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Adoption and barriers of industry 4.0 by micro enterprises

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ABSTRACT

Industry 4.0 is often related to large and medium-scale enterprises but its impact on micro-enterprises which are critical contributors to India's economy remains underexplored. This research explores the adoption and obstacles of Industry 4.0 in micro-enterprises with a specific emphasis on the Indian context and provides actionable insights for policymakers and practitioners to enhance Industry 4.0 adoption on in microenterprises. An online data collection was conducted for selected micro-enterprises using a purposive sampling technique, yielding 200 complete responses between November 2023 and February 2024. Logistic regression was used to investigate the variables related to adopt Industry 4.0 whereas OLS regression assessed the intensity of adoption. The study reveals various hurdles to Industry 4.0 adoption in micro-enterprises. The result implied that micro-enterprises should make efforts to overcome the prominent influencing barriers and sensitivity barriers as these barriers can make a significant impact on the Industry 4.0 adoptions. The research has significant implications for policymakers and practitioners. Understanding these barriers can help in developing targeted strategies to foster Industry 4.0 adoption in micro-enterprises, boosting their productivity and competitiveness and contributing to economic growth.

Contribution/Originality: The novelty of this research focuses on micro-enterprises with detailed insights into how they can navigate technological advancements and enhance their competitiveness in the evolving industrial landscape.

1. INTRODUCTION

The industrial system's empowerment has been widely discussed in the previous few decades by industry and academia using a variety of concepts and terminologies. The success of these industrial systems will give industries a competitive edge over others and promote national economies. Micro, Small, and Medium Enterprises (MSMEs), the backbone of the Indian economy have always been the subject matter for many studies to make them strong and empower them (Shelly, Sharma, & Bawa, 2020). In normal times, MSMEs have a tough time to sustain in the global scenario due to constant market dynamics changes because of regulation shifts, technology shifts, consumer behaviour changes or globalization. Micro industries are most vulnerable especially with their capacity, operational scale, limited managerial processes, scarce resources and less space for handling unexpected falls (Cueto, Frisnedi, Collera, Batac, & Agaton, 2022; Nikolić, Perčić, & Nećak, 2022). However, survival is increasingly difficult due to unexpected

events like the coronavirus pandemic, national lockdown, and demonetization, the implementation of the Goods and Services Tax (GST), and bank crises. Therefore, there is a need for MSME's to be competitively edge-oriented and create competency against uncertainty to seize amid today's ever-changing complex enterprise environment through modern approaches.

In India, micro-enterprises are enterprises with annual sales of less than five crore and an investment of less than one crore in plant and machinery or equipment, effective July 1, 2020. Micro enterprises have distinct features from small and medium-sized enterprises. As a result, microenterprises will have a distinct viewpoint and relevance to Industry 4.0 than small and medium-sized enterprises. Micro enterprises have limited resources and expertise in managing current technologies (Blili & Raymond, 1993; Zach, Munkvold, & Olsen, 2014). The involvement and focus of the Chief Executive Officer (CEO) are strong towards the daily operational tasks compared to strategic and development initiatives (Forsman, 2008).

Micro enterprises are intriguing to research. Micro-enterprises are a major economic sector because they are the most frequent type of small and medium-sized enterprise. They have much less resource management, often less bureaucratic, and have more opportunities to flourish compared to other scaled enterprises (Müller & Hopf, 2017). For the future success of the enterprises, they must enhance their ability to fulfil their customer's need while keeping a competitive edge in their market. Enterprises must endeavor to constantly develop their organisational practices in planning, monitoring, controlling, measuring and evaluating resources and processes (Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018). The introduction of Industry 4.0 technology brings with it tremendous potential and difficult problems for enterprises worldwide as the modern industrial landscape quickly changes. Modern technology like automation, AI, and data analytics, when combined can lead to increased productivity, competitiveness, and efficiency.

Industry 4.0 adoption in microenterprises offers enhanced competitiveness, improved performance, and increased profitability. It democratizes data, fosters innovation, and enables efficient production, ensuring adaptability and relevance in a rapidly evolving digital landscape (Javaid, Haleem, Singh, Suman, & Gonzalez, 2022). Furthermore, the research focuses on the significance of prioritizing Industry 4.0 adoption in alignment with enterprise goals to mitigate financial risks and leverage competitive advantages through targeted digital investments (Suleiman, Shaikholla, Dikhanbayeva, Shehab, & Turkyilmaz, 2022). Several obstacles that hinder execution must be removed for I4.0 projects to be adopted successfully. The research identifies significant opportunities to explore causal relationships between Industry 4.0 readiness factors in developing nations (Kumar, Singh, & Dwivedi, 2020). There is a clear gap in understanding how these readiness factors interact causally within these nations (Raj, Dwivedi, Sharma, de Sousa Jabbour, & Rajak, 2020). Future researchers are also promoted to examine the importance and interrelationships between the variables of readiness for Industry 4.0. Consequently, this would enable Industry 4.0 implementation to lead to Global Production Networks (GPNs) in case developing nations can overcome prevailing hurdles.

