Jurnal Teknologi Industri Pertanian 35 (3): 217-228, December 2025
DOI: https://doi.org/10.24961/j.tek.ind.pert.2025.35.3.217
ISSN: 0216-3160 EISSN: 2252-3901

KEY DRIVER AND BARRIER OF RUBBER COMPOUND TECHNOLOGY ADOPTION AMONG FINISHED RUBBER PRODUCT SMES: A MULTIPLE CASE STUDIES

FAKTOR PENDORONG DAN PENGHAMBAT ADOPSI TEKNOLOGI KOMPON KARET PADA UKM BARANG JADI KARET: SEBUAH STUDI MULTI-KASUS

Ari Kristiyanto[1)*], Elisa Anggraeni[2)], and Illah Sailah[2)]

[1)]Study Program of Agro-Industrial Engineering, Graduate School, IPB University
Raya Dramaga Street, Bogor 16680, Indonesia
Email: ari.kristiyanto@apps.ipb.ac.id
[2)]Department of Agroindustrial Technology, IPB University, Dramaga, West Java 16680, Indonesia

Paper: Received December 21, 2024; Revised August 26, 2025; Accepted September 21, 2025

ABSTRAK

Penelitian ini menginvestigasi faktor pendorong dan hambatan adopsi teknologi kompon karet pada usaha kecil dan menengah (UKM) dalam sektor barang jadi karet di Indonesia. Posisi Indonesia sebagai produsen karet alam terbesar kedua di dunia menjadikan potensi pertumbuhan di sektor ini perlu direalisasikan. Namun, adopsi teknologi untuk merealisasikan pertumbuhan menjadi tantangan bagi UKM karena sebagian besar UKM fokus pada kendala sumberdaya termasuk persepsi terhadap teknologi, organisasi, dan kondisi lingkungan. Metode penelitian kualitatif dengan pendekatan studi kasus multi-kasus digunakan, dengan data dikumpulkan melalui wawancara semi-terstruktur dengan pemilik UKM atau manajemen puncak. Analisis yang dilakukan melalui within-case analysis dan cross-case anaylsis menunjukkan bahwa kompleksitas teknologi menjadi hambatan signifikan, sementara keahlian manusia menjadi pendorong utama keberhasilan adopsi. Temuan ini menyoroti pentingnya investasi strategis dalam pengembangan sumber daya manusia dan penerapan bertahap untuk mengurangi kompleksitas. Wawasan ini memberikan kontribusi pada literatur yang membahas keberhasilan adopsi teknologi di UKM. Secara manajerial, panduan praktis bagi pembuat kebijakan dan pemimpin industri dalam mendukung UKM guna meningkatkan daya saing dan mendorong pertumbuhan sektor.

Kata kunci: adopsi teknologi, UKM, difusi teknologi, teknologi-organisasi-lingkungan, studi multi kasus

ABSTRACT

This study investigates the drivers and barriers to the adoption of rubber compounding technology among small and medium enterprises (SMEs) in Indonesia's finished rubber product sector. As the world's second-largest natural rubber producer, Indonesia has significant potential for growth in this sector. However, technology adoption in SMEs faces several challenges, primarily due to resource constraints and perceptions of technology, organizational, and environmental conditions. A qualitative multiple case study method was employed, with data collected through semi-structured interviews with business owners or top management. Analysis, conducted through within-case and cross-case comparisons, revealed that while technological complexity acts as a significant barrier, human expertise is a key driver of successful adoption. The findings highlight the importance of strategic investment in human capital and phased implementation strategies to reduce complexity. These insights contribute to discussions on technology adoption success factors in SMEs. Managerially, they provide policymakers and industry leaders with practical guidance on supporting SMEs to enhance competitiveness and drive sector growth.

Keywords**:** technology adoption, SMEs, diffusion of technology, Technology-Organization-Environment, multiple case study

INTRODUCTION

The Plantation sector play an important role in the Indonesian national development by providing employment opportunities and giving the largest contribution to the total national GDP, 3.88% (BPS, 2024). One of contributors from this plantation sector is rubber as Indonesia is the world's second-largest producer and exporter of natural rubber signifying the important of rubber in improving national welfare. Yet, in 2023, natural rubber production decreased by 17,53%, from 2.72 million tons to 2.24 million tons (BPS, 2024). Although there is a surplus of 1.575 million tons of natural rubber export and import volume, the export volume decreased by 13.85% and the import volume has increased by 60.5% in 2023 (BPS, 2024). These conditions call for expansion of downstream rubber industry that requires product lines diversification to reduce import dependency, create employment opportunities and improve farmer's welfare (Perdana, 2020).

