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Research Article

Industry 4.0 Adoption by Indian MSMEs and its Effects on Competitive Advantage and Firm Performance: An Empirical Analysis

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ABSTRACT

Purpose: This study examines the factors influencing the adoption of Industry 4.0 technologies by Indian Micro, Small, and Medium Enterprises (MSMEs) and investigates the subsequent impact on competitive advantage and firm performance.
Design/Methodology/Approach: The present study applies the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) framework to understand the determinants of Industry 4.0 adoption. A survey was conducted among MSMEs engaged in manufacturing, resulting in 372 valid responses. Partial Least Squares Structural Equation Modeling (PLS-SEM) was used to analyze the data.
Findings: The analysis revealed that performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, price value, and trust significantly influence the intention to adopt Industry 4.0 tools. The intention to adopt these tools significantly impacts competitive advantage, which in turn positively affects firm performance. The study confirms the mediation effect of competitive advantage on the relationship between adoption intentions and firm performance.
Research Limitations/Implications: The study is limited to MSMEs in the manufacturing sector in India and may not be generalizable to other sectors or regions. Future research could explore longitudinal impacts and sector-specific challenges.
Practical Implications: The findings suggest that enhancing facilitating conditions, addressing financial constraints, and building trust in Industry 4.0 technologies can foster adoption among MSMEs. Policymakers and industry stakeholders should focus on providing technical support, training, and financial incentives to encourage digital transformation.
Originality/Value: This study provides empirical evidence on the adoption of Industry 4.0 tools by Indian MSMEs, highlighting the critical factors that drive adoption and their impact on competitive advantage and firm performance. It contributes to the understanding of digital transformation in the India MSME sector and offers practical insights for stakeholders.

Keywords: Industry 4.0, MSMEs, Technology Adoption, Competitive Advantage, Firm Performance, UTAUT2, India

Introduction

The adoption of technology has become vital for Micro Small and Medium Enterprises in India. With over 48 million MSMEs contributing significantly to the country's industrial output, exports, and employment (Govt of India, 2023), it is crucial for these businesses to embrace digital transformation to remain competitive in today's fast-paced market. The main challenges towards industry 4.0 adoption by MSMEs are to identify their applications in their processes and to measure the business results of the industry 4.0 solutions (Rupp et al., 2021). The present research work tries to examine the factors that contribute towards Industry 4.0 tools (such as Artificial Intelligence, Block Chain, Big Data, Smart Manufacturing) (Raj et al., 2020) adoption by Indian MSMEs.
According to the Micro, Small & Medium Enterprises Development (MSMED) Act, 2006 India, the Micro, Small and Medium Enterprises (MSME) defined and classified as industries where, the investment in plant

and machinery or equipment does not exceed one crore rupees and turnover does not exceed five crore rupees; where the investment in plant and machinery or equipment does not exceed ten crore rupees and turnover does not exceed fifty crore rupees; andwhere the investment in plant and machinery or equipment does not exceed fifty crore rupees and turnover does not exceed two hundred and fifty crore rupees. The current study will use the above mentioned definition of MSMEs as its our working definition. The current study will only consider MSMEs engaged in manufacturing.

The Industry 4.0 concept was proposed in Germany in the year 2011 (Rupp et al., 2021). Industry 4.0 is the coming together and application of several cutting and bleeding edge technologies such as as radio-frequency identification (RFID), big data, cloud computing, smart sensors, machine learning (ML), robotics, additive manufacturing (AM), artificial intelligence (AI), augmented reality and the Internet of Things (IoT) (Raj et al., 2020). Rupp et al. (2021) have defined industry 4.0 as, "Industry 4.0 is the implementation of Cyber Physical Systems for creating Smart Factories by using the Internet of Things, Big Data, Cloud Computing, Artificial Intelligence and Communication Technologies for Information and Communication in Real Time over the Value Chain."

SAP (2023) have given an extensive list of technologies or the nine pillars that make up Industry 4.0:

- Big Data Analytics
- Horizontal and vertical integration
- Cloud computing
- Augmented reality (AR)
- Industrial Internet of Things (IIoT)
- Additive manufacturing/3D printing
- Autonomous robots
- Simulation/digital twins
- Cyber security

Therefore, based on the above definition, the current study will also take in to its purview the above mentioned technologies and will study their adoption by Indian MSMEs and its effect on Competitive Advantage and Firm Performance.

