MINISTRY OF FINANCE

UNIVERSITY OF FINANCE – MARKETING

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FACTORS INFLUENCING INDUSTRY 4.0 ADOPTION IN SMALL AND MEDIUM-SIZED ENTERPRISES IN HO CHI MINH CITY: AN INTEGRATION OF TOE-DOI FRAMEWORK

Major: Business Administration

Code: 9340101

SUMMARY OF DOCTORAL THESIS

Ho Chi Minh City, 2026

The thesis was completed at: University of Finance and Marketing
Supervisors 1: Asoc. Prof. Dr. Tran Nguyen Ngoc Anh Thu
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Inpendent reviewer 1: ……..
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Reviewer 1: ……
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The dissertation will be fend before the University-level Thesis Committee at the University of Finance and Marketing.

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PUBLICATIONS RELATED TO DISSERTATION

- **Scientific Research:**
  - *Topic 1: "Factors affecting Organic Food Purchasing Decisions of Kindergartens in Ho Chi Minh City"*

    The role of the PhD candidate in carrying out the research project: Research team leader.

    Implementation – acceptance period: 2017

    Acceptance test result: Third Prize - Ministerial-level student scientific research and First Prize - Young Economic Talent Award of UFM.
  - *Topic 2: "Factors Influencing Digital Transformation Acceptance among Small and Medium-Sized Enterprises in Vietnam". Code: CS-69-22.*

    The role of the PhD candidate in carrying out the research project: Member.

    Implementation – acceptance period: 2022 – 2023.

    Acceptance test result: Pass
- **Published scientific articles related to the research topic:**

  (1) Truong Thi Hong & Tran Nguyen Ngoc Anh Thu. (2024). The Role of Leadership Characteristic: From Readiness to Adoption Industry 4.0 at Small and Medium Enterprises. *Journal of Economy and Focast Review. e-ISSN:2734-9365.*

  (2) Truong Thi Hong & Tran Nguyen Ngoc Anh Thu. (2025). The Impact of Readiness to Industry 4.0 Adoption in Supply Chain Management of Small and Medium Enterprises in Ho Chi Minh City. *Journal of State Management Review. e-ISSN: 2815-5831.*

(3) Truong Thi Hong. (2025). Literature Review of Industry 4.0 Adoption in Small and Medium-Sized Enterprises: A Bibliometric Analysis. *Journal of State Management Review. e-ISSN: 2815-5831*

- **Published another scientific article:**

(1) Truong Thi Hong, & Nguyen Xuan Truong. (2020). Factors affecting organic food purchasing decisions of kindergartens in Ho Chi Minh City. *Journal of Distribution Science*, *18*(7), 73-81.

- **Conference and seminar proceedings:**

(1) National Conference on Logistics and Supply Chain Management 2024 (CLSCM-2024).

Topic: The Impact of Readiness to Industry 4.0 Adoption in Supply Chain Management of Small and Medium Enterprises in Ho Chi Minh

(2) 2019 International Conference on Business and Economic (ICBE 2019).

Topic: Factors Affecting Organic Food Purchasing Decisions of Kindergarten Schools in Ho Chi Minh.

(3) 2017 Student Scientific Research Review Conference.

Topic: Factors affecting organic food purchasing decisions of kindergartens in Ho Chi Minh City.

(4) The 1st National Forum on Organic Agriculture Development: Solutions for Vietnam (2017).

Topic: The organic agricultural market in Vietnam and around the world.

(5) Workshop on Brand Building and Protection – University of Finance and Marketing (October 2017)

Topic: Branding Vietnam's Agricultural Products: A Focus on Collective Brands..

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CHAPTER 1: RESEARCH OVERVIEW

1.1. The necessity of research

1.1.1. About the practical background

In the era of the rapid advancement of Industry 4.0, characterized by the emergence of numerous groundbreaking technologies, there is a profound convergence of knowledge across physical, digital, and biological domains, which exerts a pervasive influence on all sectors, national economies, and industries (Hermann, Pentek, & Otto, 2016). At the core of Industry 4.0 lie technological breakthroughs in fields such as Artificial Intelligence (AI), Robotics, the Internet of Things (IoT), Autonomous Vehicles, 3D Printing, and Nanotechnology (Schwab, 2017). Industry 4.0 optimizes and automates production processes and methods, thereby fostering diverse business models, a new generation of the workforce, and smart factories, while significantly disrupting existing value chains. Furthermore, technological evolution has the potential to enhance the quality, speed, and cost-efficiency of goods, enabling small and medium-sized enterprises (SMEs) to bolster their production capacity and achieve global competitiveness (Elhusseiny & Crispim, 2022).

In Vietnam, according to statistics from the Ministry of Planning and Investment, as of the end of the first quarter of 2025, there are approximately 900,000 enterprises, of which 98% are classified as Small and Medium-Sized Enterprises (SMEs). Specifically, micro-enterprises account for 69.3%, small enterprises represent 24.5%, and only about 3.5% are medium-sized enterprises (Hoang Thi Hong, 2025). Data from the General Statistics Office as of March 2025 further indicates that the private economic sector-with SMEs at its core-consistently plays a pivotal role in socio-economic development. This sector contributes over 50% of the GDP and 30% of the

total state budget revenue, while creating more than 40 million jobs, representing over 82% of the total labor force in the national economy