The current structure of Indonesia's downstream finished rubber industry is predominantly composed of tire production (50%),

*Coressponding Author

followed by gloves (15%) and other products (35%) (Perdana, 2020). Notably, most of the downstream rubber production, aside from tire manufacturing, operates at a small and medium enterprise (SME) scale, producing approximately 218 types of finished rubber products such as tires, pedal rubbers, wiper blades, footwear, and conveyor belts (Fauzi, 2013). Despite this potential, SMEs in this sector face significant challenges that hinder their growth and productivity. Mastery of this technology allows SMEs to diversify their product offerings and add substantial value to finished goods. For example, investing in downstream technologies can help reduce dependence on single-product markets and create opportunities in areas such as hoses, foam rubber, shoe soles, and automotive spare parts (Fauzi, 2013).

SMEs are mostly unorganized in their manufacturing processes and driven by price sensitivities resulting in focusing on the constraints (Rajkumar and Jadadale, 2024). Further, SMEs face limited financial capacity and access to capital restrict SMEs from investing in advanced technologies (Fauzi, 2013). This leads SMEs to focus less on adopting necessary technologies to meet quality standards efficiently or be better than the competitors. Diffusion of technology has been proposed as a strategy to empower SMEs, allowing them to enhance their capabilities, improve product quality, reduce costs, and enable product diversification (Marizka *et al.,* 2014). Improving the adoption of technology will help the SMEs to improve the quality of their products and cost efficiencies, hence, increase its competitiveness.

In terms of the need to expand of Indonesia's downstream rubber industry, rubber compounding technology is deemed to be critical. Rubber compounding technology, which involves the precise blending of raw materials, is essential for SMEs to enhance their performance and competitiveness (Marizka *et al.,* 2014). The adoption of compounding technology will help meeting the properties of materials to quality standards, better processing requirements and balance between properties and price suitable for industrial and commercial applications (Sisanth *et al.,* 2017; Bandyopadhyay, 2024). Yet, the adoption of technology for SMEs is challenging due to the tendency of SMEs to focus on the limited resources available (Rajkumar and Jadadale, 2024) and the high cost of infrastructure, less technical skills and efficiency, less support from the government, adoption challenges, and lack of organizational support (Shaikh *et al.,* 2021). In adopting technologies, SMEs face challenges that are related to attitude of the employees and owner, budget constraints to cover switching costs, and internal organizational characteristics (Shaikh *et al.,* 2021).

This paper aims at exploring the drivers and barriers to technology adoption among SMEs in Indonesia. Indonesian SMEs play a crucial role in the national economy, contributing to GDP and creating jobs for millions. Yet, many SMEs face major hurdles in adopting new technologies that are essential for staying competitive in a fast-paced digital world. Indonesia ranks low (80 out of 133) in knowledge diffusion, as shown in the Global Innovation Index (WIPO, 2024), highlighting a clear gap. In key sectors like finished rubber manufacturing, low productivity and outdated processes limit growth and efficiency. Many SMEs struggle to adopt advanced technologies, such as rubber compounding, which could improve product quality and streamline operations. This lack of technological integration restricts their capacity to compete and innovate. Understanding the challenges and opportunities around technology adoption is vital to helping SMEs overcome these limitations.

This paper also addresses a critical research gap in understanding the adoption of rubber compounding technology among SMEs in the finished rubber product sector by using an integrated model combining Innovation Diffusion Theory (IDT) and Technology Organization (TOE) framework. Despite the extensive application of these frameworks in other fields, their use in the SMEs, particularly in finished rubber product sector remains limited. Existing literature reveals significant gaps in integrating theoretical and methodological frameworks, with only 39% of studies on SME technology adoption employing theoretical frameworks, and just 6% integrating multiple frameworks like IDT and TOE (Zamani, 2022). This lack of integration underscores the need for a comprehensive approach to studying technology adoption in this context. Thus, this study aims to conduct an exploratory investigation into the adoption of rubber compounding technology among SMEs, focusing on identifying the drivers and barriers influencing their intention to adopt such technology. By applying the integrated IDT-TOE model, this research seeks to provide insights into the technological, organizational, and environmental factors that impact the adoption process and propose strategies for overcoming barriers to facilitate successful implementation in SMEs.

RESEARCH METHOD

This study employs a qualitative approach using a multiple case studies method. The inherent breadth of qualitative research requires an approach that aligns with the study's objectives and scope (Njie and Asimiran, 2014). The case study method, as outlined by Yin (2018) facilitates a detailed and technical examination of phenomena within their actual contexts, particularly when the boundaries between context and phenomena are not distinct. Ensuring the validity and reliability of case study results, procedures from Yin (2009) were used. Construct validity was ensured by identifying appropriate operational measures and developing

conceptual framework before conducting case study and used to develop case study protocol to collect data (Yin, 2009). The conceptual framework was also used to establish relationships between variables and used in within and cross-case analysis to ensure internal validity (Yin, 2009). Reliability was done by ensuring replicability of the case study protocol and develop chain of evidence in the within case analysis and used of multiple sources from interviews, documents and observation (Yin, 2009).