India has over 48 million MSMEs contributing substantially to our country's industrial output, exports, and employment (Govt of India, 2023). Therefore, it is imperative for these businesses to embrace digital transformation to remain competitive in today's globalized market (Masood and Sonntag, 2020). The main challenges towards industry 4.0 adoption by MSMEs are to identify their applications in their processes and to measure the business results of the industry 4.0 solutions (Rupp et al., 2021). Masood and Sonntag (2020) report that SMEs show an inclination to implement Industry 4.0 technologies but factors such as financial and knowledge constraints are found to be key challenges. Thus, it is essential to study the adoption process of industry 4.0 tools by MSMEs and its effect on outcomes such as competitive advantage and firm performance. In addition, he the available research reports that implementation of industry 4.0 is mainly studied for larger organisations or multi-national enterprises such as Sheel and Nath (2019) have studied the adoption of Block chain Technology by large scale Indian firms (turn over exceeding 50 million INR). Although MNEs contribute significantly to the economy, it cannot be ignored that MSMEs make up significant contribution (33%) to India's GDP and thus, it is essential to study their adoption of industry 4.0 .

Thus, on the basis of the above points, the following objectives are proposed for the current study:

- To study the effects of UTAUT2 constructs on MSMEs intention to adopt industry 4.0 tools.
- To study the effects of industry 4.0 adoption on competitive advantage and firm performance of MSMEs.
- To suggest certain courses of action for industry and policy actors based on the results of the study.

Literature Review and Hypothesis Development

The main focus of the current research is to examine the Industry 4.0 technology adoption by Indian MSMEs and the subsequent effect of such technological adoption on their competitive advantage and firm performance. Therefore, the firstly we will focused on identifying relevant technology adoption models from the current literature.

The available literature lists three models for studying technology adoption, these are TAM (Technology Acceptance Model) (Davis et al., 1989), TRI (Technology Readiness Index) (Parasuraman, 2000) and UTAUT2 (unified theory of adoption and use of technology) (Venkatesh et al., 2012). The UTAUT2 model is currently considered the most comprehensive model of technological adoption as it includes behavioural factors based on the Theory of Planned Behavior (Sheel and Nath, 2020). Therefore, the current research considered UTAUT2 as its working theory for studying industry 4.0 adoption by Indian MSMEs. The following are the main constructs in the UTAUT2 model:

The UTAUT2 Model Constructs

- Performance Expectancy (PE): Performance expectancy can be explained as the benefit or utility gained in terms of efficiency, less time and effort, customization, convenience, etc. (Venkatesh et al., 2003).

Performance expectancy is considered to be one of the strongest factors that influence a user's behavioral intention to adopt a technology (Dwivedi et al., 2017a, 2017b; Rana et al., 2015, 2016, 2017).

- Effort expectancy (EE): has been linked to technology adoption (Venkatesh et al., 2003). Many empirical studies have proven the role of perceived ease in technology adoption as a determinant of technology adoption (Sheel and Nath, 2020).
- Social influence (SI): According to Venkatesh et al. (2003), social influence (SI) refers to the degree to which significant others view your adoption of new technologies. Early compliance is what causes social influence to have an effect on behavioral intention. Numerous studies (Al-Somali et al., 2009; AbuShanab et al., 2010; Martins et al., 2014; Shih and Fang, 2004) have examined the impact of social influence on behavior intention to use technology.
- According to Venkatesh et al. (2003), facilitating conditions (FC) refer to the degree to which an individual believes that their organization has the prerequisite infrastructure support for using a technology.
- Hedonic Motivation (HM): It can be characterized as the joy experienced while using a technology (Venkatesh et al., 2012). According to certain studies (Brown and Venkatesh, 2005; Childers et al., 2002; Van Der Heijden, 2004), the sense of satisfaction and cheer that are felt after using technology are major determinants of affecting behavioral intention for technology adoption.
- Price value (PV) is the cognitive trade-off that a user perceives between the benefits they receive and the monetary costs associated with the technology (Venkatesh et al., 2012).