In Ho Chi Minh City, small and medium-sized enterprises (SMEs) have made substantial contributions to the city's economic growth in recent years. According to 2021 data from the Statistics Office, SMEs account for approximately 98% of the total number of enterprises in the city, generating over 23% of the regional GDP and providing employment for about one-third of the local workforce. Beyond their contribution to urban economic growth, SMEs play a vital role in the sustainable development of the broader Vietnamese economy. According to a report by the Vietnam Chamber of Commerce and Industry (VCCI), Ho Chi Minh City branch, the total investment in digital transformation by SMEs in the city was estimated at 500 billion VND in 2023, representing a 20% increase compared to 2022 (VCCI, 2022). Many enterprises have invested heavily in constructing IT infrastructure, training a digital-ready workforce, and procuring specialized software. Despite this progress, approximately 40% of SMEs in Ho Chi Minh City still encounter significant obstacles in implementing digital transformation due to a lack of financial resources, skilled personnel, and technological expertise. Small-scale enterprises often face difficulties in accessing essential consultancy services and technical support.

The research project, titled “Factors Influencing Industry 4.0 Adoption in Small And Medium-Sized Enterprises in Ho Chi Minh City: An Integration of TOE-DOI Framework” aims to identify and clarify the influencing factors and their respective magnitudes on the adoption of Industry 4.0 within SMEs. Based on these findings, the study proposes managerial implications and policy recommendations to facilitate the development of SMEs in the digital economy.

1.1.2. About the theoretical background

Research on the adoption of Industry 4.0 within small and medium-sized enterprises (SMEs) has garnered increasing academic attention in recent years. Existing literature indicates that SMEs' consideration of Industry 4.0 implementation is primarily driven by potential benefits, such as increased productivity, enhanced operational efficiency, and the expansion of market opportunities (Kharuddin et al., 2015; Horváth & Szabó, 2019; Müller et al., 2018). Conversely, the implementation process is beset by numerous barriers regarding resources, technological capabilities, and managerial competencies. These obstacles diminish organizational readiness and frequently lead to a strategic decision to forego investment in Industry 4.0 applications (Masood & Sonntag, 2020; Jensen et al., 2019).

A systematic review of 62 recent studies reveals a significant surge in research regarding Industry 4.0 adoption since 2020. Geographically, these studies are predominantly concentrated in emerging economies such as India, Malaysia, and China, whereas scholarly contributions from Vietnam remain remarkably limited. Extant literature can be categorized into four primary thematic groups: (1) core concepts and enabling technologies of Industry 4.0; (2) perceived benefits, barriers, and challenges; (3) readiness and maturity models; and (4) determinants of Industry 4.0 adoption and its subsequent impact on the business performance of SMEs. Although the fourth research cluster offers vital avenues for inquiry, empirical investigations into the factors influencing Industry 4.0 adoption within SMEs in emerging markets specifically Vietnam remain sparse.

From a theoretical perspective, existing studies primarily employ the Technology-Organization-Environment (TOE) framework and the Diffusion of Innovation (DOI) theory; however, domestic research has largely utilized these frameworks in isolation. Furthermore, the majority of TOE-based

studies have concentrated on analyzing the direct effects of various factor groups, often failing to fully account for organizational readiness or the underlying indirect transmission mechanisms. Meanwhile, although technology behavior research indicates that attitude plays a crucial mediating role between perception and technology adoption behavior (Davis, 1989), this construct has yet to be comprehensively integrated into the body of literature regarding Industry 4.0 adoption.

Furthermore, while numerous studies have underscored the significance of leadership characteristics in the decision to adopt technological innovations, there remains a notable void in research examining the moderating role of these traits within the relationships between readiness, attitude, and Industry 4.0 adoption among SMEs. Drawing from the aforementioned analysis, the study titled 'Factors Affecting the Adoption of Industry 4.0 in Small and Medium-sized Enterprises in Ho Chi Minh City: An Application of the Integrated TOE-DOI Model' is proposed. This research aims to provide empirical evidence, extend the existing theoretical framework, and offer pertinent managerial implications for SMEs navigating the complexities of the digital economy.

1.1.3. Research gaps

The thesis identifies several research gaps, which are detailed as follows:

The first gap relates to current research trends: In Vietnam, studies examining the factors influencing Industry 4.0 adoption within SMEs remain remarkably scarce, particularly within the rapidly evolving context of the Fourth Industrial Revolution.

The second gap pertains to the theoretical framework: The Technology-Organization-Environment (TOE) and Diffusion of Innovation (DOI)

models have predominantly been applied in isolation within existing literature regarding the adoption of new technological products. To date, there is a significant paucity of domestic research providing a comprehensive assessment of the determinants influencing Industry 4.0 adoption through an integrated TOE-DOI framework.

The third gap concerns the interrelationships between factors: Specifically, the roles of Industry 4.0 readiness and attitude towards adoption as mediating variables. There is a critical need to evaluate how these constructs mediate the influence of internal and external determinants (technological, organizational, and environmental factors) on the actual adoption of Industry 4.0. To date, this mediating mechanism has not been sufficiently addressed in the existing literature.

The fourth research gap pertains to the moderating role of leadership characteristics: This study investigates how the influence of Industry 4.0 readiness and attitude towards adoption on the dependent variable-Industry 4.0 implementation-is moderated by CEO characteristics. This represents a significant novelty of the current research, as this specific moderating mechanism has remained largely unaddressed in previous scholarly literature.

1.2. Objectives and research questions

1.2.1. Research objectives

General objectives:

The overarching objective of this research is to identify and analyze the factors influencing the adoption of Industry 4.0 within small and medium-sized enterprises (SMEs) in Ho Chi Minh City, grounded in an integrated TOE-DOI framework. Based on the empirical findings, the study aims to propose a set of managerial implications to facilitate and

accelerate the implementation of Industry 4.0 among SMEs in the Ho Chi Minh City area.