Case Study Stages

The initial stage involved defining and designing the study by developing a conceptual model based on the TOE framework and selecting relevant SMEs for analysis. The second stage focused on preparation, data collection, and within-case analysis. Each case report provided detailed insights into rubber compounding technology, organizational attributes, and the external environment. The final stage comprised cross-case analysis and conclusion drawing, wherein data from the SMEs were compared to identify patterns and variations. This approach allowed for an in-depth understanding of how different TOE factors influenced the technology adoption process. The findings offer practical implications and contribute to theoretical advancements by facilitating conceptual development, providing insights and theory generation, consistent with approach described by Eisenhardt (1989) on explanatory case studies.

Stage 1 : Conceptual Model and Case selections

The adoption of technological innovations is an area of extensive research, with several models developed to understand the factors influencing adoption. These models include the Technology Acceptance Model (TAM) originally developed by Davis (1989), the Theory of Planned Behavior (TPB) developed by Ajzen (1985), the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh *et al.* (2003), the Innovation Diffusion Theory (IDT) by Rogers (2003), and the Technology Organization Environment (TOE) framework by Tornatzky and Fleischer (1990). While TAM, TPB, and UTAUT are commonly applied at the individual level, IDT and TOE are more suitable for exploring technology adoption at the organizational level (Qudrat-Ullah and Khan, 2021). IDT emphasizes that the speed of technological adoption is influenced by attributes such as relative advantage, compatibility, complexity, trialability, and observability (Rogers, 2003). The TOE framework, developed by Tornatzky *et al.* (1990), considers the technological, organizational, and environmental contexts of adoption.

Research indicates that IDT's focus on innovation attributes, such as relative advantage, compatibility, and complexity, is relevant for understanding technology adoption in SMEs (Mamun, 2018). The TOE framework complements this by addressing organizational factors and environmental factors (Awa *et al.,* 2016; Chiu *et al*., 2017). Combining IDT and TOE enables a more holistic analysis of the factors influencing technology adoption in SMEs. The integration of IDT and TOE provides a comprehensive understanding of technology adoption within SMEs, accounting for both internal capabilities and external pressures (Chiu *et al.,* 2017). Integrating these characteristics within the TOE framework allowed for a nuanced examination of the technological determinants impacting SMEs as shown in Figure 1.

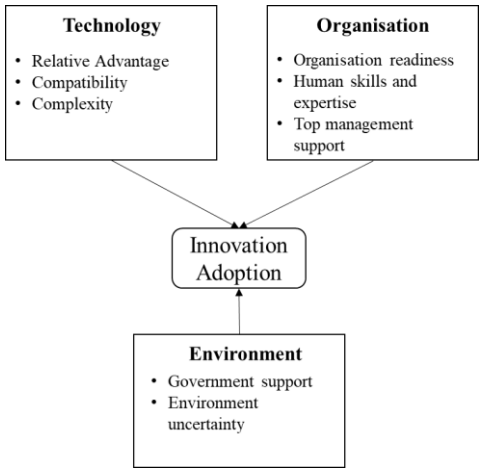

Figure 1. Conceptual framework

Technology Context

The IDT theory, as initially conceptualized by Rogers (2003), posits that the adoption of innovations is influenced by several key attributes of the technology itself, such as relative advantage, compatibility, complexity, trialability, and observability. Integrating these attributes with the TOE framework allows for a detailed examination of the technological determinants that affect adoption within SMEs. Relative advantage, reflects the perceived benefits of an innovation over existing solutions. Research has consistently demonstrated that the greater the perceived relative advantage, the higher the likelihood of adoption by SMEs, as these firms are often driven by efficiency gains and competitive positioning (Ramdani *et al.,* 2009; Kendall *et al.,* 2001; Pathan *et al.,* 2017). Compatibility refers to the degree to which an innovation aligns with the existing values, experiences, and needs of the organization (Rogers, 2003). High compatibility reduces the potential disruptions during integration, thus facilitating smoother adoption processes (Wang *et al.,* 2010; Kendall *et al.,* 2001). Complexity, defined as the perceived difficulty in understanding and using a new technology, often acts as a significant barrier to adoption, particularly in SMEs where technical expertise may be limited. The literature finds that perceived complexity negatively impacts the

likelihood of adoption, as firms may lack the necessary skills and resources to effectively implement and manage complex technologies (Rogers, 2003; Setiyani *et al.,* 2022).