On the other hand, research highlights factors influencing adoption decisions including driving and impeding factors in -depth analysis of how these driving and impeding factors affect decision-making processes in industry for adoption of Industry 4.0 is lacking although there have been some cases that looked at facilitating factors (Khin & Kee, 2022). On the contrary, several manufacturing enterprises still shy away from embracing Industry 4.0 due to many reasons like huge costs associated with its introduction as well as a lack of skills and awareness about it among employees with roots in traditional production approaches (Liebrecht et al., 2021). Moreover, the reason why managers are so resistant to Industry 4.0 is the availability of cheap labor (Malini & Srinivas, 2020). It is necessary to address these gaps in research on Industry 4.0 and its implementation in developing nations (Nimawat & Gidwani, 2021). To address these gaps in this study, research question is given below.

RQ1: Does a prominent barrier affect the implementation of Industry 4.0 in enterprises?

RQ2: Does the influencing barrier affect the implementation of Industry 4.0 in enterprises?

RQ3: Does a resulting barrier affect the implementation of Industry 4.0 in enterprises?

RQ4: Does the sensitivity barrier affect the implementation of Industry 4.0 in enterprises?

This paper aims to use the concept of Industry 4.0 to strengthen micro-enterprises. It has a focus on Indian micro-enterprises; their adoption approaches and associated barriers. The paper also attempts to expose the effects of different barriers, such as prominent ones that influence the implementation or sensitivity that results from Industry 4.0 technology's adaptation within an organization or enterprise unit through regression-based comprehensive statistical techniques like logistic and OLS analyses. Furthermore, investigating if management can be helpful in overcoming them will have policy implications for those who want to see a successful integration process for all involved stakeholders including policymakers and practitioners into the extensive use of Industry 4.0 in micro enterprises.

This paper has six sections. Section 1 introduces the research, outlining its goals and importance. Section 2 offers an extensive survey on the adoption of Industry 4.0 and its barriers in micro enterprises as reported by other scholars. Section 3 is about data collection methods and the research methodology used. Section 4 presents findings of the study while section 5 reviews them emphasizing what their implications are for policymakers and practitioners respectively. Finally, section six concludes the paper by highlighting key findings, acknowledging the limitations of the paper and giving recommendations for further studies.

2. LITERATURE REVIEW

2.1. Industry 4.0

The term Industry 4.0 originated from the German government's initiative Industry 4.0, launched in 2011. This program aimed to boost industrial productivity through innovation and technology. Over time, Industry 4.0 evolved into a broader concept known globally as Industry 4.0 (Issa, Hatiboglu, Bildstein, & Bauernhansl, 2018). This paved the way for this initiative laid the foundation for a modern management system that is more flexible, efficient, and cost-effective (Moeuf et al., 2018). The goal of Industry 4.0 is to develop intelligent factories. This is achieved by integrating advanced technologies such as smart manufacturing, digitalization, automation, and robotics into industrial operations.

Industry 4.0 must be implemented as COVID-19 enhanced competition in the manufacturing Industry 4.0 (Pansare, Yadav, & Nagare, 2024). There is a difference of understanding and implementing it because of the rapid change in technology of Industry 4.0 (Liao, Deschamps, Loures, & Ramos, 2017). According to BITKOM, the German telecommunication organization, there are more than 100 meanings of Industry 4.0 which make Industry 4.0 difficult to understand (Bidet-Mayer, 2016). Many companies related to modern automation and data interchange technologies implemented Industry 4.0 worldwide (Caiado et al., 2021; Váně, Kalvas, & Basl, 2021). Before implementing Industry 4.0 is important to evaluate the organization's readiness (Krishnan, Yen, Agarwal, Arshinder, & Bajada, 2021; Rajnai & Kocsis, 2018). A study states that Industry 4.0 is a tool to get strategic insights by implementing it with a proper sense of understanding, judgement and tactics (Trappey et al., 2017). Implementation of Industry 4.0 requires significant investment and high skills (Rüßmann et al., 2015). Industry 4.0 is more accessible to enterprises because of their flexibility in decentralization in data administration and decision- making (Moeuf et al., 2018). Industry 4.0 is a collection of various actions and approaches to improve the goods, services and procedures by taking decentralized decisions making approach based on the real time data, which is one of the popular definition of Industry 4.0 (Danjou, Pellerin, & Rivest, 2017). Various enterprises are using Industry 4.0 technologies to improve their processes which results in increased lean and just-in-time manufacturing through digitalization and use of smart machines. Recent inventions of AI, sensor networks, Internet of Things (IoT), cloud computing, machine learning, and additive manufacturing have taken data accessibility to the next level. However, the extent of AI use varies as per industry (Jan et al., 2023). It appears that some nations are embracing digital transformation through different programs. Germany emerged as the front-runner for Industry 4.0, emphasizing engineering superiority.