Specific objectives:

(1) To identify the factors influencing the adoption of Industry 4.0 among small and medium-sized enterprises (SMEs) in Ho Chi Minh City, based on an integrated TOE-DOI framework.

(2) To empirically test the magnitude of influence exerted by factors within the integrated TOE-DOI framework and other determinants on Industry 4.0 adoption among small and medium-sized enterprises (SMEs) in Ho Chi Minh City.

(3) To explore and statistically test the moderating effect of leadership characteristics on the relationships between (i) Industry 4.0 readiness and Industry 4.0 adoption, and (ii) attitude towards adoption and actual Industry 4.0 implementation within SMEs in Ho Chi Minh City.

(4) Proposing actionable managerial implications aimed at fostering the implementation of Industry 4.0 within organizations, thereby enhancing the business performance of Small and Medium-Sized Enterprises (SMEs).

1.2.2. Research questions

(1) Drawing upon the integrated TOE-DOI framework, what are the key factors influencing the adoption of Industry 4.0 among small and medium-sized enterprises (SMEs) in Ho Chi Minh City?

(2) To what extent do the factors within the integrated TOE-DOI framework and other determinants impact the adoption of Industry 4.0 among SMEs in Ho Chi Minh City?

(3) Do leadership characteristics exert a moderating effect on the relationships between (i) Industry 4.0 readiness and Industry 4.0

adoption, and (ii) attitude towards adoption and actual Industry 4.0 implementation within SMEs in Ho Chi Minh City?

(4) What managerial implications can be proposed to foster the adoption and implementation of Industry 4.0 within their respective organizations?

1.3. Research object

- *Research object:*

The research subject of this thesis encompasses the factors influencing Industry 4.0 adoption within small and medium-sized enterprises (SMEs) in Ho Chi Minh City, grounded in an integrated TOE-DOI framework.

- *Survey object:*

Participants for the in-depth interviews in the qualitative research phase include subject-matter experts, comprising researchers and academics in the field of organizational behavior with extensive expertise in the research topic, as well as corporate managers who exert a decisive influence on their organizations' Industry 4.0 adoption decisions.

Participants for the focus group discussions during the qualitative phase comprise key decision-influencers regarding Industry 4.0 adoption within SMEs. This group includes business owners and individuals holding mid-level management positions or higher, who possess the authority to represent their organizations in the research interviews.

The target population for the quantitative research phase consists of small and medium-sized enterprises (SMEs) currently operating in Ho Chi Minh City.

1.4. Research scope

- *Research Content Scope:*

The scope encompasses theoretical and empirical issues related to the determinants influencing Industry 4.0 adoption within Small and Medium-Sized Enterprises (SMEs) in Ho Chi Minh City.

Conceptual Scope: Within the framework of this study, Industry 4.0 adoption in SMEs is conceptually delimited to the implementation and integration of advanced technological solutions into core business and production operations. These include, but are not limited to, generative AI (e.g., ChatGPT), cloud computing, big data analytics, Enterprise Resource Planning (ERP) systems, and AI-integrated management software.

Scope of Research Literature: Given the relative scarcity of empirical evidence regarding Industry 4.0 adoption within the SME sector, and considering the intrinsic links between Industry 4.0, Information Technology (IT), and technological innovation, this study draws upon and synthesizes prior research on IT adoption to delineate the determinants of Industry 4.0 implementation among SMEs in Ho Chi Minh City. The research focuses on aggregating and analyzing theoretical models and empirical studies related to organizational technology acceptance behavior, specifically leveraging the Technology-Organization-Environment (TOE) framework and the Diffusion of Innovations (DOI) theory as the foundational pillars.

- *Spatial Scope:*

The spatial scope is focused on small and medium-sized enterprises (SMEs) in Ho Chi Minh City. Specifically, the criteria for classifying SMEs are based on the Government's Decree No. 80/2021/ND-CP, effective as of October 15, 2021. Furthermore, the administrative boundaries of Ho Chi Minh City are defined in accordance with Resolution No. 1111/NQ-UBTVQH14, dated December 9, 2020.

- *Temporal Scope:*

- Overall Research Period: The study was conducted over a five-year period, spanning from 2020 to 2025.
- Literature Review: The author synthesized and analyzed scholarly works published in reputable journals from 2010 to the present to establish a comprehensive theoretical foundation.
- Qualitative Phase: The qualitative research stage, involving expert interviews and focus group discussions, was carried out between 2023 and 2024.
- Quantitative Phase: Primary data for the quantitative analysis was surveyed and collected during 2024 to ensure the timeliness of the empirical findings.

1.5. Research Methods

This study employs a mixed-methods research design, integrating both qualitative and quantitative approaches. This methodology is considered the most robust framework for determining the impact levels of independent, mediating, and moderating variables, thereby enhancing the overall statistical power and validity of the findings.

1.6. Meaning of the study

1.6.1. Scientific significance

This study extends prior research on Industry 4.0 adoption by shifting the focus toward the context of small and medium-sized enterprises (SMEs) in emerging economies, where empirical evidence remains scarce.

This study proposes an integrated model combining the Technology-Organization-Environment (TOE) framework and the Diffusion of Innovations (DOI) theory. By doing so, it addresses the limitations of single-theory models, which often examine influential factors in isolation.

The study successfully constructs and validates second-order constructs for technological, organizational, and environmental readiness within the Industry 4.0 context, thereby elucidating the multidimensional nature of the readiness concept.

