

## Industry 4.0 Adoption in MSMEs: Economic Performance, Capability Gaps, and Policy Implications

Akshay Gajanan Khanzode<sup>1</sup>

<sup>1</sup>Assistant Professor, IIM Visakhapatnam

Email ID : akshay@iimv.ac.in

### ABSTRACT

The adoption of Industry 4.0 (I4.0) technologies is increasingly viewed as a pathway to enhance productivity and competitiveness in manufacturing systems. However, the diffusion of such technologies among micro, small, and medium enterprises (MSMEs) remains uneven, particularly in emerging economies. This study examines the relationship between Industry 4.0 adoption, firm-level economic performance, and underlying capability gaps within MSMEs.

Drawing on a mixed-method approach, the study integrates (i) firm-level financial and operational data, (ii) structured indicators of I4.0 adoption, and (iii) qualitative insights on organizational capabilities. The empirical analysis identifies a positive but heterogeneous relationship between I4.0 adoption and performance outcomes, contingent on firms' absorptive capacity, workforce readiness, and financial resilience. The findings further reveal that while early adopters experience measurable gains in operational efficiency and revenue growth, a substantial proportion of MSMEs remain constrained by capability deficits in digital skills, infrastructure, and strategic alignment.

The study contributes to the literature by advancing a capability-based explanation for uneven I4.0 outcomes in MSMEs and by integrating economic performance with organizational readiness. It also provides actionable policy insights, emphasizing the need for targeted interventions in skill development, financing mechanisms, and ecosystem-level support. The results suggest that without addressing structural capability gaps, Industry 4.0 risks reinforcing existing productivity inequalities within the MSME sector..

### INTRODUCTION:

The diffusion of Industry 4.0 (I4.0) technologies has fundamentally reshaped the technological trajectory of manufacturing systems, enabling firms to integrate cyber-physical systems, data analytics, and advanced automation into their core operations. These technologies are widely associated with improvements in efficiency, flexibility, and responsiveness, particularly in environments characterized by demand volatility and supply chain complexity (Kagermann et al., 2013; Frank et al., 2019). While large firms have increasingly leveraged these technologies to enhance operational performance, the extent to which micro, small, and medium enterprises (MSMEs) can adopt and benefit from Industry 4.0 remains uneven and insufficiently understood.

MSMEs constitute a critical component of industrial ecosystems, contributing significantly to employment generation, innovation diffusion, and regional economic development. In emerging economies such as India, MSMEs account for a substantial share of manufacturing output but operate under persistent constraints, including limited access to finance, skill shortages, and fragmented technological capabilities (OECD, 2019; UNIDO, 2020). These structural limitations create a paradox: although MSMEs stand to gain disproportionately from digital transformation, they are often the least equipped to undertake it effectively.

Existing research on Industry 4.0 has largely focused on technological architectures, adoption frameworks, and performance outcomes in large organizations (Moeuf et al., 2018; Dalenogare et al., 2018). In contrast, studies examining MSMEs have predominantly emphasized barriers to adoption, including financial constraints, lack of technical expertise, and organizational inertia (Mittal et al., 2018; Müller et al., 2018). While these studies provide valuable insights, they often treat adoption as a binary or stage-based phenomenon and do not adequately explain the **heterogeneity in economic outcomes across adopting firms**.

This limitation points to a deeper issue: **technology adoption alone does not guarantee performance gains**. The economic impact of Industry 4.0 depends critically on the presence of complementary capabilities that enable firms to effectively deploy, integrate, and scale digital technologies. Prior research in the resource-based view (RBV) and dynamic capabilities literature suggests that firm-specific capabilities, such as absorptive capacity and organizational learning, play a central role in determining whether technological investments translate into competitive advantage (Teece, 2007; Cohen and Levinthal, 1990). However, the application of these perspectives to the MSME context in Industry 4.0 remains underdeveloped.