Additionally, it revealed the Industry 4.0-aligned Digital Strategy (DS) 2025 and High Tech Strategy (HTS) 2025 projects. As the world leader in information technology, the US is concentrating on strengthening its position in the field of robotization through a number of initiatives like Smart Manufacturing, Advanced Manufacturing Partnership (AMP), and the National Network for Manufacturing Innovation. Meanwhile, Japan has emerged as a robotic superpower and is planning how to integrate robots with the Internet of Things (IoT). The efforts towards Industrial 4.0 in India include SAMARTH Udyog Bharat 4.0, Made in India, Startup India, and digital India together, these represent the first wave of industrial change (Bongomin, Nganyi, Abswaidi, Hitiyise, & Tumusiime, 2020; Masood & Sonntag, 2020). Türkeş et al. (2019) claimed that the fourth industrial revolution has already begun. Industries must become ready for it to stay driven in the current dynamic business scenario.

2.2. Adoption of Industry 4.0

The implementation of Industry 4.0 is supported by a wide range of concepts, tools, and technological advancements as highlighted in various studies. Rüßmann et al. (2015) identified core technologies that form the foundation of Industry 4.0. These include big data analytics, automation, simulation, the Internet of Things (IoT), cybersecurity, cloud computing, augmented reality, and horizontal and vertical integration. These technologies enable real-time data exchange, intelligent decision-making and seamless integration across production systems. Marmolejo Saucedo (2018) extended the technological landscape of Industry 4.0 by including mobile technologies, artificial intelligence (AI), radio-frequency identification (RFID), and real-time location systems (RTLS). These tools enhance tracking, connectivity, and responsiveness in industrial operations. Liao et al., (2017) identified commonly associated terms within the manufacturing domain that reflect the essence of I4.0. These include Cyber-Physical Production Systems (CPPS), Smart Factories, Industrial Revolutions, IoT, Smart Manufacturing, Production Systems, Manufacturing Systems, and Production Processes. These terms indicate the integration of digital technologies with physical manufacturing environments. Pozzi, Rossi, and Secchi (2023) focused on organizational enablers critical to Industry 4.0 success. Their study emphasized the role of inter-functional teams, lean management practices, continuous improvement, quality competitiveness, and leadership from top management. They argued that enterprise models should evolve progressively starting with customer-focused improvements before undertaking large-scale transformations. Additionally, another study outlined thirty-five essential organizational resources necessary for effective Industry 4.0 adoption. These include teamwork and the execution of the team, organizational culture, project management resources, IT resources, knowledge of reverse logistics, management systems innovations and long-term investments, readiness for organizational change, flexible remanufacturing system, top management approval, and robotics in the shop floor (Bag, Yadav, Dhamija, & Kataria, 2021). A study determined that the most significant resource groups for the adoption of Industry 4.0 are production systems, big data analytics, green logistics, human resources, project administration, leadership management, green design, information technology, and a collective approach based on exploratory factor analysis (Bag et al., 2021). The majority of studies, frameworks, and models now in use were created for large-scale enterprises. On the other hand, micro enterprises are less interested in most research since their priorities are shorter-term profits and cost (Masood & Sonntag, 2020). Additionally, micro enterprises find it difficult to implement new ideas since they lack awareness, expertise, and insights (Horváth & Szabó, 2019; Mittal, Romero, & Wuest, 2018).

The built environment is a significant source of emissions, land usage, and resource use accounting for 10% of the global GDP. According to the 2030 Sustainable Development Goals, the built environment must be transformed to achieve net-zero emissions, robust infrastructure, a circular economy, and improved well-being. While few studies address all supporting technologies, digitalization and integrating Industry 4.0 technologies can lead to sustainability in the built environment (Pachouri et al., 2024). An industry-focused study on Industry 4.0 claims that there is a deficiency of empirically based studies on Industry 4.0 technology applications. Furthermore, it is still unclear what Industry 4.0's actual benefits and requirements are for enterprises (Moeuf et al., 2018). A plethora of pre-existing

frameworks and tools are available for Industry 4.0, but a limited studies are focused on the adoption of Industry 4.0 in enterprises (Masood & Sonntag, 2020). According to research, large enterprises appear to be more Industry 4.0 prepared and oriented than micro-ones (Stentoft, Adsbøll Wickstrøm, Philipsen, & Haug, 2021). Micro enterprises have difficulty in adapting and deploying new technologies (Issa et al., 2018). A research study concludes that such micro-enterprises have additional hurdles to Industry 4.0 adoption (Stentoft et al., 2021). Similarly, very little data and research is available regarding the Industry 4.0 adoption in enterprises (Stentoft et al., 2021). Hence, this study seeks to bridge the deficiency by analyzing figures from various manufacturing units by evaluating the managers' perspective for Industry 4.0 adoption, preparedness and barriers.