The research findings contribute to the refinement and standardization of measurement scales for Industry 4.0 readiness, thereby establishing a robust theoretical foundation for future scholarly inquiries.

The study provides additional empirical evidence regarding the mediating roles of readiness and attitude toward Industry 4.0 adoption, thereby significantly enhancing the model's explanatory power.

Identifying the moderating role of leadership characteristics extends the existing theoretical framework by integrating behavioral and managerial perspectives into the body of research on Industry 4.0 and digital transformation.

The proposed research model provides a solid theoretical foundation for future studies investigating the impacts and adoption of Industry 4.0 across diverse sectors and industries.

1.6.2. Practical significance

From a practical perspective, the research findings provide scientific evidence that enables SME managers to systematically identify the key determinants influencing Industry 4.0 adoption.

The study demonstrates that effective Industry 4.0 adoption depends not only on the perceived value and benefits of new technologies but also on a synchronized preparation of financial resources, absorptive capacity, top management support, and Information Technology (IT) infrastructure, as well as the ability to leverage external environmental factors. Based on these findings, managers can make informed investment and implementation

decisions, thereby mitigating risks during the transformation process and enhancing the probability of successfully adopting Industry 4.0 solutions.

For policymakers, this research provides valuable empirical evidence to support the formulation and recalibration of policies aimed at promoting Industry 4.0 adoption within the SME sector. Furthermore, the study serves as a useful reference for consultancy firms and technology providers in developing and deploying Industry 4.0 products and services that align with the specific needs and absorptive capacities of small and medium-sized enterprises.

1.7. Research layout

The thesis is structured into five chapters as follows: Chapter 1: Research Overview; Chapter 2: CHAPTER 2: Theoretical Basis and Research Model; Chapter 3: Research Process and Methodology; Chapter 4: Research Results and Discussion; Chapter 5: Conclusions and Managerial Implications

CHAPTER 2: THEORETICAL BASIS AND RESEARCH MODEL

2.1. Concepts

2.1.1. Industry 4.0

The essence of Industry 4.0 is rooted in digital platforms and the integration of smart technologies to optimize production processes and methodologies (Schwab, 2017). Industry 4.0 is characterized by the application of advanced technologies; according to Rüßmann et al. (2015), it comprises nine foundational pillars: Cybersecurity, Simulation, Autonomous Robots, Big Data and Analytics, Cloud Computing, Augmented Reality, the Internet of Things (IoT), Cyber-Physical Systems (CPS), and Horizontal and Vertical System Integration (Machine-to-Machine communication). These

advancements collectively enhance the productivity, efficiency, flexibility, and adaptability of small and medium-sized enterprises (SMEs).

2.1.2. Adoption Industry 4.0 - AD

Industry 4.0 adoption in the context of SMEs refers to the integration of superior and groundbreaking technological advancements into their operational, organizational, and production activities (Parhi et al., 2022).

2.1.3. Small and Medium Enterprise - SMEs

In Vietnam, according to the Law on Support for Small and Medium-Sized Enterprises (2017), small and medium-sized enterprises (SMEs) encompass micro, small, and medium enterprises. These entities are characterized by an average annual number of employees participating in social insurance not exceeding 200 and must satisfy one of two criteria: (1) total capital not exceeding 100 billion VND, or (2) total revenue of the preceding year not exceeding 300 billion VND. Micro, small, and medium enterprises are further classified by sectors, including Agriculture, Forestry, and Fisheries; Industry and Construction; and Trade and Services (Government, 2017). For the purpose of this study, the criteria for identifying SMEs are based on the Government's Decree No. 80/2021/ND-CP.

2.2. Foundational theories

2.2.1. Theory of Planned Behaviour - TPB

The Theory of Planned Behavior (TPB), developed by Ajzen (1991) as an extension of the Theory of Reasoned Action (Ajzen & Fishbein, 1975), posits that a specific behavior can be predicted or explained by the intention to perform that behavior. According to TPB, intention is assumed to capture motivational factors and is defined as the intensity of an individual’s effort to execute a behavior. As the most proximal antecedent of behavior, intention

is, in turn, predicted by three core determinants: Attitude Toward Behavior (AB), Subjective Norm (SN), and Perceived Behavioral Control (PBC).

2.2.2. Technology Acceptance Model - TAM

The Technology Acceptance Model (TAM), originally introduced by Davis in 1985, is grounded in two foundational theories: the Theory of Reasoned Action (TRA) and the Theory of Planned Behavior (TPB), to predict the adoption behavior of information technology systems. Within the TAM framework, the key constructions employed to explain and predict technology usage behavior include Perceived Usefulness (PU), Perceived Ease of Use (PEOU), and Attitude Toward Using.

2.2.3. Diffusion of Innovation - DOI

The Diffusion of Innovations (DOI) theory is a seminal framework in the field of communication studies, developed by Everett Rogers in 1962 through a synthesis of 508 studies to explain the mechanisms by which innovations spread and are adopted within communities and organizations. This theory posits that organizational innovativeness is influenced by individual characteristics, internal structures, and external contexts, while emphasizing the pivotal role of technological attributes and user perceptions in adoption decisions aimed at enhancing operational performance (Teo et al., 2003). According to Rogers and Shoemaker (1971), five perceived attributes of an innovation-relative advantage, compatibility, complexity, trialability, and observability-are the key determinants affecting the rate and speed of adoption. Furthermore, the innovation-decision process unfolds through five distinct stages: knowledge, persuasion, decision, implementation, and confirmation, reflecting the transition from initial awareness to the final acceptance or rejection of an innovation (Rogers, 1983; 2003).