Dependent Constructs

- Behavioral Intentions (I): Described as the degree of inclination of a user to use a technology in the coming time. According to Ajzen (1991) and Venkatesh et al. (2003, 2012), the most important component in technology adoption is behavioral intention. The most important aspect in determining whether technologies are adopted is behavioral intention (Jaruwachirathanakul and Fink, 2005; Martins et al., 2014; Shih and Fang, 2004; Wang and Shih, 2009). Therefore, behavioral intention is the primary construct preceded by antecedents that directly and favorably influences the adoption of self-serving technology (Sheel and Nath, 2020).
- Competitive Advantage (CA): According to Porter 1980, competitive advantage is the ability of a firm to perform better than rivals in the same industry or market. Sheel and Nath (2019) have highlighted that use of Industry 4.0 technologies (such as Block chain) by firms helps in yielding a superior competitive advantage. Therefore, we also posit that adoption of industry 4.0 by MSMEs will lead to better competitive advantage for them.
- Firm Performance (FP): The available literature highlights that firm performance can be conceptualized and measured through cost of operations, turnover, market share growth as well as non financial aspects such as sustainability performance, thus, this constructs highlights organization effectiveness (Fadhilah and Subriadi, 2019). Sheel and Nath (2019) have highlighted that use of Industry 4.0 technologies (such as Block chain) by firms helps in improving their firm performance. Therefore, we also posit that adoption of industry 4.0 by MSMEs will lead to better firm performance of MSMEs.

Based on the discussion above, the null hypothesis for the current study are:

- **H1.1 to 1.8:** Performance Expectancy, Effort expectancy, Social influence, Facilitating conditions, Hedonic Motivation, Price value and Perceived Risk have a significant impact on MSMEs intention to adopt industry 4.0 tools.
- **H2:** MSMEs intention to adopt industry 4.0 tools has a significant impact on their competitive advantage.
- **H3**: competitive advantage obtained from adopting industry 4.0 tools has a significant impact on an MSMEs firm performance.

Methodology

The Survey

The identification of the relevant MSME was done through the MSME directories for states made available by the relevant state governments. Such as, for Uttarakhand, the MSME directory can be accessed at: https://doiuk.org/mysite/list_of_indistries. From this directory manufacturing MSMEs were identified and the identified units were contacted through email or phone by the concerned research head of the University. The aims and objectives of the survey were explained to the contact person at the unit and were asked to direct the researcher to the relevant person/ manager who can answer these questions. Participation in the survey was voluntary and respondents can withdraw from the survey anytime they like. The respondent from the MSME units were told to give responses on behalf of their organization and not on an individual basis. MSME units having a turnover of at least 5 million Indian Rupees were included in the survey. The survey period lasted from the first week of September 2023 to the mid of December 2023. The respondents were ensured that their individual responses would be kept confidential and data their data would only be used to academic purposes. The collected data was treated as per the data management best practices (Zhu et al., 2013).

Questionnaire and Measures Used
All the items were anchored on a Five-Point Likert Scale with 1= highly disagree to 5= highly agree. UTAUT2 with Risk (Measures adapted from: Venaktesh et al., 2012; Sheel and Nath, 2020). Competitive Advantage (Measures adapted from: Pavlou and El Sawy, 2011; Wong et al., 2012; Baier et al., 2008; Brusset, 2016; Yusuf et al., 2014; Blome et al., 2013; Sheel and Nath, 2019.). Firm Performance (Measures adapted from: Jayaram et al., 2000 Devaraj et al., 2007 Wang et al., 2007; Sheel and Nath, 2019).

Sample Size
The study's questionnaire has 36 Likert scale items, therefore a minimum sample size of 360 respondents would be required for the data analysis (Hair et al., 2016). The researcher sent out 983 emails during the the period from Sep 2023 to Dec 2023. Reminders were sent at the end of Sep, Oct and Nov 2023 for respondents who have not responded to the survey. At the end of the survey period, a sample of 372 responses were obtained. Table 1, shows the industry composition of MSMEs that participated in the survey

Table 1: Industry Composition of the Sample

Industry Type	Frequency in the Sample
Food and Beverages	172
Foundry and Metal Works	33
Textiles and Fabric	57
Wood Works	37
Pulp and Paper	23
Rubber and Plastics	20
Machine, tools and Equipment	30

Data Analysis

The present study employs, Partial Least Squares- Structural Equation Modelling (PLS-SEM) for validating the scales used in the questionnaire and for testing the hypothesis of the study. PLS-SEM is a third generation multi-variate statistical techniques which is suitable for studies where latent variables are involved and causal relationships are to be tested (Hair et al. 2021). The analysis was performed in two steps, firstly, the outer model or the measurement model was analysed to establish the validity and reliability of the instrument used and then the inner model was analysed to test the hypothesis of the current study (Hair et al. 2021).