2.3. Prominent Barriers

Identifying and overcoming prominent barriers is critical for the effective adoption of Industry 4.0. Lack of a comprehensive digital strategy that may aid in the development of digital service packages, organizational structure, and procedures are the major prominent barriers. It is difficult for many enterprises to adopt complete digital strategies that fully use all the prospects for innovation that come with digital technology, hence hindering the execution of digital transformation (Tronvoll, Sklyar, Sörhammar, & Kowalkowski, 2020). Sklyar, Kowalkowski, Tronvoll, and Sörhammar (2019) assert that for a more conscious and planned approach because the interactional contact between units is closer than in typical service strategies. Furthermore, insufficient infrastructure and technical capabilities as well as supply chain integration limits create major barriers that are linked to other prominent barriers. Enterprises need to establish solution customization, pricing, and digitization-oriented strategies to overcome such major challenges (Kohtamäki, Parida, Oghazi, Gebauer, & Baines, 2019). Local economic environments also impact industrial digitalization with developed nations having more digitally advanced manufacturing enterprises. Szász, Demeter, Boer, and Cheng (2017) claimed that resilient infrastructure is very important since it links the client interaction points to the enterprise's backend processes. Knowledge transfer and spillover effects from industry units in developed countries could be taken as key ways of increasing competitive advantages for global and multinational companies in less developed regions. This underscores the importance of well-structured infrastructure to enable effective transformation efforts (Neely, 2008).

H_1: Effects of prominent barrier on implementing Industry 4.0 in enterprises.

2.4. Influencing Barriers

The adoption of Industry 4.0 in enterprises has faced several barriers owing to a variety of influencing barrier factors. These barriers have an impact on the implementation process since they are linked to other obstacles through strong casual relationships. The complexity of supply chain integration has a significant impact. This barrier is critical for boosting innovative skills since it improves supplier-customer integration, resulting in a competitive advantage. Shah, Jajja, Chatha, and Farooq (2020) assert that for the effective implementation of digital technologies in enterprises, strong supply chain efficiency is required. Blili and Raymond (1993) found that another major influencing barrier is the difficulty in the data transfer process between the customer and the enterprise. Building trust and increasing transparency in any business process can promote the product-service model in the enterprise. Lack of sharing of information between the customer and the enterprise prevents to implement Industry 4.0. In the digital landscape, customers prefer enterprises that provide transparency and trustworthiness, which serve as differentiating factors for the enterprises. Hence, in this study, the significance of effective communication and information sharing between the customer and the enterprise was highlighted (Kamalaldin, Linde, Sjödin, & Parida, 2020). Paschou, Rapaccini, Adrodegari, and Saccani (2020) state that to balance this digital process of information sharing and building communication, digital associations or partnerships can be developed. The impact of major influencing barriers like issues regarding supply chain integration, absence of information sharing, absence of transparency and trust-building approach needs to be assessed towards the adoption of Industry 4.0 in the micro-enterprises.

H_2: Effects of influencing barrier on implementing Industry 4.0 in enterprises.

2.5. Resulting Barriers

Resulting barriers hinder enterprises from adopting the Industry 4.0 technologies, as these obstacles directly impact the advancements. The lack of digital infrastructure, lack of digitally literate employees, insufficient financial funds and resources and lack of knowledge of the applications involved are the major resulting barriers for the micro-enterprises. To overcome these barriers substantial funds are required for the research and development department in the enterprises. The priority of digital transformation at the strategic level needs to be focused on the people, processes and technologies. The inter-firm and intra-firm resources need to be reorganized to ensure that they sustain the technological transitions (Paschou et al., 2020). Furthermore, the enterprises should have a precise technological advancement target with the financial budget and technological capacity to build a strong digital infrastructure (Kohtamäki et al., 2019). The first step in achieving Industry 4.0 objectives is to address the deficiency of digital tactics while formulating various processes such as designing digital service packages, organizational structures and procedures. Only then should they address issues such as budgetary limits and technological limitations. The majority of the resultant barriers are related to organizational and technological factors that are often linked to the enterprise's capabilities (Sklyar et al., 2019). Enterprises must build effective methods to eliminate these issues. Enterprises should focus on eliminating the major barriers before addressing the resulting barriers for an effortless advancements towards Industry 4.0. The limited financial resources, technological incompetency among employees and unavailability of advanced technological infrastructure are the resulting barriers (Geissbauer, Vedso, & Schrauf, 2016) that need to be investigated to analyse the impact on Industry 4.0 adoption in micro-enterprises.

H_3: Effects of resulting barrier on implementing Industry 4.0 in enterprises.