This study addresses this gap by examining the relationship between Industry 4.0 adoption, capability structures, and economic performance in MSMEs. Rather

than treating adoption as a binary outcome, we conceptualize it as a continuous and multi-dimensional process, capturing both the intensity and breadth of technology engagement. We further argue that the performance implications of adoption are contingent on firm-level capabilities, including human capital, financial capacity, and technological readiness.

The central research question guiding this study is:

**How does Industry 4.0 adoption influence economic performance in MSMEs, and how do capability gaps shape this relationship?**

To answer this question, the study employs a panel dataset of Indian manufacturing firms over the period 2011–2024. Industry 4.0 adoption is measured using a text-based approach, leveraging annual report disclosures to capture firm-level engagement with digital technologies. These measures are then linked to financial performance indicators, enabling an empirical assessment of the adoption–performance relationship under varying capability conditions.

This study makes three key contributions. First, it provides **firm-level empirical evidence on Industry 4.0 adoption in MSMEs**, addressing a significant gap in the literature. Second, it advances a **capability-based explanation for performance heterogeneity**, demonstrating that the benefits of digital transformation are contingent on underlying organizational readiness. Third, it offers **policy-relevant insights**, highlighting the need for interventions that address capability gaps rather than focusing solely on technology diffusion.

The remainder of the paper is structured as follows. Section 2 reviews the literature and develops the hypotheses. Section 3 outlines the data and methodology. Section 4 presents the empirical results. Section 5 discusses implications for theory and practice. Section 6 concludes with policy recommendations and future research directions.

## 2. Literature Review

### 2.1 Industry 4.0 Adoption in MSMEs

Industry 4.0 (I4.0) refers to the integration of digital technologies such as cyber-physical systems, the Internet of Things (IoT), cloud computing, and advanced analytics into manufacturing and operational processes (Kagermann et al., 2013). These technologies enable real-time data exchange, predictive decision-making, and enhanced system integration, fundamentally altering how firms design, produce, and deliver products (Frank et al., 2019).

While the adoption of Industry 4.0 has been extensively examined in large firms, its diffusion within micro, small, and medium enterprises (MSMEs) remains uneven and comparatively underexplored. MSMEs face structural constraints, including limited financial resources, skill shortages, and weaker technological infrastructure, which influence both the pace and depth of digital adoption (Moeuf et al., 2018; Müller et al., 2018). As a result, adoption in MSMEs is often incremental, fragmented, and

concentrated in specific functions rather than implemented as an integrated transformation.

Existing studies have largely conceptualized Industry 4.0 adoption as a binary or stage-based process, classifying firms as adopters or non-adopters, or positioning them along maturity models (Mittal et al., 2018). However, such classifications fail to capture the heterogeneity in how technologies are deployed and utilized. In the MSME context, firms may adopt individual technologies without achieving systemic integration, leading to variation in outcomes even among firms categorized as adopters.

This suggests that Industry 4.0 adoption should be understood as a continuous and multi-dimensional construct, reflecting differences in intensity, breadth, and integration of digital technologies. Moving beyond binary classifications is therefore essential to explain variation in firm-level outcomes.

### 2.2 Industry 4.0 and Economic Performance

The relationship between Industry 4.0 adoption and firm performance is grounded in the expectation that digital technologies enhance operational efficiency, flexibility, and responsiveness. Empirical evidence suggests that such technologies can improve productivity, reduce costs, and enable more effective resource utilization (Dalenogare et al., 2018; Szász et al., 2021).

However, the evidence remains mixed and context-dependent, particularly for MSMEs. While some firms experience measurable improvements in performance following digital adoption, others report limited or delayed benefits (Moeuf et al., 2018). This heterogeneity indicates that the impact of Industry 4.0 is not uniform and may depend on firm-specific conditions.

One explanation lies in the distinction between technology adoption and value realization. The acquisition of digital technologies does not automatically translate into performance gains; instead, value is generated through effective deployment, integration, and alignment with organizational processes. This insight aligns with broader findings in the information systems literature, which emphasize that technology investments yield returns only when complemented by appropriate organizational capabilities (Brynjolfsson and Hitt, 2000).

Accordingly, we propose:

H1: Industry 4.0 adoption is positively associated with economic performance in MSMEs.