Organization Context

Organizational context plays a crucial role in shaping a firm's capacity to adopt and implement new technologies. Within this context, three primary factors stand out as significant determinants: organizational readiness, human expertise and skills, and top management support. Organizational readiness plays a pivotal role in the successful adoption of technology within firms. It encompasses the financial, human, and technical resources necessary to implement new technologies effectively (Ramdani *et al.* 2009). Studies indicate that high levels of organizational readiness significantly reduce resistance to change and facilitate smoother transitions during technology adoption. For instance, Oliveira *et al.* (2019) emphasize that organizations with adequate resources are better positioned to integrate new technologies seamlessly, thus enhancing their operational capabilities. Similarly, Zhu *et al.* (2006) suggest that organizational readiness is a critical factor in the adoption process, particularly in environments where resource availability is a key determinant of success. Additionally, Fauzi (2013) stated that one of the internal problems faced by the rubber finished goods industry at the SME level is the weakness of the financing sector.

The level of human expertise and skills within an organization is another critical determinant of technology adoption. The need for quality human resources is one of the internal factors that influence the speed of the downstream process in the rubber finished goods industry. A well-skilled workforce is essential for navigating the complexities of new technologies and maximizing their potential benefits. Baig *et al.* (2021) highlights that firms with a high level of technical expertise are better equipped to manage and integrate complex technologies, thereby gaining a competitive advantage. Ferreira and Franco (2019) also underscore the importance of human capital, noting that skilled employees are crucial for fostering innovation and ensuring the successful implementation of new technologies. These findings are consistent with earlier studies, such as those by Ramdani *et al.* (2009), which demonstrate that technical expertise within a firm significantly enhances its ability to adopt and utilize new technologies effectively.

Top management support is crucial in driving the technology adoption process, particularly in small and medium-sized enterprises (SMEs), where decision-making is often centralized. Strong leadership from top management ensures that the necessary resources are allocated and that a clear strategic vision guides the adoption process. Research by Ramdani *et al.* (2009) underscores the importance of top management commitment, highlighting that it is a key factor in overcoming the barriers to technology adoption.

Environmental Context

Environmental context significantly influences the ability of firms, particularly SMEs, to adopt and integrate new technologies. Two critical factors within this context, government support and environmental uncertainty, play essential roles in shaping technology adoption decisions. Government support is a crucial enabler of technology adoption, particularly in developing countries where SMEs often face significant resource constraints. Lack of government incentives, such as subsidies, tax breaks, and favorable policies, can substantially lower the barriers to technology adoption, especially in finished rubber product (Fauzi, 2013). Research by Zhu *et al.* (2006) highlights the importance of governmental interventions in creating an ecosystem that encourages technological advancements, particularly in resource-limited settings. Malik *et al.* (2021) further emphasizes that in developing countries, where financial and technical barriers are more pronounced, government support is often the determining factor in whether SMEs can adopt and implement new technologies effectively.

Environmental uncertainty presents a significant challenge to technology adoption, particularly for SMEs operating in highly volatile markets. This uncertainty, characterized by the unpredictability of external conditions such as market competition, regulatory changes, and shifts in consumer preferences, complicates the decision-making process regarding new technologies (Sharma *et al.,* 2023). As competition intensifies and changes become less predictable, the risks associated with technology adoption increase, leading to more complex and cautious decision-making. Environmental uncertainty arises when managers perceive their business environment or one of its components as unpredictable, creating ambiguity not only about external factors but also about how organizations should operate within the business environment (Milliken, 1987; López-Gamero *et al.,* 2011). This unpredictability makes it difficult for SMEs to assess the potential benefits of new technologies against the heightened risks, often resulting in a more conservative approach to adoption.

Case Selections

Three SMEs were selected to represent different stages and outcomes of technology adoption in the finished rubber product production sector: SME 1 and SME 2 (non-adopters) and SME 3 (adopter). This selection aimed to provide a comparative perspective on how technological, organizational, and environmental factors influence the adoption of rubber compounding technology. SME 1 and SME 2

were chosen due to their reliance on traditional production methods without incorporating rubber compounding technology, while SME 3 represented a successful case of full adoption, offering valuable insights into overcoming barriers and achieving implementation. The companies were located in West Java, with two SMEs in Garut and one in Bandung. Despite the close proximity, only one SME successfully adopted the technology, which helped isolate the influence of location when analyzing drivers and barriers. Data collection was conducted from February to August 2024, focusing on SMEs in the finished rubber sector in West Java.

Stage 2: Data Collection Protocol and within-case analysis

The data collection protocol was structured according to the TOE framework from the previous stage. Data collection protocol was used to guide the development of interview questions and ensure consistency. The interview guide included sections designed to address key aspects of the technological, organizational, and environmental contexts. For the technological context, questions were centered on the perceived complexity, relative advantage, and compatibility of rubber compounding technology. The organizational context section included topics related to human resource capabilities, organizational readiness, and top management support. Lastly, the environmental context encompassed probing questions about external factors such as government support and the uncertainty of external environment. This comprehensive approach ensured that the data collected provided a well-rounded perspective on the factors influencing technology adoption in SMEs.