2.2.4. Technology - Organization - Environment Framework (TOE)

The Technology-Organization-Environment (TOE) framework is one of the most widely utilized theoretical models for examining technology adoption behavior at the organizational level. Originally developed by Tornatzky and Fleischer (1990), the TOE framework identifies three distinct contexts that influence the process of adopting and implementing technological innovations: technological, organizational, and environmental contexts. The technological context, which is deeply rooted in the Diffusion of Innovations (DOI) theory, the Technology Acceptance Model (TAM), and the Theory of Planned Behavior (TPB), encompasses both the existing internal technologies within the firm and the pool of external technologies available in the marketplace (Chang et al., 2020). The organizational context pertains to the firm's scope, size, and managerial structure. Lastly, the environmental context refers to the external arena in which the firm conducts its business, being shaped by competitors and government policies and regulations (Tornatzky, Fleischer, & Chakrabarti, 1990).

2.2.5. Integration of TOE-DOI framework

Traditional technology acceptance models, such as TRA, TPB, TAM, and UTAUT, primarily explain adoption behavior at the individual level, thus exhibiting limitations when applied to organizational-level research. In the context of SMEs implementing Industry 4.0, integrating the Technology-Organization-Environment (TOE) framework with the Diffusion of Innovations (DOI) theory is highly appropriate. These two theories complement each other in elucidating the determinants of firm-level technology adoption decisions. While the TOE framework allows for a concurrent analysis of technological, organizational, and environmental factors, DOI clarifies the role of innovation characteristics-namely relative advantage, compatibility, complexity, trialability, and observability.

Integrating DOI attributes into the technological context of TOE facilitates the construction of a comprehensive analytical model that better explains the readiness and Industry 4.0 adoption decisions of SMEs, particularly within the context of developing economies.

2.3. Relevant Empirical Research

Empirical studies on Industry 4.0 adoption within the SME sector remain sparse and tend to focus in isolation on specific technological products, such as cloud computing, big data, virtual reality, augmented reality (AR), enterprise resource planning (ERP) systems, and blockchain. A comprehensive literature review and critical analysis reveal that:

International studies predominantly adopt the TOE, DOI, and RBV frameworks, or integrated models. Findings indicate that Industry 4.0 adoption in SMEs is simultaneously influenced by three primary clusters of factors. First, technological factors-such as relative advantage, compatibility, complexity, trialability, and security risks-significantly impact technology adoption. Second, organizational factors, particularly technological capability, financial resources, personnel skills, and top management support, play a pivotal role in driving readiness and implementation. Third, environmental factors, including competitive pressure, vendor support, regulatory frameworks, and government policies, exert a substantial influence on the adoption process. Recent scholarship emphasizes that no single factor dictates success; rather, a dynamic combination of multiple factors is required, with leadership roles, technological competence, and external support being paramount. Nevertheless, many existing studies remain conceptual or based solely on literature reviews, lacking comprehensive validation through empirical data.

Domestic research focuses extensively on digital transformation, big data, cloud computing, and Industry 4.0 within the context of Vietnamese

SMEs, primarily utilizing the TOE, DOI, and TAM frameworks or integrated models. Findings indicate that factors such as relative advantage, technological infrastructure, organizational capability, competitive pressure, and support from both leadership and the government exert positive influences on adoption decisions and the extent of technology integration. Concurrently, numerous studies point out that Vietnamese SMEs face significant constraints regarding financial resources, human capital, technology, and external support, resulting in a relatively low level of Industry 4.0 readiness and implementation.

Despite their significant contributions, previous studies exhibit several limitations, including a narrow research scope that focuses on isolated technologies, a lack of integrated models that concurrently examine the roles of readiness, attitudes, leadership characteristics, and contextual factors, and an insufficient clarification of the magnitude and mechanisms of impact for each factor within the specific context of Vietnamese SMEs. Consequently, developing and validating an integrated research model to analyze the factors influencing Industry 4.0 adoption among SMEs in Ho Chi Minh City is essential, offering both substantial theoretical contributions and practical significance.

2.4. Concepts within the Research Model

2.4.1. Technological Readiness - TR

Technological readiness is defined as the preparedness to enhance existing technological standards and embark on the adoption of higher-level technologies (Ismail et al., 2023; Nugroho & Fajar, 2017). In analyzing the components of technological readiness, this study identifies four primary dimensions: relative advantage, compatibility, trialability, and perceived security/safety, which are inherited from the DOI theory and the empirical findings of Maroufkhani, Wan Ismail, and Ghobakhloo (2020).

Consequently, the concept of technological readiness serves as a measurement framework grounded in the TOE theoretical context (Sari & Santoso, 2020).

2.4.2. Organization Readiness - OR

In this study, organizational readiness is conceptualized as the extent to which SMEs possess comprehensive access to financial capital, skilled personnel, knowledge resources, analytical capabilities, and the necessary infrastructure to maximize the potential of Industry 4.0 technologies. The measurement components of the organizational readiness construct include: Top management support, Absorptive capacity, Financial resources, and Information Technology infrastructure.