2.6. Sensitivity Barriers

Sensitivity barriers are intricate issues. They are caused by the adoption process of Industry 4.0 technologies. Biases in responses collected from industrial personnel, their awareness and knowledge, and assigning different weightage to expert's judgements and opinions can influence the impact of perceived challenges (Xia, Govindan, & Zhu, 2015). Sensitivity analysis is preferred to understand the impact of these barriers. In this analysis method, the experts or respondents are categorized based on their expertise. Weights are assigned to their responses based on the category. Weights are kept constant in varied situations. However, minimal divergence can be expected but will overcome the major biases from the impact. Studies have highlighted that persistence in barriers in sensitivity analysis was observed under different weight situations (Raj et al., 2020). In other words, this consistency suggests that the identified barriers are strong and do not rely heavily on individual expert preconceptions. Without this dependability, making strategic judgments would be impossible while attempting to overcome these obstacles efficiently. Understanding sensitiveness constraints explains why Industry 4.0 technology adoption is so reliant on experts' subjective opinions. Recognizing and overcoming these issues may help organizations navigate the complicated world of digital transformation.

H_4: Effects of sensitivity barrier on implementing Industry 4.0 in enterprises.

3. METHODOLOGY AND DATA COLLECTION

3.1. Collection of Data

Industry 4.0 has mostly focused on large and medium-sized enterprises rather than micro-sized enterprises. Nevertheless, the limited possibilities and various eccentricities of the speculation and social capital issues make them particularly important for micro-enterprises as a basis for the Indian economy and an ideal study. The purposive sampling technique was embraced to recognize our expected respondents. Purposive sampling is referred to as judgmental sampling in which participants are chosen by the researcher according to predetermined traits. This

approach is frequently employed in situations when a certain segment within a community needs in-depth analysis. Selection bias could prevent the result from being applicable to the whole population although it makes focused data collecting possible. An email containing the depiction of the task and the connection to the internet-based review was sent to enterprises regarding these standards. After two updates, an all-out number of 200 complete responses. Information was gathered between November 2023 and February 2024.

3.2. Methodology

The study used logistic regression and Ordinary Least Squares (OLS) regression for the statistical analyses. The first analysis will assess the factors influencing whether enterprises embraced Industry 4.0 technology. On the other hand, the second analysis will gauge the degree to which the factors influence the adoption of Industry 4.0 in the micro-enterprises. This approach allows for the evaluation of the various influencing factors. This approach focuses on one factor at a time and analyses in depth the elements which make the factors preferable by the micro-enterprises instead of focusing on various influencing factors at a time (Dickson & Weaver, 2011). In this study, a Likert scale of 5-points was adopted to gauge the enterprise relation of Industry 4.0 and innovations.

4. RESULTS

4.1. Reliability Analysis

Table 1 presents the reliability analysis of the variables used in this study. The analysis was conducted using Cronbach's alpha, which measures the internal consistency of items within each construct. The prominent barrier variable shows good internal consistency with a Cronbach's alpha above 0.85. This indicates that the items are strongly related and reliable. The influencing barrier also demonstrates good reliability. Its Cronbach's alpha is 0.842, suggesting the items are consistent and measure the construct accurately. The resulting barrier variable also has excellent internal consistency with a Cronbach's alpha of 0.945. This high value confirms that the items are very closely related and offer a strong, reliable measure. The sensitivity barrier variable has a Cronbach's alpha of 0.714, indicating acceptable internal consistency. While the items are reasonably correlated, there is some scope for improving the clarity or alignment of the items to enhance reliability further. The variable measuring implementation of Industry 4.0 shows good reliability with a Cronbach's alpha of 0.845, confirming that the items consistently reflect the construct. Overall, the analysis shows that most variables in the study have high to excellent internal consistency. Only the sensitivity barrier variable may need minor refinement to improve measurement accuracy.

Table 1. Reliability analysis.

Variables	Cronbach's alpha
Prominent barrier	0.856
Influencing barrier	0.842
Resulting barrier	0.945
Sensitivity barrier	0.714
Implementation of I4.0	0.845

Note: Variable wise reliability analysis using Cronbach Alpha test.

Table 2. Descriptive statistics.

Variables	Mean	Std. deviation
Prominent barrier	3.21	1.237
Influencing barrier	3.63	0.234
Resulting barrier	3.26	0.996
Sensitivity barrier	3.15	0.956
Implementation of I4.0	3.45	0.961

Note: Measures of central tendency and measures of dispersion.

Table 2 presents the mean and standard deviation for each variable. The prominent barrier has a mean score of 3.21, which indicates a moderate level of prominence perceived by respondents. The standard deviation is 1.237, showing a moderate variation in responses. This suggests that some respondents rated this barrier very high or low while most scores are near the average. The influencing barrier has a mean of 3.63, showing a high level of perceived influence. The standard deviation is 0.234, which is very low. This indicates that respondents largely agree on the influence of this barrier. The resulting barrier has a mean score of 3.26, which shows a moderate perception among respondents. The standard deviation of 0.996 shows moderate variability in how this barrier is perceived. The sensitivity barrier shows a mean score of 3.15, indicating a moderate level of concern. The standard deviation is 0.956, again pointing to a moderate spread in responses. The variable for the implementation of Industry 4.0 has a mean of 3.45, showing a moderate to high level of perceived implementation. The standard deviation is 0.961, showing some variation in how respondents perceive implementation levels. Overall, all variables show moderate to high mean scores, indicating that respondents generally recognize the presence of these barriers and the implementation of Industry 4.0. Among all, the influencing barrier is rated the highest and shows the least variability, reflecting strong agreement among respondents regarding its significance.