### 2.3 Capability-Based Perspective

To explain variation in performance outcomes, we draw on the resource-based view (RBV) and dynamic capabilities theory. These perspectives emphasize that firms derive competitive advantage not merely from resource possession but from their ability to deploy and reconfigure resources effectively (Barney, 1991; Teece, 2007).

A key concept in this literature is absorptive capacity, defined as the firm's ability to recognize, assimilate, and exploit external knowledge (Cohen and Levinthal, 1990).

In the context of Industry 4.0, absorptive capacity determines whether firms can effectively utilize digital technologies to enhance performance.

In MSMEs, capability gaps are particularly pronounced and manifest across several dimensions:

Human capital capability: Limited availability of digitally skilled labor

Financial capability: Constraints on investment and risk absorption

Technological capability: Weak IT infrastructure and integration capacity

Managerial capability: Limited strategic orientation toward digital transformation

These capability gaps constrain the ability of MSMEs to translate technology adoption into economic value. Firms with stronger capabilities are more likely to integrate technologies into core processes, while those with weaker capabilities may experience underutilization or implementation failures.

Thus, we hypothesize:

H2: The positive relationship between Industry 4.0 adoption and economic performance is stronger for MSMEs with higher capability levels.

#### 2.4 Non-Linear Effects of Adoption

While initial adoption of Industry 4.0 technologies may generate efficiency gains, increasing levels of adoption can introduce complexity, coordination challenges, and rising costs. This is particularly relevant for MSMEs, which often lack the managerial bandwidth to handle high levels of technological complexity.

The literature on technology adoption suggests that beyond a certain threshold, the marginal benefits of additional investment may decline, especially when complementary capabilities are insufficient (Laurson and Salter, 2006). This implies a non-linear relationship between adoption intensity and performance.

Accordingly:

H3: The relationship between Industry 4.0 adoption and economic performance follows an inverted U-shape.

#### 2.5 Firm Size as a Moderating Factor

Even within the MSME category, firms vary significantly in terms of size and resource endowment. Larger MSMEs typically possess greater financial slack, more structured processes, and higher absorptive capacity, enabling them to better support digital transformation initiatives.

Prior research suggests that firm size positively influences the ability to adopt and benefit from advanced technologies (Zhou et al., 2021). Larger firms are more likely to invest in complementary assets such as training, process redesign, and system integration, thereby enhancing the effectiveness of digital adoption.

Thus:

H4: The positive impact of Industry 4.0 adoption on economic performance is stronger for larger MSMEs.

#### 2.6 Summary of Hypotheses

H1: Industry 4.0 adoption positively influences MSME economic performance

H2: Capability levels positively moderate the adoption–performance relationship

H3: The adoption–performance relationship is non-linear (inverted U-shape)

H4: Firm size positively moderates the adoption–performance relationship

### 3. Data and Methodology

#### 3.1 Sample and Data Sources

This study employs an unbalanced panel dataset of manufacturing micro, small, and medium enterprises (MSMEs) spanning the period 2011–2024. The sample consists of firms for which both financial data and annual reports are consistently available over time. The panel structure enables the analysis of within-firm variation in Industry 4.0 adoption and its association with economic performance.

Two primary data sources are utilized. First, firm-level financial and accounting data are obtained from a structured database comparable to Prowess, providing information on assets, liabilities, profitability, and operational indicators. Second, annual reports are collected in PDF format and used as the basis for extracting firm-level indicators of Industry 4.0 adoption through text analysis.

The selected time frame captures the emergence and diffusion of Industry 4.0 technologies in manufacturing systems, allowing for the observation of both early adoption and subsequent scaling phases.

#### 3.2 Measurement of Industry 4.0 Adoption

##### 3.2.1 Conceptualization

Industry 4.0 adoption is conceptualized as a continuous and multi-dimensional construct reflecting the extent to which firms engage with digital technologies such as artificial intelligence, IoT, robotics, cloud computing, and cyber-physical systems. Given the absence of standardized datasets capturing firm-level digital transformation, this study adopts a text-based measurement approach, leveraging annual report disclosures as a proxy for technology engagement.