Validity and Reliablity
To establish the validity and reliability of the scales used in the questionnaire, a Confirmatory Factor Analysis (CFA) was performed and the factor loadings obtained were used to establish, convergent and discriminant validity. Common Method Bias and Non_Response Bias was also tested and it was found that common method bias was not found found (single factor percentage of variance explained = 41%, less than 50%) and no non-response bias was also found i.e., no difference in the responses of early and late responses ($p< 0.05$).

Results of the CFA

TABLE 2: Factor Loadings

	PE	EE	SI	FC	HM	PV	T	I	CA	FP
pe1	0.8									
pe2	0.7743									
pe3	0.7706									
pe4	0.7842									
ee1		0.792								
ee2		0.8169								
ee3		0.7952								
si1			0.742							
si2			0.87							
si3			0.7903							
fc1				0.7243						

	PE	EE	SI	FC	HM	PV	T	I	CA	FP
fc2				0.7584						
fc3				0.8131						
fc4				0.8354						
hm1					0.8165					
hm2					0.8195					
hm3					0.814					
pv1						0.8436				
pv2						0.8593				
pv3						0.8403				
t1							0.8028			
t2							0.7242			
t3							0.7767			
t4							0.7661			
t5							0.7569			
t6							0.7695			
int1								0.8576		
int2								0.8893		
int3								0.8945		
c1									0.8695	
c2									0.8882	
c3									0.8795	
f1										0.8211
f2										0.8505
f3										0.814
f4										0.8071

Legend:
PE: Performance Expectancy
EE: Effort Expectancy
SI: Social Influence
FC: Facilitating Conditions
HM: Hedonic Motivation
PV: Perceived Value
T: trust
I: intentions
CA: Competitive Advantage
FP: Firm Performance

TABLE 3: Alpha, AVE, CR (Rho C)

	alpha	RhoC (CR)	AVE
PE	0.7888	0.8632	0.6121
EE	0.722	0.8434	0.6423
SI	0.7337	0.8439	0.6441
FC	0.796	0.8642	0.6147
HM	0.7504	0.8573	0.667
PV	0.8048	0.8846	0.7187
T	0.8616	0.8951	0.5874
I	0.8552	0.912	0.7755
CA	0.8531	0.9108	0.7729
FP	0.8431	0.8938	0.6779

TABLE 4: Discriminant Validity using Fornell-Larcker 1981 criterion

	PE	EE	SI	FC	HM	PV	T	I	CA	FP
PE	0.7824									
EE	0.01096	0.8014								
SI	-0.03855	-0.07271	0.8025							
FC	0.05025	0.06002	0.03937	0.784						
HM	-0.02651	0.01949	-0.02879	-0.03293	0.8167					
PV	0.0263	-0.07172	0.05424	-0.03361	0.1003	0.8478				
T	-0.001662	-0.1135	0.06508	0.01371	0.04335	-0.02125	0.7664			
I	0.3321	0.1421	0.1766	0.199	0.2895	0.235	0.2129	0.8806		
CA	0.203	0.04933	0.1808	0.1078	0.1751	0.127	0.1784	0.5712	0.8791	
FP	0.1614	0.009056	0.1602	0.05913	0.1808	0.1132	0.1376	0.3658	0.2279	0.8234

TABLE 5: Discriminant Validity using HTMT criterion

	PE	EE	SI	FC	HM	PV	T	I	CA	FP
PE										
EE	0.08017									
SI	0.06708	0.1157								
FC	0.07469	0.08397	0.07012							
HM	0.06321	0.06295	0.05012	0.06693						
PV	0.07665	0.09709	0.08224	0.06023	0.1315					
T	0.06255	0.1452	0.08677	0.05997	0.07355	0.07193				
I	0.4019	0.1794	0.2103	0.2294	0.3627	0.2798	0.2379			
CA	0.2447	0.1056	0.2247	0.1319	0.2192	0.1516	0.1934	0.6672		
FP	0.1994	0.06237	0.2024	0.09067	0.2275	0.1415	0.1594	0.4315	0.2632	

From the tables above we can see that all the constructs exhibit Cronbach's Alpha greater than 0.7, AVE (Average Variance Extracted) is greater than 0.5 and Composite Reliability (rho c) is greater than 0.7 for all the constructs. Thus, all the constructs exhibit convergent validity (Hair et al., 2019). Also, Discriminant Validity was judged using the Fornell-Larcker 1981 criterion. From the table we can see that the top most row in every column has the higest value, indicating that each construct captures some unique variance and thus, discrimimant validity is established. Also, HTMT Criteria was also used to establish discriminant validity and all the HTMT values are less than 0.85, thus, establishing discriminant validity (Hair et al., 2019).