Data collection involved semi-structured interviews with one key informant from each SME. For SME 1 and SME 2, the informants were the business owners, while for SME 3, the informant was a member of top management. All informants were involved in decision-making regarding the adoption of new technologies. The key informants were interviewed individually, with each session lasting approximately 40-60 minutes. The interviews were recorded using an audio recorder and later transcribed to identify drivers and barriers in each SME. Interviews were conducted on-site, with two SMEs located in Garut and one in Bandung Regency. The transcribed data were used for both within-case and cross-case analyses. In addition to interviews, various sources of information, including company reports and direct observations, were used to construct the profiles of the SMEs.

Each case was analyzed using within-case analysis to develop an in-depth understanding of the unique conditions, challenges, and drivers affecting each SME's approach to technology adoption. This within-case analysis provided detailed insights into how each SME perceived and navigated the technological, organizational, and environmental factors influencing their decisions.

Stage 3: Cross-case Analysis

Following the completion of within-case analyses, cross-case analysis was conducted to identify common themes and patterns across the cases. This process involved comparing data from the SMEs to explore similarities and differences in how technological, organizational, and environmental factors influenced technology adoption. The aim was to uncover underlying trends and derive insights into the collective experiences of the SMEs, which helped to build a more comprehensive understanding of technology adoption dynamics.

The cross-case analysis allowed for the synthesis of findings that highlighted the shared barriers and drivers across the SMEs while noting unique factors that might apply to specific cases. This comparative approach enhanced the robustness of the study's conclusions, as it provided a broader view of the influences at play and helped refine theoretical contributions and practical recommendations.

RESULTS AND DISCUSSION

Within-case Analysis

The within-case analysis provides a detailed examination of the SMEs included in this study, representing both those who have adopted and those who have not adopted new technologies. This analysis allows for a deeper understanding of the specific factors that influence technology adoption decisions, highlighting the diverse challenges and drivers experienced by SMEs in different stages of technology integration.

SME1

SME 1, a finished rubber product manufacturer based in Indonesia, operates with a modest workforce of 7 employees and an initial investment of approximately 300 million rupiah. The company has a production capacity of 320,000 units per day, serving a nationwide market. Despite this potential, SME 1 has yet to adopt rubber compounding technology, a critical innovation that could significantly enhance both production efficiency and product quality.

The primary barrier identified by SME 1 is the perceived complexity of rubber compounding technology. The management expressed significant concerns over the challenges associated with adopting this technology, particularly regarding its complexity. As noted by the management, "For us, compounding technology is very difficult, especially in formulating the composition of chemical materials, and we are not yet familiar with the technology. On a scale of 5, we would rate it 5 out of 5." This indicates a high level of difficulty in integrating the technology into their existing operations, largely due to unfamiliarity with the technological components and the intricate process of

chemical formulation. Additionally, the company highlighted the need for skilled workers to operate this technology effectively: "If we could find human resources with the expertise to use compounding technology, we would certainly consider adopting it." This statement underscores the importance of human expertise as a critical enabler of technology adoption, which SME 1 currently lacks. These statements confirm that perceived complexity negatively impacts the likelihood of adoption (Rogers, 2003; Setiyani *et al.,* 2022). These perceived complexities is highly influenced by the level of skills of labors as the highly skilled labors is one condition for successful technological adaptation in the SMEs (Prasanna *et al.,* 2020)

Furthermore, SME 1's decision-making process is influenced by the competitive environment in which they operate. The company is facing significant market competition, with many competitors offering similar products at lower prices. As noted by the management, "The market competition is very tough right now; many can provide this product at a much lower price." This competitive pressure drives the need for technological upgrades to maintain market position. However, the rapidly changing market dynamics and fluctuations in government regulations introduce a level of environmental dynamism that complicates the timing of such investments. Despite the management's support for adopting the technology as quoted "We, as management, strongly support our company adopting this compounding technology" they remain cautious due to the high risks associated with the complex and dynamic external environment. These statements confirms the need of SMEs to adopt technologies so that they are able to improve product quality and reduce costs and product diversification that are necessary to compete in a tough competitive market (Marizka *et al.,* 2014).

In conclusion, adoption of technology by SME 1 is hindered by its perception that compounding technology is highly complex for their limited skilled workforce and insufficient management support. Further, it is also challenged by its perception that its external environment is highly competitive and has felt pressure from the market. Thus, although they deemed that technological innovation is important to compete, SME 1 needs to focus on the existing constraints in their organization.