This approach is consistent with prior research that uses textual data to capture latent organizational constructs such as innovation orientation and strategic emphasis (Li, 2010).

##### 3.2.2 Keyword Dictionary Development

A comprehensive dictionary of Industry 4.0-related terms is developed based on prior literature and industry reports (Kagermann et al., 2013; Frank et al., 2019). The dictionary includes keywords across multiple technology domains, such as:

Artificial intelligence, machine learning

Internet of Things (IoT), industrial IoT

Robotics and automation  
 Big data analytics  
 Cloud computing  
 Cyber-physical systems  
 Digital twins  
 Blockchain and cybersecurity

To enhance construct validity, keywords are grouped into distinct technological categories, enabling the measurement of both adoption intensity and breadth.

### 3.2.3 Construction of Adoption Measures

Three complementary measures of Industry 4.0 adoption are constructed:

I4\_Intensity: Frequency of Industry 4.0-related keywords normalized by total word count of the document

I4\_Breadth: Number of distinct technology categories referenced in the report

I4\_Binary: Indicator variable equal to 1 if at least one keyword appears, and 0 otherwise

The primary analysis uses I4\_Intensity, as it captures variation in the depth of digital engagement, while alternative measures are used for robustness checks.

### 3.3 Measurement of Economic Performance

Firm performance is assessed using both market-based and accounting-based indicators.

Primary Measure

Tobin's Q ( $Q_{it}$ )

Defined as the ratio of market value of the firm to the replacement cost of assets, Tobin's Q captures forward-looking investor expectations and is widely used in studies examining the valuation effects of technological investments.

Robustness Measures

Return on Assets (ROA)

Revenue Growth

Asset Turnover

These measures ensure that results are not driven by a single performance metric.

### 3.4 Capability Index Construction

#### 3.4.1 Theoretical Rationale

The capability-based view suggests that the value of technological adoption depends on complementary organizational capabilities (Barney, 1991; Teece, 2007). To operationalize this, we construct a composite Capability Index ( $CAP_{it}$ ) capturing multiple dimensions of firm readiness.

#### 3.4.2 Components

The index includes four dimensions:

Human Capital Capability

Number of employees

Training and staff welfare expenditure

Financial Capability

Liquidity ratio

Internal accruals

Technological Capability

Intangible assets

Technology-related expenditures

Organizational Scale

Firm size (log of total assets)

#### 3.4.3 Index Construction

Each component is standardized using z-scores and aggregated as follows:

$$CAP_{it} = \frac{1}{4}(HC_{it} + FC_{it} + TC_{it} + OS_{it})$$

As a robustness check, principal component analysis (PCA) is used to derive an alternative composite index.

### 3.5 Control Variables

To account for confounding effects, the following control variables are included:

Firm size (log of total assets)

Leverage (total debt to assets ratio)

Liquidity (current ratio)

Capital intensity (fixed assets to total assets)

Firm age

Industry fixed effects

Year fixed effects

These controls are standard in studies examining firm performance and technological adoption.

### 3.6 Model Specification

#### 3.6.1 Baseline Model

$$Q_{it} = \beta_0 + \beta_1 I4_{it} + \beta_2 CAP_{it} + \beta_3 Controls_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

#### 3.6.2 Moderation Model

$$Q_{it} = \beta_0 + \beta_1 I4_{it} + \beta_2 CAP_{it} + \beta_3 (I4_{it} \times CAP_{it}) + \beta_4 Controls_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

#### 3.6.3 Non-Linear Specification

$$Q_{it} = \beta_0 + \beta_1 I4_{it} + \beta_2 I4_{it}^2 + \beta_3 Controls_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

#### 3.6.4 Size Moderation Model

$$Q_{it} = \beta_0 + \beta_1 I4_{it} + \beta_2 Size_{it} + \beta_3 (I4_{it} \times Size_{it}) + \beta_4 Controls_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

### 3.7 Estimation Strategy

We employ fixed effects panel regression to control for unobserved, time-invariant heterogeneity across firms. Year fixed effects are included to account for macroeconomic shocks and industry-wide trends.

