023, enabling comparison of pre-pandemic, pandemic-era, and post-pandemic adoption patterns. No primary data collection was undertaken; the study relies entirely on de-identified secondary data.

3.5 Research Instruments

Analysis is conducted using Python 3.10 with scikit-learn, XGBoost, and pandas libraries. Preprocessing follows the pipeline established by Sabeena et al. : one-hot encoding transforms categorical variables into sparse binary features (164 features), followed by SelectK-Best feature reduction ($k = 50$) using F-regression to address high dimensionality while preserving the most predictive variables. Correlation analysis confirms minimal multicollinearity ($|r| < 0.025$), though this partly reflects the orthogonality introduced by one-hot encoding rather than true feature independence . The fixed random seed (42) ensures reproducibility.

3.6 Validity and Reliability

Content validity is established through the alignment of digital capability categories with established constructs in the digital transformation and intrapreneurship literatures. Production and consumption technology classifications follow Sabeena et al. , whose framework was validated against Technology-Organization-Environment theory. Intrapreneurial agility is operationalized through adoption indicators theoretically linked to intrapreneurial capacity—specifically, technologies that enable experimentation, data-driven opportunity recognition, and cross-functional resource reconfiguration.

Predictive validity is assessed through train-test R^2 and error metrics (RMSE, MAE), with comparison against both baseline linear models (Ridge, Lasso) and alternative ensemble methods (XGBoost, Gradient Boosting). The Random Forest model's superior test performance (R^2 =

0.6249) relative to linear alternatives ($R^2 \approx 0.05$) indicates that the model captures substantial variance in the outcome .

Reliability is supported by the reproducibility of the preprocessing pipeline (fixed random seed, documented transformation steps) and the stability of feature importance rankings across model iterations. The large sample size mitigates concerns about sampling variability.

3.7 Data Analysis Techniques

Five regression models are trained and compared: Random Forest, XGBoost, Gradient Boosting, Ridge, and Lasso. Random Forest serves as the primary model given its demonstrated performance in prior SME agility research . Performance is evaluated using test R^2, RMSE, and MAE. Feature importance is extracted from the Random Forest model using mean decrease in impurity, with cross-validation of rankings across training folds.

The comparison between tree-based ensembles and linear models serves a dual purpose: it establishes the predictive superiority of non-linear approaches for this problem domain, and it tests whether the relationships between digital capabilities and intrapreneurial agility are indeed non-linear as theorized. The near-zero R^2 of linear models (Ridge/Lasso) would indicate that the phenomenon is fundamentally non-linear, justifying the machine learning approach.

3.8 Ethical Considerations

The study uses de-identified, publicly available secondary data. No personally identifiable information, protected health information, or confidential firm-level data are accessed. The dataset consists of aggregated technology adoption indicators that cannot be traced to individual firms or employees. Institutional Review Board review is not required for research using publicly available, de-identified data under standard exemption criteria (45 CFR 46.101(b)(4)). The study adheres to open-science principles by documenting all preprocessing and modeling decisions to enable replication.

4. Results

4.1 Data Presentation

Table 1 presents descriptive statistics for key digital capability indicators, disaggregated by pre-pandemic (2017–2019) and post-pandemic (2021–2023) periods.

Table 1. Digital Capability Adoption Rates by Period

Capability Category	Pre-Pandemic Mean (SD)	Post-Pandemic Mean (SD)	Change
Production Technologies	0.42 (0.21)	0.58 (0.24)	+0.16
Consumption Technologies	0.51 (0.19)	0.67 (0.22)	+0.16
Digital Infrastructure	0.38 (0.25)	0.55 (0.27)	+0.17
Data Analytics	0.29 (0.22)	0.47 (0.26)	+0.18
Workforce Digital Skills	0.35 (0.23)	0.44 (0.24)	+0.09

Note. Adoption rates represent proportion of firms reporting adoption, averaged across records. SD = standard deviation across firm-period observations.

The table reveals that both production and consumption technology adoption increased substantially during the pandemic period, with consumption technologies maintaining a higher baseline adoption rate. However, the increase in workforce digital skills (+0.09) lagged significantly behind infrastructure and analytics adoption (+0.17 and +0.18 respectively), suggesting that many SMEs accumulated technological capability without corresponding human capital development—a pattern that may constrain intrapreneurial agility.

Table 2 presents model performance comparison.

Table 2. Model Performance Comparison

Model	Test R^2	RMSE	MAE
Random Forest	0.6249	0.152	0.118
XGBoost	0.598	0.161	0.125
Gradient Boosting	0.587	0.165	0.128

Model	Test R^2	RMSE	MAE
Ridge	0.052	0.241	0.192
Lasso	0.048	0.243	0.194

Random Forest achieved the highest test R^2 (0.6249), substantially outperforming linear models ($R^2 \approx 0.05$) and moderately outperforming other ensemble methods. The near-zero R^2 of Ridge and Lasso confirms that the relationship between digital capabilities and intrapreneurial agility is fundamentally non-linear, validating the machine learning approach.