SME 2

SME 2, a finished rubber product manufacturer in Indonesia, operates with a workforce of 29 employees and an investment of approximately Rp 1,000,000,000, boasting a production capacity of 1,000,000 units per day to serve the nationwide market. Despite its operational scale, SME 2 has not yet adopted rubber compounding technology, primarily due to the perceived complexity of the technology, which management has rated at a level of 4 out of 5. This high complexity rating reflects their concerns about the technical challenges involved in integrating the technology into their existing processes. The management believes that this could disrupt production and strain their operational capabilities, especially given the current lack of sufficient skilled human resources. This statement also confirms that perceived complexity of the technology hinders the adoption of compounding technology (Rogers 2003; Setiyani *et al.,* 2022)

The company demonstrates strong organizational readiness, particularly in terms of financial preparedness for investing in new technology. However, this readiness faces challenges due to difficulties in sourcing skilled labor, which is essential for effectively implementing and operating the new system. One top manager described the situation, explaining that although the company is financially prepared, they are still searching for suitable compounding technology that aligns with their needs. This pursuit aims to create opportunities for entering the automotive market which is a prospective market. The use of rubber compounding technology will help meeting the quality standards of materials being used in automotive industry (Sisanth *et al.,* 2017; Bandyopadhyay, 2024). This scenario illustrates the gap between financial capability and the availability of both the right technology and skilled labor, which are critical for successful adoption. This also confirms that availability of highly skilled labors is conditional to the adoption of technology (Prasanna *et al.,* 2020).

Furthermore, the competitive environment in which SME 2 operates adds another layer of complexity to their decision-making process. The intense competition in the market compels the company to consider technological upgrades to maintain its competitive edge. However, the risks associated with the technology's complexity and the need for skilled labor pose significant barriers to adoption. The management expressed, "For skilled human resources, it's quite difficult to find, sir, but we will immediately look for skilled workforce if we have decided to invest in this technology." Additionally, the external competitive pressures were emphasized by another quote: "If you enter the rubber business, you need to have strong mental resilience because the competition is very tough." This cautious approach reflects the company's need to balance the potential benefits of technology adoption with the challenges of navigating a highly competitive and dynamic market.

In conclusion, adoption of technology by SME 2 is hindered by its perception that compounding technology is highly complex for their limited skilled workforce and organizational readiness. Further, it is also challenged by its perception that its external environment is highly competitive. Thus, although they deemed that technological innovation is important to compete, SME 2 needs to focus on balancing future

development and the existing constraints in their organization.

SME 3

SME 3, a finished rubber product manufacturer in Indonesia, operates with a workforce of 20 employees and an investment of approximately Rp 1,000,000,000, achieving a production capacity of 1,000,000 units per day. The company has adopted rubber compounding technology but still faces challenges related to its complexity. The management reported that "Initially, it was difficult because we had to experiment a lot until we got it right. However, we still sometimes fail in making rubber compounds. We think we're at level 3 out of 5 with this technology." This statement reflects the ongoing struggle with mastering the technology, which continues to pose challenges even after adoption.

The adoption of this technology by SME 3 can be largely attributed to its skilled workforce. Management underscored the importance of human expertise, noting that having a knowledgeable team is crucial for determining the correct formulas and meeting customer demands. High customer demand often presents challenges, particularly when it comes to producing products that adhere to specific standards and specifications. This scenario emphasizes the vital role of human skills in navigating the complexities of the technology and ensuring that products meet stringent customer requirements.

The competitive market environment adds another layer of complexity to the situation for SME 3. Management noted that intense competition, especially from competitors offering lower prices, has pushed the company to diversify its product range. This competitive pressure drives SME 3 to continuously enhance its processes and expand its offerings, even as it navigates the challenges of adopting new technology. Additionally, the company acknowledges the crucial role of government support in boosting its technological capabilities. Management expressed a desire for government assistance in acquiring knowledge of better formulas to produce high-quality rubber products, emphasizing the need for external support in their innovation efforts. This confirms that the need of government supports in the adoption of technology especially for SMEs (Shaikh *et al.,* 2021).

In conclusion, SME 3 has adopted compounding technology and underlined the importance of the ability of skilled human resources to understand the technology. It plays a crucial role in the adoption of technology. Market competition is perceived to put pressure on the company but opened the opportunity to access government supports that focus on improving competitiveness of finished rubber product SME, especially that SME 3 has higher technological capabilities.

Cross-Case Analysis

In analyzing the cases, several key themes emerged that provide a deeper understanding of the factors influencing technology adoption among SMEs in the rubber manufacturing sector. As shown in Table 1, the cross-case analysis highlights both the common barriers and drivers across the SMEs, as well as the moderating role of environmental factors in the adoption process.

Across the cases analyzed, complexity emerged as the primary barrier to technology adoption, particularly in the context of rubber compounding technology. Both SME 1 and SME 2 perceived the technology as highly complex, rating it 4 out of 5. The intricacies involved in integrating this technology into their existing operations posed significant challenges, particularly in terms of the expertise required to manage it effectively. Even SME 3, which successfully adopted the technology, faced initial difficulties and rated the complexity at level 3 out of 5. This consistent concern about complexity underscores its role as a major deterrent in the technology adoption process within SMEs in the rubber manufacturing sector. It is important to note that observability, compatibility and trialability have not emerged as factors influencing compounding technologies. These might have been caused by the contextual factors such as resource constraints which making the three SMEs to focus on the relative advantage and complexity factors before considering the compatibility, observability and triability. Results of Cross-case analysis presented in Table 1.