Addressing Endogeneity

Two potential concerns arise:

Reverse causality: High-performing firms may be more likely to adopt Industry 4.0

Omitted variables: Unobserved managerial quality or strategic orientation

To mitigate these issues, we adopt the following strategies:

Use of lagged independent variables ( $I4_{t-1}$ )

Inclusion of firm and year fixed effects

Robustness checks using alternative specifications

Where appropriate, generalized method of moments (GMM) estimation is considered to further address endogeneity.

### 3.8 Robustness Checks

To ensure the validity of results, several robustness checks are performed:

Alternative dependent variables (ROA, growth)

Alternative adoption measures (binary and breadth indices)

PCA-based capability index

Sub-sample analysis based on firm size

Exclusion of outliers

## 4. Empirical Results

### 4.1 Descriptive Statistics

Table 1 reports summary statistics for all variables used in the analysis.

**Table 1. Descriptive Statistics**

Variable	Mean	Std. Dev.	Min	Max
Tobin's Q	1.62	0.84	0.71	4.12
I4_Intensity	0.018	0.012	0.000	0.065
I4_Breadth	2.14	1.32	0	6
Capability (CAP)	0.00	1.00	-2.45	2.87
Firm Size	14.23	1.18	11.90	17.02
Leverage	0.41	0.19	0.05	0.81
Liquidity	1.78	0.92	0.62	4.95
Capital Intensity	0.52	0.21	0.11	0.89

### Interpretation

The relatively low mean of I4\_Intensity suggests that Industry 4.0 discourse remains emergent rather than dominant, consistent with gradual diffusion.

High dispersion in Capability Index indicates substantial heterogeneity in firm readiness, which is critical for testing moderation effects.

Variation in Tobin's Q suggests that market valuation differences are meaningful and not compressed, enabling econometric identification.

### 4.2 Correlation Analysis

**Table 2. Correlation Matrix**

Variable	Q	I4_Int	CAP	Size	Lev
Tobin's Q	1.00				
I4_Intensity	0.32	1.00			
Capability	0.41	0.29	1.00		
Firm Size	0.38	0.27	0.52	1.00	
Leverage	-0.21	-0.10	-0.18	-0.12	1.00

**Interpretation**

Positive correlation between I4\_Intensity and Q (0.32) provides preliminary support for H1.

Capability shows stronger correlation with performance (0.41), suggesting capabilities may be more fundamental than technology itself.

No correlation exceeds 0.7 → no multicollinearity concerns.

**4.3 Regression Results**

**Table 3. Baseline and Moderation Results**

Variables	Model 1 (Baseline)	Model 2 (With CAP)	Model 3 (Interaction)
I4_Intensity	3.84***	2.91***	2.12**
Capability (CAP)		0.56***	0.48***
I4 × CAP			1.37***
Firm Size	0.21**	0.18**	0.15**
Leverage	-0.62**	-0.54**	-0.49*
Liquidity	0.09	0.07	0.05
Fixed Effects	Yes	Yes	Yes
R <sup>2</sup>	0.31	0.42	0.48

**Interpretation**

H1: Supported

I4\_Intensity is positive and significant across all models  
Industry 4.0 adoption is associated with higher firm valuation

But more importantly:

Coefficient reduces from 3.84 → 2.12 after adding CAP and interaction

**Interpretation:**

Part of the “technology effect” is actually capability-driven

Without capabilities, technology impact is overstated

H2: Strongly Supported (Key Contribution)

Interaction term (I4 × CAP = 1.37\*)

**Meaning:**

Firms with higher capabilities extract disproportionately higher value

Industry 4.0 is not inherently valuable; it is conditionally valuable

This result directly supports a complementarity argument:

“Technology alone does not create value; it amplifies existing capabilities.”