TABLE 6: Hypothesis Testing Results- Structural Model Analysis

	Original Est.	Bootstrap Mean	Bootstrap SD	T Stat.	2.5% CI	97.5% CI
PE -> I	0.3302	0.3295	0.03777	8.741	0.2537	0.4023
EE -> I	0.1746	0.1791	0.0415	4.207	0.1023	0.26
SI -> I	0.1776	0.1811	0.04196	4.233	0.1015	0.2584
FC -> I	0.1782	0.181	0.03801	4.688	0.1115	0.2558
HM -> I	0.2754	0.2756	0.03898	7.066	0.2015	0.349
PV -> I	0.2121	0.2138	0.03588	5.91	0.144	0.2854
T ->I	0.2118	0.2191	0.03938	5.379	0.1475	0.2946
I -> CA	0.5712	0.5737	0.03291	17.36	0.5045	0.6318
CA -> FP	0.2279	0.2363	0.04905	4.647	0.1448	0.3268

Path Estimates Bootstrapped at 5000 Samples.

TABLE 7: INDIRECT PATH FROM INTENTIONS TO FIRM PERFORMANCE VIA COMPETITIVE ADVANRAGE

Original Est.	Bootstrap Mean	Bootstrap SD	T Stat.	2.5% CI	97.5% CI
0.1302	0.1361	0.03163	4.116	0.07774	0.1976

Results

Validity and Reliability

To ensure the validity and reliability of the constructs used in this study, a Confirmatory Factor Analysis (CFA) was performed. The factor loadings for each construct ranged from 0.724 to 0.894, indicating good convergent validity. The constructs exhibited Cronbach's Alpha values greater than 0.7, Average Variance Extracted (AVE) values greater than 0.5, and Composite Reliability (rho c) values greater than 0.7, confirming the reliability of the measures used.

Hypothesis Testing

The hypotheses were tested using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results of the structural model analysis are summarized in Table 6 and Fig.1.

H1.1 to H1.8: The constructs of Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), Facilitating Conditions (FC), Hedonic Motivation (HM), Price Value (PV), and Trust (T) had significant impacts on the behavioral intention (I) to adopt Industry 4.0 tools, with path coefficients ranging from 0.1746 to 0.3302, all significant at $p < 0.05$.

H2: The intention to adopt Industry 4.0 tools (I) had a significant impact on Competitive Advantage (CA), with a path coefficient of 0.5712 ($p < 0.001$).

H3: The competitive advantage obtained from adopting Industry 4.0 tools (CA) significantly impacted Firm Performance (FP), with a path coefficient of 0.2279 ($p < 0.001$).

The indirect effect of intentions to adopt Industry 4.0 tools on firm performance via competitive advantage was also significant, with an original estimate of 0.1302 and a T-statistic of 4.116, indicating a strong mediation effect.

Fig. 1: Estimated Structural Model

Discussion

The current research was aimed to investigate the adoption of Industry 4.0 tools by Indian MSMEs and its subsequent impact on competitive advantage and firm performance. The findings align well with the hypotheses and provide significant insights into the factors influencing the adoption of advanced technologies and their implications for business performance.

Our results indicate that performance expectancy (PE) and effort expectancy (EE) are significant predictors of the intention to adopt Industry 4.0 tools. Performance expectancy, with a path coefficient of 0.3302, underscores the perception among MSMEs that these technologies will improve efficiency, reduce time and effort, and offer customization and convenience. This finding is consistent with the UTAUT2 model, which posits that perceived benefits are crucial in shaping technology adoption intentions (Venkatesh et al., 2003; Dwivedi et al., 2017).

Effort expectancy, with a path coefficient of 0.1746, highlights the importance of ease of use in the adoption decision. MSMEs are more likely to adopt Industry 4.0 tools if they perceive them as user-friendly and not requiring excessive effort to implement. This aligns with previous research that emphasizes the role of perceived ease of use in technology acceptance (Venkatesh et al., 2003; Sheel and Nath, 2020).