Despite the challenges posed by complexity, human expertise and skills were identified as the main drivers that facilitated technology adoption. SME 3, which had successfully adopted the technology, emphasized the critical role of skilled human resources in mastering the complexities of rubber compounding. Similarly, SME 2 recognized the importance of having a capable workforce as a prerequisite for adopting the technology. The emphasis on human expertise across the cases highlights the need for a well-trained and knowledgeable workforce to overcome the barriers associated with technological complexity. These findings signify the importance of the availability of skilled workforce to enable the integration of technology into value creation activities in SMEs (Prasanna *et al.,* 2019). As skilled workforce is a source of internal knowledge necessary for value creation Hurley and 8 Hult, 1998; Nonaka and Takeuchi, 1995), thus, it is important factors influencing technology adoption in SMEs.

Table 1. Results of Cross-case analysis

Context	SME1 (Non-adopter)	SME2 (Non-adopter)	SME 3 (Adopter)
Number of employees	7 employees	29 employees	20 employees
Production size	320,000 units per day Nationwide market	1,000,000 units per day Nationwide market	1,000,000 units per day Nantionwide market
Education level	Elementary to High School.	Elementary to High School.	Elementary to High School.
Technology	Perceived as highly complex (rated 5/5 for difficulty)	High complexity (rated 4/5)	Initial difficulty (rated 3/5) but overcame through trial and adaptation.
Organization	Limited skilled workforce, insufficient management support.	Strong financial readiness but lacks skilled human resources.	Skilled workforce pivotal to adoption, strong organizational readiness.
Environment	High competition and market pressure.	Intense competition, external pressures from regulations and market dynamics.	Competitive environment drives innovation, supported by government programs.
	Complexity Top management Support Human Expertise and skills Market competition	Complexity Organizational readiness Human expertise and skill External competition	Complexity Human Expertise and Skill Market Competition Government Support

The findings align with prior research indicating that the complexity of new technologies can negatively impact inter-organizational trust to implement technology, as it increases transaction costs and complicates relational dynamics (Bruneel *et al.,* 2017). Complexity serves as a significant barrier to technology adoption, contributing to resistance to change within organizations. When new technologies are perceived as complicated or difficult to understand, employees may fear job loss or feel inadequate due to a lack of knowledge. This psychological barrier, combined with bureaucratic resistance and cultural differences, can hinder the acceptance of innovations (Preet and Pal, 2024). The consistent concern about complexity across the cases underscores its role as a major deterrent in the technology adoption process within SMEs in the rubber manufacturing sector.

Environmental dynamism emerged as a new insight in this study, serving as a key moderating factor in the technology adoption process. Environmental dynamism, characterized by frequent and unpredictable changes (Aldrich, 2008; Rosenzweig, 2009), was particularly relevant due to the competitive pressures and regulatory shifts that the SMEs faced. Both SME 1 and SME 3 highlighted how intense competition and significant changes in government regulations impacted their technology adoption decisions. In such volatile environments, rapid changes make it challenging for organizations to accurately assess, forecast, and respond to market demands and regulatory requirements (Patel *et al.,* 2013). To manage these challenges, firms must adapt their structures to handle increased information processing and revise their strategic planning to align with the dynamic environment (Miller and Friesen, 1983).

This study highlights the importance of integrating TOE into IDT by providing a deeper understanding in the role of organizational factors (organizational readiness, expertise, and access to resources), and environmental factors in adopting technology. The perception of technology complexity as a barrier is further exacerbated by non-technical challenges, such as a lack of awareness and knowledge about technology selection and implementation, which accounts for 80% of the barriers to adoption in SMEs (Estrin *et al.,* 2003).

The findings also underscore the critical role of human expertise and technical skills as primary drivers of technology adoption in SMEs. SMEs with a higher level of technical expertise are better equipped to manage and integrate complex technologies, fostering a greater intention to adopt innovations. This aligns with Baig *et al.* (2021), who emphasize the importance of investing in human capital to enable SMEs to navigate technological challenges and enhance organizational knowledge. Skilled employees not only facilitate smoother integration of new technologies but also contribute to overall technological development, positioning SMEs to drive innovation and improve performance (Ferreira and Franco, 2019).

This perspective is further supported by Holford (2020), who highlights that human expertise mitigates risks and enhances creative processes, leading to better organizational outcomes. Studies by Martin *et al.* (2013) and Budiningsih *et al.* (2022) show that educated employees and strong IT capabilities significantly influence ICT adoption and business performance, contributing up to 63.2% of performance attainment. Additionally, skilled human resources foster competitive advantage and sustainability by mastering digital tools and supporting innovative strategies essential for business growth and continuity (Endrawati *et al.,* 2022). These findings emphasize the necessity of prioritizing human capital development to enable SMEs to effectively adopt and leverage technology for long-term success. The role of government to provide highly skilled workshop is crucial.