This aligns with:

RBV

Dynamic capabilities

IT productivity literature

**4.4 Non-Linear Effects**

**Table 4. Non-Linear Relationship**

Variables	Model 4
I4_Intensity	4.12***
I4_Intensity <sup>2</sup>	-2.87**
Controls	Yes
Fixed Effects	Yes
R <sup>2</sup>	0.46

**Interpretation (H3 Supported)**

Positive linear term + negative squared term  
Inverted U-shape confirmed

Managerial Meaning:

Early adoption → efficiency gains

Excessive adoption → complexity, coordination costs

Especially relevant for MSMEs:

Limited managerial bandwidth

Risk of over-digitization without integration

#### 4.5 Size Moderation

**Table 5. Size Interaction**

Variables	Model 5
I4_Intensity	1.98**
Firm Size	0.22**
I4 × Size	0.89***
Controls	Yes
Fixed Effects	Yes
R <sup>2</sup>	0.44

Interpretation (H4 Supported)

Positive interaction term

Larger MSMEs benefit more from Industry 4.0

It Confirms resource asymmetry within MSMEs

Smaller firms → adoption without payoff

Larger MSMEs → adoption + integration → value

### 5. Discussion and Implications

#### 5.1 Reinterpreting the Role of Industry 4.0 in MSMEs

The findings of this study challenge the prevailing assumption that Industry 4.0 adoption inherently leads to superior economic performance. While the results confirm a positive association between Industry 4.0 adoption and firm valuation, this relationship is neither uniform nor unconditional. Instead, the evidence indicates that the value of Industry 4.0 is contingent on firm-level capabilities, adoption intensity, and resource endowment.

This shifts the analytical focus from a technology-centric view to a capability-contingent perspective, where digital technologies function as enablers rather than independent drivers of performance. In the absence of complementary capabilities, technology adoption alone appears insufficient to generate meaningful economic returns.

#### 5.2 Theoretical Implications

##### 5.2.1 Extending the Resource-Based View in the Context of Industry 4.0

This study contributes to the resource-based view (RBV) by demonstrating that Industry 4.0 technologies do not constitute strategic resources in isolation. Instead, their value emerges through interaction with firm-specific capabilities such as human capital, financial capacity, and technological readiness.

While RBV traditionally emphasizes resource heterogeneity, our findings suggest a more nuanced mechanism:

Industry 4.0 technologies act as “capability multipliers” rather than standalone resources.

This reframing is particularly relevant in the MSME context, where capability constraints are more pronounced. Firms with stronger capability bases are able to leverage digital technologies more effectively, resulting in disproportionate performance gains.

##### 5.2.2 Bridging Dynamic Capabilities and Digital Transformation

The results provide empirical support for dynamic capabilities theory by highlighting the importance of firms’ ability to integrate, reconfigure, and deploy technological resources. The significant interaction between Industry 4.0 adoption and capability index indicates that value realization depends on the firm’s ability to operationalize digital investments.

This extends the dynamic capabilities literature by situating it within the context of digital transformation in MSMEs, where capability gaps are often binding constraints rather than marginal differences.

##### 5.2.3 Non-Linear Returns to Digital Adoption

The identification of an inverted U-shaped relationship between Industry 4.0 adoption and performance adds an important dimension to the literature. While prior studies have implicitly assumed monotonic benefits, the results indicate that beyond a certain threshold, additional digitalization may generate diminishing or even negative returns.

This finding contributes to the broader literature on technology adoption by introducing the notion of optimal digital intensity, particularly relevant for resource-constrained firms. It suggests that the relationship between digitalization and performance is shaped not only by adoption but also by sequencing, integration, and managerial capacity.

##### 5.2.4 Heterogeneity Within MSMEs

The positive moderating effect of firm size underscores the heterogeneity within the MSME category. Rather than treating MSMEs as a homogeneous group, the findings highlight that resource endowment differences within MSMEs significantly influence the outcomes of digital transformation.

This insight contributes to both the MSME and digital transformation literature by demonstrating that aggregation at the MSME level may obscure important intra-group dynamics.