2.4.3. Environment Readiness - ER

Environmental readiness refers to the extent to which users within an organization are prepared and willing to adopt technology due to perceived external pressures (Yang et al., 2015). In the study by Maroufkhani, Wan Ismail, and Ghobakhloo (2020), competitive pressure, external support, and government regulations or support are identified as the constituent factors measuring environmental readiness, which influence the adoption of Industry 4.0 technologies among small and medium-sized enterprises

2.4.4. Industry 4.0 readiness level - RL

Industry 4.0 readiness refers to an organization's propensity to embrace and utilize emerging technologies. In this study, Industry 4.0 readiness is defined as the preparedness of enterprises for the digital transformation process towards Industry 4.0, specifically regarding management commitment, operational resources, and technological requirements. This readiness level is evaluated and analyzed through the foundational TOE framework, encompassing three dimensions: technological readiness,

organizational readiness, and environmental readiness (Sari & Santoso, 2020).

2.4.5. Attitude toward adoption Industry 4.0 - AT

Behavioral attitude refers to an individual's positive or negative feelings regarding the performance of a target behavior (Fishbein & Ajzen, 1975). Attitude toward technology usage is defined as an individual's overall affective reaction to using a system (Venkatesh et al., 2003). Consequently, attitude is the product of behavioral beliefs and the evaluation of outcomes (Ajzen & Fishbein, 2005). Attitude can be categorized into three domains: affective attitude, cognitive attitude, and behavioral attitude.

2.4.6. CEO Characteristics - CEO

In prior studies concerning small and medium-sized enterprises, CEOs are identified as pivotal decision-makers, often fulfilling the dual role of both manager and owner (Thong & Yap, 1995). Specifically, since CEOs directly determine the strategic direction of SMEs, their individual characteristics are considered critical factors in driving innovative changes within these organizations (Yoon, Lim, & Park, 2020). In this study, leadership characteristics are examined through two primary dimensions: the CEO's innovativeness and the CEO's knowledge of Industry 4.0 (Thong & Yap, 1995).

2.5. Hypotheses research

H1a: Technological readiness has a positive impact on Industry 4.0 readiness.

H1b: Technological readiness has a positive impact on attitudes toward Industry 4.0 adoption.

H2a: Organizational readiness has a positive impact on Industry 4.0 readiness.

H2b: Organizational readiness has a positive impact on attitudes toward Industry 4.0 adoption.

H3a: Environmental readiness has a positive impact on Industry 4.0 readiness.

H3b: Environmental readiness has a positive impact on attitudes toward Industry 4.0 adoption.

H4a: Industry 4.0 readiness positively influences attitudes toward Industry 4.0 adoption.

H4b: Industry 4.0 readiness positively influences Industry 4.0 adoption.

H5: Attitudes toward Industry 4.0 adoption have a positive impact on Industry 4.0 adoption.

H6a: Leadership characteristics positively moderate the relationship between Industry 4.0 readiness and Industry 4.0 adoption.

H6b: Leadership characteristics positively moderate the relationship between attitudes toward Industry 4.0 adoption and Industry 4.0 adoption

2.6. Proposed research model

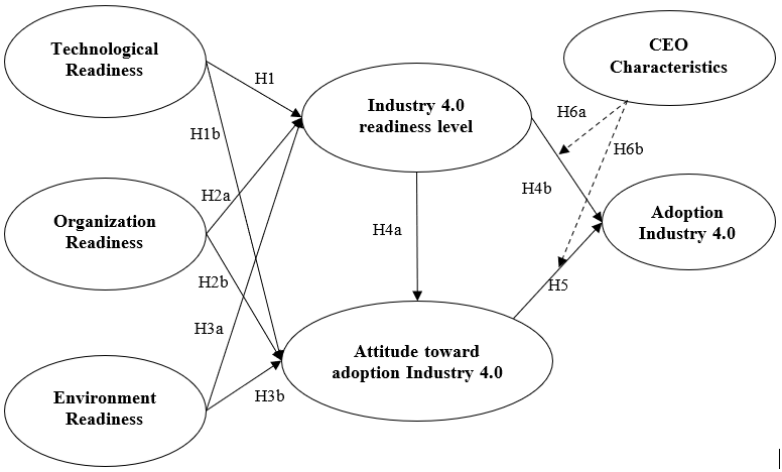

Figure 1: Proposed Research Model

CHAPTER 3: RESEARCH PROCESS AND METHODOLOGY

3.1. Research Process

The research process of this dissertation is implemented through three primary stages: Stage 1: Literature review and qualitative research; Stage 2: Preliminary quantitative research; and Stage 3: Formal quantitative research.

3.2. Scales Design

In this research, technological readiness, organizational readiness, and environmental readiness are conceptualized as second-order constructs, adapted and developed from the original scales of Yang et al. (2015) and Polites, Roberts, and Thatcher (2012). Technological readiness comprises four primary components: relative advantage, compatibility, trialability (Agrawal, 2015; AlBar & Hoque, 2019), and perceived security/safety (Lutfi et al., 2022). Similarly, organizational readiness consists of four key dimensions: top management support, absorptive capacity (Agostini &

Nosella, 2019; AlBar & Hoque, 2019; Ooi et al., 2018; Premkumar & Roberts, 1999), financial resources, and IT infrastructure (AlBar & Hoque, 2019; Premkumar & Ramamurthy, 1995). Environmental readiness is measured through three core elements: government support, competitive pressure, and external support (Agrawal, 2015; AlBar & Hoque, 2019; Lutfi et al., 2022). For the first-order constructs-including Industry 4.0 readiness, attitudes toward Industry 4.0 adoption, Industry 4.0 adoption, and leadership characteristics-the measurement scales are inherited from Jensen et al. (2019), Chen et al. (2015), Virmani et al. (2023), Yoon, Lim, and Park (2020), and Yap and Thong (1995).