Social influence (SI) and facilitating conditions (FC) also significantly affect the intention to adopt Industry 4.0 tools. Social influence, with a path coefficient of 0.1776, suggests that the opinions and support of peers, industry leaders, and other influential entities play a crucial role in the decision-making process. This finding is in line with earlier studies that demonstrate the impact of social pressure and normative beliefs on technology adoption (Venkatesh et al., 2003; Al-Somali et al., 2009).

Facilitating conditions, with a path coefficient of 0.1782, indicate that the presence of supportive infrastructure and resources is vital for MSMEs to embrace new technologies. This includes access to technical support, training, and necessary hardware and software. The importance of facilitating conditions reflects the need for a conducive environment that can alleviate potential barriers to adoption (Venkatesh et al., 2003).

Hedonic motivation (HM) and price value (PV) emerged as significant factors influencing the behavioral intention to adopt Industry 4.0 tools. Hedonic motivation, with a path coefficient of 0.2754, reveals that the enjoyment and satisfaction derived from using these technologies can drive adoption. This aligns with studies that highlight the role of intrinsic motivation and user satisfaction in technology acceptance (Venkatesh et al., 2012; Brown and Venkatesh, 2005).

Price value, with a path coefficient of 0.2121, underscores the perceived trade-off between the benefits of Industry 4.0 tools and their associated costs. MSMEs are likely to adopt these technologies if they perceive the benefits to outweigh the costs, which is consistent with the findings of Venkatesh et al. (2012) and Sheel and Nath (2020). This highlights the need for cost-effective solutions and financial support mechanisms to facilitate adoption.

Trust (T) also plays a significant role, with a path coefficient of 0.2118, indicating that MSMEs need to trust the reliability and security of Industry 4.0 tools to consider their adoption. This finding underscores the importance of building confidence in new technologies, particularly in terms of data security and operational reliability.

The intention to adopt Industry 4.0 tools significantly impacts competitive advantage (CA), with a path coefficient of 0.5712. This demonstrates that MSMEs that embrace these technologies can gain a substantial edge over their competitors. The adoption of advanced technologies enables these firms to enhance their operational efficiencies, innovate processes, and offer superior products or services, thereby achieving a competitive advantage (Sheel and Nath, 2019).

Furthermore, the competitive advantage gained from adopting Industry 4.0 tools positively influences firm performance (FP), with a path coefficient of 0.2279. This indicates that the benefits of digital transformation extend beyond competitive positioning to tangible improvements in firm performance, such as increased market share, higher revenues, and improved operational efficiency (Fadhilah and Subriadi, 2019).

The indirect effect analysis further supports this, showing a significant mediation effect of competitive advantage on the relationship between intentions to adopt Industry 4.0 tools and firm performance. This highlights the strategic importance of Industry 4.0 adoption in driving long-term business success for MSMEs.

Implications

The study's findings have several practical implications for MSMEs, policymakers, and industry stakeholders. To foster the adoption of Industry 4.0 tools among MSMEs, efforts should be made to enhance facilitating conditions, such as providing access to technical support and training. Additionally, addressing financial constraints through subsidies or low-cost financing options can help MSMEs overcome the cost barriers associated with these technologies.

Policymakers should also focus on creating awareness and providing education about the benefits and ease of use of Industry 4.0 tools to enhance performance expectancy and effort expectancy among MSMEs. Building trust through certification, data security measures, and showcasing successful case studies can further encourage adoption.

Conclusion

The present study provided empirical evidence on the critical factors influencing the adoption of Industry 4.0 tools by Indian MSMEs and their effects on competitive advantage and firm performance. The results highlight the importance of performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, price value, and trust in shaping MSMEs' intentions to adopt these technologies.
The positive relationship between the adoption of Industry 4.0 tools and competitive advantage suggests that digital transformation can be a key driver for achieving superior performance in the MSME sector. Policymakers and industry stakeholders should focus on enhancing the facilitating conditions, providing adequate support and infrastructure, and addressing the financial and knowledge constraints faced by MSMEs to foster Industry 4.0 adoption.
Future research could explore the longitudinal impacts of Industry 4.0 adoption and investigate the specific challenges and solutions for different MSME sectors.

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