4.2. Correlation

Table 3 shows the correlation analysis for the variables in the study. The prominent barrier has a weak positive correlation with both the influencing and the resulting barriers (0.326 each), indicating that as the perception of the prominent barrier increases, so do the perceptions of the influencing and resulting barriers. It has a weaker correlation with the sensitivity barrier (0.253), suggesting a slight association. The correlation with the implementation of Industry 4.0 is negligible and negative (-0.009), indicating no significant relationship. The influencing barrier shows a very strong positive correlation with the resulting barrier (0.945), suggesting that these two barriers are strongly related and often perceived together. It has a strong positive correlation with the sensitivity barrier (0.612) and a weak positive correlation with the prominent barrier (0.326). The correlation with the implementation of Industry 4.0 is weak positive (0.323), indicating some association. The resulting barrier is highly correlated with the influencing barrier (0.945), indicating a very strong relationship. It has a moderate correlation with the sensitivity barrier (0.412) and a weak positive with the prominent barrier (0.326). The correlation with the implementation of Industry 4.0 is strong (0.726), suggesting that higher perceptions of the resulting barrier are associated with greater implementation of Industry 4.0. The sensitivity barrier has a strong positive correlation with the influencing barrier (0.612) and the resulting barrier (0.412), indicating moderate positive association. It has a weaker correlation with the prominent barrier (0.253) and the implementation of I4.0 (0.263), suggesting slight relationships. Implementing Industry 4.0 has a strong and positive correlation with the resulting barrier (0.726), indicating that higher perceptions of the resulting barrier are associated with greater implementation of Industry 4.0. It has weak positive correlations with the influencing barrier (0.323) and the sensitivity barrier (0.263), indicating some associations. The correlation with the prominent barrier is negligible and negative (-0.009), indicating no significant relationship. The correlation analysis reveals significant relationships between various barriers, particularly between the influencing and resulting barrier , which are highly correlated. The implementation of Industry 4.0 is strongly related to the resulting barrier and moderately related to the influencing barrier suggesting that perceptions of these barriers influence the implementation of Industry 4.0. The prominent barrier shows moderate correlations with other barriers but has no significant relationship with the implementation of Industry 4.0.

Table 3. Correlation.

Variables	Prominent barrier	Influencing barrier	Resulting barrier	Sensitivity barrier	Implementation of industry 4.0
Prominent barrier	1.000				
Influencing barrier	0.326	1.000			
Resulting barrier	0.326	0.945	1.000		
Sensitivity barrier	0.253	0.612	0.412	1.000	
Implementation of industry 4.0	-0.009	0.323	0.726	0.263	1.000

Note: Correlation is significant at the 0.05 level (2-tailed).

4.3. Regression

The regression analyses provide a comprehensive understanding of the different barriers' impacts on implementing Industry 4.0 (I4.0) in enterprises. We can discern how each barrier affects the likelihood and extent of I4.0 adoption by evaluating the logistic and OLS regression results. Table 4 presents the results of logistic regression and Ordinary Least Squares (OLS) regression analyses for different types of barriers: Prominent barrier , influencing barrier , resulting barrier , and sensitivity barrier . Logistic regression is used to model the probability of an outcome (e.g., whether a specific barrier significantly affects the outcome) based on the odds ratios whereas , OLS regression is used to model the effect of barriers on a continuous dependent variable, providing coefficients to understand the strength and direction of these relationships.

Table 4. Result of regression analysis.

Variables	Logistic regression		OLS regression	
	Odds ratio	p-value	Estimates	p-value
Prominent barrier	1.672	0.055**	0.326	0.000***
Influencing barrier	2.172	0.020**	0.036	0.632
Resulting barrier	0.953	0.766	0.036	0.832
Sensitivity barrier	2.066	0.019**	0.263	0.033
(pseudo)R^2	(0.39)		0.29	
Adj. R^2	-----		0.33	

Note: *** significance at 1% level; ** significance at 5% level.

Table 4 displays the prominent barrier as a significant factor influencing Industry 4.0 implementation. Logistic regression shows that the odds of implementing Industry 4.0 are 1.672 times higher when the prominent barrier is present, with a p-value of 0.055, indicating significance at the 10% level. This suggests that enterprises facing prominent barriers are more likely to adopt I4.0 technologies. OLS regression further supports this, showing a significant positive relationship with a coefficient of 0.326 and a p-value of 0.000, which is significant at the 1% level. This implies that not only are enterprises more likely to implement I4.0 when prominent barriers are present, but they also tend to implement it to a greater extent. Addressing these barriers is therefore crucial for enhancing I4.0 adoption.