Managerial Implications

The findings of this study emphasize the need for managers to simplify technology implementation to address the complexity barrier. Selecting user-friendly technologies that align with existing processes is crucial to minimize disruptions. Implementing phased strategies, where complex technologies are broken down into manageable stages, allows employees to adapt gradually, reducing perceived complexity and enhancing the likelihood of successful adoption, especially in dynamic environments where rapid adjustments are essential Dimoso and Utonga, 2024). Additionally, implementing technology scanning is vital for SMEs to manage technology complexity effectively. By actively monitoring technological advancements, SMEs can identify relevant technologies that align with their business needs, simplifying decision-making processes and ensuring a more targeted approach to technology adoption (Dilip, 2015).

Building human capital is also essential for effective technology adoption. The role of technical expertise in successful adoption underscores the importance of comprehensive training programs focused on developing specific technical skills. By fostering a skilled workforce, managers can facilitate smoother adoption processes and improve organizational adaptability to technological advancements, particularly valuable in rapidly changing markets (Baig *et al.,* 2021). Additionally, forming strategic alliances with research institutions, industry associations, or larger firms can help SMEs access external expertise, share resources, and strengthen their innovation capacity (Ferreira and Franco, 2019). This highlights the role of government in facilitating SMEs to access external resources in terms of intellectual assets and highly skilled workforces.

In highly dynamic environments, the complexity of technology adoption necessitates enhanced human expertise and cross-functional collaboration. SMEs must cultivate a collective mindset and move beyond traditional control-based management practices to achieve resilience in navigating unpredictable challenges (Andersen 2020). Business managers can use these findings to allocate resources more efficiently by prioritizing investments in dynamic capabilities such as learning, integration, and coordination, which foster sustainable innovation performance (Taghizadeh *et al.,* 2023). External factors, such as market turbulence and regulatory changes, can significantly influence the effectiveness of dynamic capabilities in driving innovation performance. In turbulent conditions, the ability to coordinate and integrate resources effectively becomes even more critical, enabling SMEs to achieve robustness and adaptability. Thus, in studying technology adoption in SMEs it is important to consider not only the characteristics of technology (Rogers, 2003) but also the organizational factors proposed by TOE framework (Tornatzky and Fleischer, 1990) and environmental factors in terms of the scale and specificity of industrial context.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study conducted an exploratory investigation into the adoption of rubber compounding technology among SMEs in the finished rubber product sector, aiming to identify the drivers and barriers influencing their intention to adopt such technology. The cross-case analysis revealed that technological complexity is a significant barrier to adoption, as indicated by the high complexity ratings reported by SMEs 1 and 2. This finding highlights the challenges associated with integrating advanced technology into existing operations, particularly for SMEs with limited technical capabilities.

Conversely, human expertise and skills emerged as a critical driver for successful technology adoption, as demonstrated by SME 3. This case underscored the essential role of a skilled workforce in overcoming technological complexities and achieving effective implementation. The study also emphasized the role of environmental factors, such as intense market competition and government support, in shaping the decision-making process for technology adoption. These contextual factors influence the ability of SMEs to manage risks, seize opportunities, and adapt to technological changes in a competitive landscape.

This study highlights the importance of integrating the IDT theory with TOE framework in studying technology adoption in SMEs. Characteristics of technology as one factors influencing successful adoption of technology are influenced by organizational factors that facilitate the acquisition of external resources, open access to

sources of competitive advantage outside of the SMEs.

Recomendations

This study, while offering valuable insights into the adoption of rubber compounding technology among SMEs, is limited by its qualitative nature and case-specific findings, which may restrict generalizability. To address this, future research should apply a quantitative approach using Structural Equation Modelling (SEM) to test the relationships identified in this study across a larger sample of SMEs. SEM allows researchers to assess the strength and direction of relationships between variables, offering statistical validation and greater generalizability of findings (Hair *et al.,* 2017; Kline, 2015). By employing a survey-based SEM, future studies can quantitatively examine how perceived complexity, human expertise, and environmental dynamism influence technology adoption, thus providing a broader and more rigorous analysis of the adoption process in the rubber manufacturing sector (Byrne, 2010).

Additionally, conducting experimental studies can further enrich the understanding of technology adoption among SMEs by isolating specific factors and observing their direct effects under controlled conditions. Experimental designs can help identify causality, revealing whether interventions such as training programs or simplified technology interfaces, effectively reduce perceived complexity and enhance adoption rates (Shadish *et al.,* 2002). By simulating real-world conditions in experimental settings, future research can offer actionable insights for policymakers and managers to develop more effective strategies that facilitate technology adoption (de Ruyter *et al.,* 2001).

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