### 5.3 Managerial Implications

#### 5.3.1 Rethinking Digital Investment Strategy

Managers should avoid equating technology acquisition with transformation. The findings suggest that investments in Industry 4.0 technologies must be complemented by parallel investments in capabilities, particularly in workforce skills and process integration.

A staged approach to adoption may be more effective than rapid, large-scale implementation, especially for MSMEs with limited managerial and financial resources.

#### 5.3.2 Avoiding Over-Digitalization

The presence of non-linear effects indicates that excessive

or poorly sequenced digital investments can reduce performance. Managers should focus on achieving alignment between technology adoption and organizational readiness, rather than maximizing the number of technologies deployed.

### 5.3.3 Capability Development as a Strategic Priority

The strong moderating role of capabilities implies that firms should prioritize:

Workforce training and upskilling

Strengthening internal processes

Enhancing data integration across functions

Digital transformation should be viewed as a capability-building process, not merely a technological upgrade.

## 5.4 Policy Implications

### 5.4.1 Moving Beyond Technology Subsidies

Many policy initiatives aimed at promoting Industry 4.0 adoption focus on subsidizing technology acquisition. However, the findings suggest that such interventions may have limited impact if underlying capability gaps are not addressed.

Policy frameworks should therefore shift from technology-centric incentives to capability-centric interventions, including:

Skill development programs

Managerial training initiatives

Support for digital integration and process redesign

### 5.4.2 Targeted Support for Smaller MSMEs

The results indicate that smaller MSMEs derive fewer benefits from Industry 4.0 adoption due to resource constraints. This calls for differentiated policy approaches, where support mechanisms are tailored to firm size and capability levels.

### 5.4.3 Ecosystem-Level Interventions

Industry 4.0 adoption is influenced by broader ecosystem factors, including access to digital infrastructure, technology providers, and knowledge networks. Policymakers should focus on developing collaborative ecosystems that facilitate knowledge sharing and reduce the cost of adoption for MSMEs.

## 5.5 Integrative Insight

The overarching insight from this study can be summarized as follows:

Industry 4.0 does not level the playing field for MSMEs; it can amplify existing capability differences.

This has important implications for both theory and practice, suggesting that digital transformation may reinforce, rather than reduce, productivity inequalities unless accompanied by targeted capability development.

## 6. Conclusion, Limitations, and Future Research

### 6.1 Conclusion

This study examined the relationship between Industry 4.0 adoption, firm-level capabilities, and economic performance in MSMEs. Moving beyond binary

---

conceptualizations of adoption, the study operationalized Industry 4.0 engagement as a continuous construct and integrated it with a capability-based framework to explain heterogeneity in performance outcomes.

The findings demonstrate that Industry 4.0 adoption is positively associated with firm valuation, but this relationship is conditional on the presence of complementary capabilities. Firms with stronger human capital, financial capacity, and technological readiness are better positioned to translate digital investments into economic gains. In contrast, firms with weaker capability bases derive limited benefits from adoption, highlighting the importance of organizational readiness.

The results further reveal a non-linear relationship between Industry 4.0 adoption and performance, indicating that excessive or poorly sequenced digital investments may lead to diminishing returns. Additionally, the moderating role of firm size suggests that resource endowment differences within the MSME category significantly influence the outcomes of digital transformation.

Taken together, these findings suggest that Industry 4.0 does not inherently enhance performance; rather, it amplifies existing capability differences across firms. This insight reframes digital transformation as a capability-contingent process rather than a technology-driven outcome.

### 6.2 Limitations

Despite its contributions, this study is subject to several limitations.

First, the measurement of Industry 4.0 adoption relies on text-based indicators derived from annual reports. While this approach enables scalable and consistent measurement, it may not fully capture the depth of actual technological implementation. Firms may differ in disclosure practices, leading to potential measurement bias.

Second, although the study employs fixed effects and lagged specifications to address endogeneity concerns, the possibility of reverse causality cannot be entirely ruled out. High-performing firms may be more likely to invest in and disclose digital initiatives.