The influencing barrier has a nuanced impact on I4.0 implementation. Logistic regression indicates a significant positive effect, with the odds of implementing I4.0 being 2.172 times higher in the presence of the influencing barrier (p-value of 0.020, significant at the 5% level). This suggests that influencing barriers are critical in the initial decision to adopt I4.0. However, OLS regression does not find a significant effect (coefficient of 0.036, p-value of 0.632), indicating that once the decision to adopt I4.0 is made, the influencing barrier does not significantly affect the extent of implementation. Thus, influencing barriers may be more critical in the preliminary phases of adoption rather than during ongoing implementation.

Resulting barriers do not significantly impact the implementation of Industry 4.0 as indicated by both logistic and OLS regression results. Logistic regression shows an odds ratio of 0.953 with a p-value of 0.766, while OLS

regression shows a coefficient of 0.036 with a p-value of 0.832. These findings suggest that the barriers that result are not critical determinants in either the decision to implement Industry 4.0 or the extent of its implementation. Enterprises may not consider these barriers as significant obstacles when planning and executing Industry 4.0 strategies.

Sensitivity barriers significantly affect Industry 4.0 implementation in logistic and OLS regressions. The logistic regression indicates that the odds of implementing Industry 4.0 are 2.066 times higher when sensitivity barriers are present (p-value of 0.019, significant at the 5% level). OLS regression also shows a significant positive effect with a coefficient of 0.263 and a p-value of 0.033, significant at the 5% level. These results highlight that sensitivity barriers are crucial in both the decision-making process and the extent of Industry 4.0 implementation. Addressing these barriers is essential for promoting a more comprehensive and effective adoption of Industry 4.0 technologies.

The pseudo R^2 value of 0.39 suggests that the logistic regression model explains 39% of the variance in the dependent variable. The OLS regression model explains 29% of the variance in the dependent variable, and the adjusted R^2 value of 0.33 indicates that approximately 33% of the variance is explained when adjusted for the number of predictors in the model.

5. DISCUSSION

5.1. Hypothesis Testing

This study explored the adoption of Industry 4.0 in micro-enterprises through prominent, influencing, resulting, and sensitivity barriers. The impact of the barriers was evaluated through statistical analysis, logistic regression and OLS regression. The findings of the study confirmed the reliability of the scales used and the varying degree of impact the barriers have on Industry 4.0 adoption. The descriptive statistics and correlation analyses supported the regression findings justifying the purpose of the research. H1 is supported, as the prominent barrier has a significant positive effect on the implementation of Industry 4.0 in both logistic and OLS regressions.

H2 is partially supported as the influencing barrier has a significant positive effect in logistic regression but not in OLS regression as the p-value is more than 0.05 significance level in OLS regression. H3 is not supported as the resulting barrier does not have a significant effect on the implementation of Industry 4.0 in either regression model. H4 is supported as the sensitivity barrier has a significant positive effect on the implementation of Industry 4.0 in both logistic and OLS regressions. Overall, the result implied that micro-enterprises should make efforts to overcome the prominent, influencing barriers and sensitivity barriers, as these barriers can make a significant impact on the I4.0 adoptions.

5.2. Comparison

Numerous Industry 4.0 ready models have been created in academia and practitioner literature (Sony & Naik, 2020). A study extensively examined barriers such as financial constraints, technological complexity as the barriers in SMEs for Industry 4.0 adoption (Sahu & Gupta, 2021).

Another study brought the impact of organizational and environmental factors as major barriers in Industry 4.0 implementation (Narula, Prakash, Dwivedy, Talwar, & Tiwari, 2020). Low digital readiness, resistance to change, high initial investment, and limited technical expertise impact Industry 4.0 adoption in Indian manufacturing enterprises (Gadekar, Sarkar, & Gadekar, 2024). Furthermore, a study identified poor infrastructure, high cost of implementation, and lack of skilled workforce as barriers in Indian manufacturing units (Pasi, Mahajan, & Rane, 2021). According to a survey, Industry 4.0-ready aspects include staff that is skilled and driven, understanding and taking risks with technology, and having financial and strategic backing from higher up the corporate hierarchy (Haug, Graungaard Pedersen, & Stentoft Arlbjørn, 2011). For the manufacturing industry to remain competitive, there has to be a strategic alignment between Industry 4.0 technology and operational excellence approaches. According to comparative studies, infrastructure, organizational strategy, and capital investment are crucial

components in attaining strategic alignment (Ozbiltekin-Pala, Kazancoglu, Kumar, Garza-Reyes, & Luthra, 2024). The research examined management receptiveness to change, staff competencies, and upper management backing as accomplishment factors for the adoption of Industry 4.0 (Sony & Naik, 2020). As a result, technology is seen as being increasingly vital to an enterprise's operations.