3.3. Qualitative research

Participants for the qualitative study were selected using a purposive sampling technique. The researcher conducted in-depth interviews with seven experts and a focus group discussion with nine business managers. The qualitative findings resulted in the development of a measurement instrument comprising 66 observed variables to measure 16 research constructs, which were subsequently utilized in the preliminary quantitative research stage.

3.4. Quantitative research

This process encompasses the design of the survey instrument, data collection, and data analysis for both the preliminary and formal quantitative stages. Data were collected using non-probability sampling techniques-specifically, judgmental sampling for the preliminary quantitative stage and convenience sampling for the formal stage. Data analysis was conducted using SmartPLS 4.1.0.0 software and the PLS-SEM technique, which consists of two phases: assessment of the measurement model (evaluating scale reliability, convergent validity, and discriminant validity) and assessment of the structural model (evaluating multi-collinearity issues, examining the coefficient of determination R^2, estimating path coefficients,

effect size f^2, out-of-sample predictive power Q^2, NFI, and SRMR values, as well as testing for mediating and moderating effects).

3.5. Preliminary quantitative research results

Based on the preliminary quantitative research involving 188 observations processed via SmartPLS software, the evaluation results confirmed that the measurement scales achieved the requisite reliability and validity to proceed to the formal study. The preliminary data analysis resulted in the retention of 3 second-order constructs and 15 first-order constructs, with 64 observed variables maintained for the formal research phase. Two items, namely AC2 and CEO1, were excluded as they failed to meet the necessary psychometric requirements.

CHAPTER 4: RESEARCH RESULTS AND DISCUSCION

4.1. Descriptive statistics results

The survey yielded a total of 458 responses, which were screened to retain 353 valid cases for further analysis. Descriptive statistical analysis was conducted to profile the participating enterprises. Regarding organizational age, SMEs operating for less than 2 years accounted for 14.73%; those between 2 and 5 years represented 32.58%; those from 5 to under 10 years constituted the largest group at 39.38%; and finally, SMEs with 10 years or more of operation accounted for 13.31%. In terms of firm size by labor force, 29.18% of the SMEs employed fewer than 10 people, while 45.04% had between 10 and under 50 employees. SMEs with 50 to 200 employees represented 25.78%. Regarding total annual capital, the category of under 3 billion VND held the highest proportion at 47.31%, followed by capital ranging from 3 billion to under 20 billion VND (33.71%), and 20 billion to under 50 billion VND (15.30%). Concerning annual revenue, most surveyed SMEs reported earnings under 3 billion VND (39.94%), followed by 3

billion to 10 billion VND (30.88%), and 10 billion to 50 billion VND (13.88%). Regarding business sectors, the survey recorded 4.53% in Agriculture, Forestry, and Fisheries; 62.61% in Trade and Services; and 19.55% operating in both Industry and Services. Finally, in terms of market scope, 70.54% of SMEs operated exclusively in the domestic market, 6.80% in foreign markets, and 22.66% in both domestic and international markets.

4.2. Evaluation of the measurement model

Measurement Model Assessment: The results indicate that all outer loadings and Composite Reliability (CR) values for the observed variables exceed the threshold of 0.7. Therefore, the measurement scales demonstrate high internal consistency reliability.

Convergent Validity Assessment: The results show that the Average Variance Extracted (AVE) values for the constructs range from 0.608 to 0.721, all of which exceed the recommended threshold of 0.5. Consequently, the measurement scales satisfy the requirements for convergent validity.

Discriminant Validity Assessment: The discriminant validity of the measurement scales was assessed using the Fornell-Larcker criterion. The results indicate that the square root of the Average Variance Extracted (AVE) for each construct exceeds its highest correlation with any other construct. These findings confirm that all constructs in the model satisfy the requirements for discriminant validity.

4.3. Evaluation of structural model

Collinearity Assessment: The evaluation of potential multi-collinearity issues among the observed variables within the model indicates that all Variance Inflation Factor (VIF) values are below the threshold of 5. Consequently, it can be concluded that the measurement items are free from

collinearity concerns, ensuring the robustness of the structural model estimation.

Structural Model Assessment: The results of the structural model estimation and hypothesis testing indicate that all hypotheses-namely H1a, H1b, H2a, H2b, H3a, H3b, H4a, H4b, and H5-are supported at a significance level of 0.05 ($p < 0.05$).

Assessment of the Coefficient of Determination (R^2): The adjusted R^2 value for the dependent variable, Industry 4.0 adoption, indicates that the model explains 60.10% of its variance. Furthermore, the combination of technological readiness, organizational readiness, and environmental readiness accounts for 66.80% of the variance in attitudes toward adoption and 69% of the variance in organizational readiness for Industry 4.0.

Assessment of Effect Size (f^2): The results indicate that Industry 4.0 readiness and attitudes toward Industry 4.0 adoption exert a medium effect on Industry 4.0 adoption. Similarly, technological readiness and environmental readiness exhibit a medium effect on Industry 4.0 readiness. The remaining structural relationships in the model are found to have a small effect size.

Assessment of Out-of-Sample Predictive Power (Q^2): The Q^2 values indicate that the model possesses a moderate level of out-of-sample predictive relevance. Specifically, the strongest predictive power is observed in the model segment containing Industry 4.0 readiness, which yielded the highest Q^2 value ($Q^2 = 0.480$).