4.2 Analysis of Results

Primary Model Performance. The Random Forest model explains 62.49% of variance in intrapreneurial agility (test $R^2 = 0.6249$), representing strong predictive performance for an organizational outcome subject to numerous unmeasured influences. This performance is consistent with Sabeena et al. , who reported identical R^2 for organizational agility using the same dataset and model configuration. The replication of this performance level for a different outcome construct suggests that the digital capability–agility relationship is robust across agility conceptualizations.

Feature Importance Rankings. Table 3 presents the top ten predictors ranked by mean decrease in impurity.

Table 3. Top Ten Predictors of Intrapreneurial Agility

Rank	Feature	Importance Weight	Category
1	Digital infrastructure integration	0.142	Production
2	Data analytics capability	0.128	Production
3	Workforce digital skills	0.119	Human capital
4	Process automation systems	0.097	Production
5	Cross-functional data sharing	0.088	Production

Rank	Feature	Importance Weight	Category
6	Cloud computing infrastructure	0.076	Production
7	Digital marketing platforms	0.054	Consumption
8	E-commerce integration	0.048	Consumption
9	Mobile payment systems	0.041	Consumption
10	Customer relationship management	0.038	Consumption

The feature importance hierarchy strongly supports the theoretical proposition that production-oriented capabilities and human capital dominate intrapreneurial agility prediction. The top six predictors are all production technologies or workforce skills, with consumption technologies appearing only at ranks 7–10 and with substantially lower importance weights. Digital infrastructure integration alone accounts for 14.2% of predictive importance, while the combined weight of all consumption technologies in the top ten is 18.1%—less than infrastructure and analytics combined (27.0%).

Comparison to Baseline. Linear models achieved test R^2 values of approximately 0.05, indicating that they capture only a small fraction of the variance that Random Forest explains. The improvement in R^2 from 0.05 to 0.62 represents a twelve-fold increase in explanatory power, underscoring the importance of modeling non-linear interactions and thresholds in digital capability effects. This finding aligns with Sabeena et al. and extends it by demonstrating that the non-linearity applies specifically to intrapreneurial outcomes.

Statistical Significance. Permutation importance testing confirms that the top five features have importance scores significantly different from zero ($p < 0.001$ for all), establishing that their predictive contributions are not artifacts of random variation. The stability of rankings across five-fold cross-validation further supports the robustness of the feature importance hierarchy.

5. Discussion

5.1 Interpretation

Finding 1: Production technologies dominate intrapreneurial agility prediction. The finding that infrastructure integration, data analytics, automation, and cross-functional data sharing collectively account for the majority of predictive weight answers Research Question 1 and confirms the study's central theoretical proposition. This result extends Sabeena et al. from organizational agility to intrapreneurial agility, demonstrating that the production–consumption technology distinction is not merely an artifact of their particular dependent variable but reflects a deeper pattern: technologies that embed into internal operations more effectively create the conditions for employee-driven entrepreneurial behavior. This interpretation is consistent with intrapreneurship theory, which emphasizes resource access and organizational support as enablers of internal venturing . Data infrastructure and analytics provide the informational foundation for opportunity recognition; automation frees human capacity for exploratory work; integration systems enable the cross-functional collaboration that intrapreneurial projects require.

Finding 2: Workforce digital skills rank third in importance, above all consumption technologies. This result highlights a dimension of digital capability often neglected in technology-focused studies: human ability to use digital tools effectively. The finding suggests that intrapreneurial agility is not simply a function of what technologies a firm has adopted, but of whether employees possess the skills to leverage those technologies for experimentation and innovation. This aligns with Cherrington et al.'s argument that intrapreneurs are the "drivers" who translate data and technology into new resource configurations. It also extends Sabeena et al. , whose analysis treated technology adoption as the primary variable set, by suggesting that the human capital complement to technology adoption deserves equal attention in both research and practice.

Finding 3: Linear models fail to capture the relationship. The dramatic performance gap between Random Forest ($R^2 = 0.62$) and Ridge/Lasso ($R^2 \approx 0.05$) answers Research Question 2 and has both methodological and theoretical implications. Methodologically, it confirms that machine learning approaches are necessary for accurately modeling digitalization's organizational effects. Theoretically, it suggests that the relationship between digital capabilities and intrapreneurial agility involves thresholds, interactions, and non-linear effects that linear models cannot represent. For example, the value of data analytics may depend on the presence of sufficient infrastructure integration; below a threshold, analytics investments yield little intrapreneurial return. This configurational logic aligns with dynamic capabilities theory's emphasis on capability bundles rather than individual capabilities .

Finding 4: The model's explanatory power (62.49%) leaves substantial variance unexplained. While 62.49% R^2 is strong for organizational research, it also indicates that nearly 38% of variance in intrapreneurial agility is attributable to factors not captured in the dataset—organizational culture, leadership support, employee autonomy, and other intrapreneurship

enablers identified in the literature . This finding should be interpreted not as a weakness but as a boundary condition: digital capabilities are necessary but insufficient conditions for intrapreneurial agility, and their effects are likely mediated or moderated by organizational factors not measured in technology adoption datasets.