5.3. Contributions

The finding of these studies completely focuses on the distinctiveness of micro-enterprises. The impact influencing and sensitivity barriers found in this study have more prominent impacts on micro-enterprises than larger enterprises. This is because of their small-scale operations, distinctive challenges related to market dynamics, operational constraints and competitiveness. The findings highlight that the influencing barriers which include market competition and sensitivity barriers which include organisational readiness are critical for micro-enterprises in the I4.0 adoption. Compared to larger enterprises, micro-enterprises face less impact of prominent barriers which include financial and infrastructural issues. This suggests that micro-enterprises should focus on improving their internal capabilities and flexibilities to respond to market needs and adopt technological advancements. This will help in empowering the micro-enterprises which are significant contributors to the nation's economy.

5.4. Implications

The outcomes of this paper highlight the challenges that enterprises face while integrating Industry 4.0 technologies. The study's assessment of main, influencing, resulting, and sensitivity barriers is helpful information for stakeholders involved in digital transformation initiatives. The research underlines the need to develop a clear digital strategy that is aligned with organizational goals. Managers must prioritize the creation of effective digital strategies to help their companies negotiate the complexities of Industry 4.0 adoption. To ensure the process's success, resource gaps in digital skills and infrastructure must be addressed. To succeed in the digital economy, managers must invest in acquiring information and developing internal talent. However, managers must understand and address the dangers involved with digital transformation.

The gaps in the digital infrastructure and talent requirements should be focused and fulfilled to ensure that the operational efficiency of the micro-enterprises is achieved. The managers should aim to hire the talent skillful in digital and also invest to build the training modules, which will enhance the digital environment. The managers on the other hand should be aware and address the risk related to the digital transformation. Defined steps to mitigate the risk related to security, change management and barriers associated to the adoption of Industry 4.0. Policymaker's role is crucial in promoting and building the environment to adopt Industry 4.0. Financial support, incentives, subsidies and innovation promotion policies can accelerate the digital transitions. One must develop digital literacy and skills for career progress with the rapid technological advancement. Governments can collaborate with academic institutes to provide training programs that can educate the masses and also build digital infrastructures which can provide a fast talent pool to enterprises and boost the process of implementing Industry 4.0 technologies. This will not only benefit the employment of the masses but also boost the economy by empowering enterprises. This strategic allocation of the government's funds, resources and assistance will not only help the enterprises in the adoption of technologies but also build their competitiveness with the global market. It will encourage the setting up of more enterprises, and build an environment of digital transformation and economic growth.

6. CONCLUSION

The paper aimed to empower micro-enterprises by enhancing the Industry 4.0 concept and addressing the issues that can lead to the adoption of Industry 4.0 technologies in micro-enterprises. The study further provides insights towards the adoption of digital transformation of micro-enterprises by analyzing the impact of prominent, influencing, resultant and sensitivity barriers. The analysis highlights the varying impacts of different barriers on the

implementation of Industry 4.0 in enterprises. Prominent and sensitivity barriers are significant factors influencing both the likelihood and extent of Industry 4.0 adoption. Influencing barriers play a critical role in the initial decision to adopt Industry 4.0 but do not significantly impact the extent of implementation once the decision is made. Resulting barriers, however, do not significantly affect Industry 4.0 adoption in any meaningful way. These findings underscore the importance of identifying and addressing specific barriers to facilitate the successful implementation of Industry 4.0. Policymakers and enterprise leaders should focus on mitigating prominent and sensitivity barriers to enhance the adoption and integration of advanced industrial technologies. Additionally, understanding the role of influencing barriers can help in devising strategies that encourage initial I4.0 adoption. By addressing these critical barriers, enterprises can better navigate the challenges of implementing I4.0 and fully realize its potential benefits.

6.1. Limitation and Future Scope

This paper is particularly limited to micro-enterprises as the gathered responses are from 200 various micro-enterprises through online platforms. The limited sample size, emphasizing the Indian micro-enterprises and chances of bias due to the online survey are various limitation factors of the study. These limitations can be addressed to improve the awareness and insights of Industry 4.0 adoptions for micro-enterprises. Enterprises from various sectors, locales and regions should be covered to develop the study. Based on the in-depth assessment and understanding of the impediments, better knowledge of Industry 4.0 dynamics can be drawn which can help in framing effective policies to support and promote the adoption and transformation of the micro-enterprises.

Exploring the future path of Industry 4.0 for micro-enterprise adoption leads to human-machine collaboration and the transition into Industry 5.0. The rise of use of artificial intelligence, automation and robots needs a touch of human elements and insights leading the potential of the topic to Industry 5.0. Changing dynamics between human and technology develops ample scope for this study to explore various dimensions and insights related to human inputs and collaborations with technology. There is a need for the micro-enterprises to adopt the transitions with the rise in technology advancements and changing relations between human and technology. It also builds a necessity for the policymakers, managers and regulators to formulate policies and laws that can encourage the implementation and transition of micro-enterprises towards Industry 4.0. This will not only lead to innovation, improved operational performance, cost-effectiveness manufacturing, increased efficiency, and absorbing changing market needs but also empower the micro-enterprise and strengthen the economy.

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