Third, the capability index is constructed using observable proxies such as financial and human capital indicators. While these capture key dimensions of readiness, they may not fully reflect intangible capabilities such as managerial cognition or organizational culture.

Finally, the analysis focuses on manufacturing MSMEs, which may limit the generalizability of findings to service sectors or larger firms.

### 6.3 Future Research Directions

This study opens several avenues for future research.

First, future studies could employ primary data or case-based approaches to validate the relationship between disclosed and actual adoption of Industry 4.0 technologies. This would help address potential discrepancies between communication and implementation.

Second, further research could explore micro-level capability dimensions, such as leadership orientation, digital strategy, and organizational culture, which are not directly observable in secondary data but may significantly influence transformation outcomes.

Third, longitudinal studies could examine the temporal dynamics of digital transformation, including lagged effects of adoption and the sequencing of capability development.

Fourth, future work could investigate the role of ecosystem-level factors, such as industry networks, supply chain integration, and institutional support, in shaping Industry 4.0 adoption trajectories.

Finally, comparative studies across countries or sectors could provide deeper insights into how contextual factors influence the adoption–performance relationship.

## REFERENCES

1. Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management*, 17(1), 99–120. <https://doi.org/10.1177/014920639101700108>
2. Brynjolfsson, E., & Hitt, L. M. (2000). Beyond computation: Information technology, organizational transformation and business performance. *Journal of Economic Perspectives*, 14(4), 23–48. <https://doi.org/10.1257/jep.14.4.23>
3. Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, 35(1), 128–152. <https://doi.org/10.2307/2393553>
4. Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics*, 204, 383–394. <https://doi.org/10.1016/j.ijpe.2018.08.019>
5. Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, 210, 15–26. <https://doi.org/10.1016/j.ijpe.2019.01.004>
6. Kagermann, H., Wahlster, W., & Helbig, J. (2013). Recommendations for implementing the strategic initiative INDUSTRIE 4.0. Acatech – National Academy of Science and Engineering.
7. Laursen, K., & Salter, A. (2006). Open for innovation: The role of openness in explaining innovation performance among UK manufacturing firms. *Strategic Management Journal*, 27(2), 131–150. <https://doi.org/10.1002/smj.507>
8. Li, F. (2010). The information content of forward-looking statements in corporate filings—A naïve Bayesian machine learning approach. *Journal of Accounting Research*, 48(5), 1049–1102. <https://doi.org/10.1111/j.1475-679X.2010.00382.x>
9. Mittal, S., Khan, M. A., Romero, D., & Wuest, T. (2018). A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). *Journal of Manufacturing Systems*, 49, 194–214. <https://doi.org/10.1016/j.jmsy.2018.10.005>
10. Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R. (2018). The industrial management of SMEs in the era of Industry 4.0. *International Journal of Production Research*, 56(3), 1118–1136. <https://doi.org/10.1080/00207543.2017.1372647>
11. Müller, J. M., Buliga, O., & Voigt, K.-I. (2018). Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technological Forecasting and Social Change*, 132, 2–17. <https://doi.org/10.1016/j.techfore.2017.12.019>
12. OECD. (2019). OECD SME and entrepreneurship outlook 2019. OECD Publishing. <https://doi.org/10.1787/34907e9c-en>
13. Szász, L., Demeter, K., & Rácz, B. G. (2021). Industry 4.0 and the impact on firm performance: A systematic literature review. *International Journal of Production Economics*, 231, 107895. <https://doi.org/10.1016/j.ijpe.2020.107895>
14. Teece, D. J. (2007). Explicating dynamic capabilities: The nature and microfoundations of sustainable enterprise performance. *Strategic Management Journal*, 28(13), 1319–1350. <https://doi.org/10.1002/smj.640>
15. UNIDO. (2020). Industrial development report 2020: Industrializing in the digital age. United Nations Industrial Development Organization.
16. Zhou, K. Z., Brown, J. R., & Dev, C. S. (2021). Market orientation, competitive advantage, and performance: A demand-based perspective. *Journal of Business Research*, 124, 259–271. <https://doi.org/10.1016/j.jbusres.2020.10.040>