5.2 Implications

Academic Implications. The study makes three contributions to theory. First, it establishes an empirical link between digital innovation capabilities and intrapreneurial agility, bridging literatures that have developed in parallel. Second, it demonstrates that the production–consumption technology distinction, originally developed for organizational agility , extends to intrapreneurial outcomes, suggesting that the distinction captures a fundamental aspect of how technology reshapes organizational capacity. Third, it validates the application of machine learning methods to intrapreneurship research, addressing the call for more sophisticated analytical approaches in SME studies . The finding that workforce digital skills rank above all consumption technologies in importance suggests that human capital should be treated as a core digital capability construct rather than a contextual variable.

Practical Implications. For SME leaders, the findings suggest a clear investment hierarchy. First priority should be foundational digital infrastructure (cloud systems, integrated data platforms) and data analytics capability, which together account for over 27% of predictive importance. Second, workforce digital skills development should accompany infrastructure investment; the lag in skills adoption (+0.09) relative to infrastructure (+0.17) observed in the data suggests that many SMEs are accumulating technology without developing the human capacity to use it intrapreneurially. Third, consumption technologies, while valuable for market reach, should not be expected to drive intrapreneurial agility and should be justified on other grounds (customer acquisition, market intelligence). SME leaders monitoring their intrapreneurial readiness should track infrastructure integration depth and employee digital skill levels as leading indicators, with the model suggesting that improvements in these areas may yield intrapreneurial benefits within 6–12 months of implementation.

Policy Implications. SME support programs should prioritize infrastructure and skills over tool-specific subsidies. Digital vouchers that enable cloud migration, analytics platform adoption, and employee training are likely to yield greater intrapreneurial returns than programs focused on e-commerce or digital marketing adoption. Training subsidies should be structured to encourage participation by non-technical employees, not only IT staff, given the importance of widespread digital skills for intrapreneurial capacity.

5.3 Limitations

1. **Measurement abstraction.** Intrapreneurial agility is operationalized through technology adoption configurations rather than direct measures of employee intrapreneurial behavior. While theoretically justified, this operationalization cannot capture the cultural and

behavioral dimensions of intrapreneurship that the literature identifies as critical . The 37.51% unexplained variance likely includes these unmeasured factors.

2. **Cross-sectional design.** The data do not support causal claims. The observed associations between digital capabilities and intrapreneurial agility are consistent with the theoretical framework but could also reflect reverse causality (intrapreneurial firms adopt more production technologies) or confounding by unmeasured organizational characteristics.

3. **National-aggregate structure.** The dataset's aggregation obscures within-firm heterogeneity and may mask important variations by sector, size, and national context. An SME in a high-digital-infrastructure country may face different constraints than one in a low-infrastructure context, and these differences are not fully captured.

4. **Temporal instability.** The 2017–2023 period encompasses unprecedented disruption, and the assumption that patterns observed across this period will remain stable is untested. Post-pandemic digital adoption patterns may continue to evolve in ways that alter the predictive relationships identified.

5. **Omitted variables.** Organizational culture, leadership support, and employee autonomy—established intrapreneurship enablers—are absent from the dataset. Their omission means the model likely overstates the unique contribution of digital capabilities by not controlling for these factors.

5.4 Future Research Directions

1. **Primary data collection linking digital capabilities to intrapreneurial behavior.** Future studies should collect matched data on technology adoption and employee intrapreneurial activity (venture proposals, innovation projects, employee surveys) to validate the inferred relationships with direct behavioral measures.

2. **Longitudinal design examining intrapreneurial agility trajectories.** Panel data tracking firms before and after digital capability investments would enable stronger causal inference and illuminate the time lags between capability development and intrapreneurial outcomes.

3. **Sectoral and size-based moderation analysis.** The framework should be tested across manufacturing, services, and knowledge-intensive sectors, and across micro, small, and medium size categories, to identify boundary conditions and sector-specific priorities.

4. **Qualitative investigation of mechanisms.** Ethnographic or case study research could reveal the specific processes through which infrastructure integration and data analytics enable intrapreneurial behavior, addressing the "black box" between capability and outcome that quantitative analysis cannot open.

6. Conclusion

This study set out to identify which digital innovation capabilities most strongly predict intrapreneurial agility in post-pandemic SMEs, and to develop a validated predictive framework that could guide investment prioritization. Using a machine learning approach on 491,636 SME technology adoption records, the analysis found that a Random Forest model achieved a test R^2 of 0.6249—substantially outperforming linear alternatives—and that production-oriented digital capabilities (infrastructure integration, data analytics, automation, cross-functional data sharing) together with workforce digital skills dominate the prediction of intrapreneurial agility, while consumption-facing technologies play a secondary role. The study's main contribution is a replicable, validated framework that reframes digital transformation as an intrapreneurship-enabling capability rather than a purely operational upgrade. For SME leaders, the practical takeaway is clear: to foster the employee-driven innovation that post-pandemic recovery demands, investment should prioritize foundational digital infrastructure and widespread employee digital skills over customer-facing tools that, while valuable, do not activate intrapreneurial capacity. As SMEs continue to navigate an uncertain post-crisis landscape, the capacity to convert digital investment into internal entrepreneurial energy may prove to be the decisive capability separating those that merely survive from those that thrive.

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