Model Fit Indices (NFI and SRMR): The estimated model achieved an SRMR value of 0.053, which is below the 0.08 threshold (Hu & Bentler, 1999), indicating a low level of standardized residuals between the empirical correlation matrix and the model-predicted matrix. Furthermore, the model's

Normed Fit Index (NFI) reached 0.889, representing a fairly good fit that closely approaches the ideal standard. Consequently, these results demonstrate that the research model possesses a high degree of goodness-of-fit with the empirical data, ensuring the overall reliability of the findings.

4.4. Testing the mediating role of Industry 4.0 Readiness and Attitude Towards Industry 4.0 Adoption

Based on the results of specific and total indirect effects, all p-values are below the 0.05 threshold. These findings confirm that Industry 4.0 readiness (RL) and attitudes toward Industry 4.0 adoption (AT) play significant mediating roles in the relationships between technological readiness (TR), organizational readiness (OR), environmental readiness (ER), and Industry 4.0 adoption (AD).

4.5. Testing the Moderating Role of CEO Characteristics

The p-values from the t-test for the interaction effects of CEO x RL -> AD and CEO x AT -> AD were 0.000 and 0.040, respectively, both of which are below the 0.05 threshold. These results indicate that the moderating effects are statistically significant. Consequently, hypotheses H6a and H6b are supported.

4.6. Discusion of research results

4.6.1. Discussion on first-order scales and second-order construct dimensions

Theoretical foundations and previous empirical studies have provided robust support for conceptualizing technological readiness, organizational readiness, and environmental readiness as second-order constructs. The measurement scale analysis further confirms that these are complex constructs measured through various underlying dimensions. The measurement model assessment for both first-order and second-order

constructs demonstrates that the scales achieved high levels of reliability and validity, specifically in terms of convergent validity, discriminant validity, unidimensionality, content validity, and nomological validity. Furthermore, no multi-collinearity violations were detected between the first-order and second-order constructs. Compared to previous studies such as Abbasi et al. (2022) and Maroufkhani et al. (2020), which often measure these readiness factors as individual first-order constructs, this research introduces the use of second-order scales within the context of organizational Industry 4.0 adoption. This represents a significant theoretical contribution, offering the advantage of reducing the number of hypotheses and model complexity. Consequently, this approach adheres to the principle of parsimony in scientific research while still effectively achieving the research objectives.

4.6.2. Discussion of research hypothesis testing results

The research proposed 11 hypotheses, all of which (11/11) were supported at the 0.05 significance level through structural equation modeling (SEM) analysis. The acceptance of hypotheses H1a, H2a, and H3a indicates that higher levels of technological, organizational, and environmental readiness lead to greater Industry 4.0 readiness among SMEs. Technological readiness, measured through relative advantage, compatibility, trialability, and perceived security/safety, plays a crucial role. When SMEs perceive the benefits of new technologies-such as improved risk management, increased flexibility in response to environmental changes, cost reduction, timely service delivery, and enhanced business performance-their readiness increases. Furthermore, the ability to experiment with and trial new technologies positions an organization as a pioneer in innovative thinking. Ensuring high standards of security and safety mitigates concerns regarding data vulnerability, thereby fostering confidence in adoption. Additionally, when new technologies align with the existing values, operational

regulations, and infrastructure of the organization, SMEs exhibit higher confidence and readiness for implementation (Samaranayake, Ramanathan, & Laosirihongthong, 2017).

Organizations play a pivotal role in ensuring well-established business operations; therefore, assessing organizational readiness is crucial to understanding how SMEs should prepare for the major shifts associated with Industry 4.0 implementation, thereby mitigating potential risks of failure. Organizational factors, such as top management support, organizational competence, and absorptive capacity, underscore the critical role of internal dynamics in determining the Industry 4.0 readiness level of SMEs. Organizational readiness for Industry 4.0 depends heavily on the continuous support from senior management and firm leadership. Researchers argue that a key determinant of Industry 4.0 readiness is the appropriate level of support from top managers (Jensen et al., 2019), who act as catalysts in promoting the necessary knowledge and vision for Industry 4.0 adoption within the organization.

Environmental readiness and Industry 4.0 readiness are closely intertwined. The business environment presents both challenges and opportunities, requiring organizations to proactively adapt their operations to meet external demands. The interaction between an enterprise's internal and external environments significantly influences its readiness for Industry 4.0. Specifically, SMEs become more prepared for Industry 4.0 under the influence of external factors such as competitive pressure, government support, and external assistance from suppliers and partners. Prior studies have confirmed that the level of Industry 4.0 readiness is substantially affected by environmental factors, which can act as either barriers or catalysts. Governments, therefore, play a vital role in encouraging and supporting SMEs by providing guidance on management, technology, and

organizational adaptability to ensure a smooth transition to Industry 4.0 (Sari & Santoso, 2020).

The empirical support for hypotheses H1b, H2b, and H3b substantiates that technological, organizational, and environmental readiness act as significant antecedents to a positive attitude toward Industry 4.0 adoption among SMEs. These findings are consistent with Bakar et al. (2020), who demonstrated that specific dimensions of the TOE framework exert a positive influence on organizational attitudes. Specifically, when an organization perceives that Industry 4.0 integration yields strategic benefits and that adopting new technologies enhances employee job satisfaction and operational efficiency, it fosters a favorable disposition toward deployment. Furthermore, government support serves as a critical external catalyst; by implementing conducive policies and incentive schemes, authorities can effectively stimulate a pro-adoption mindset within SMEs. Finally, the steadfast commitment of top management functions as a vital internal driver, reinforcing a positive organizational attitude toward the digital transformation journey.

The empirical support for hypotheses H4a and H4b demonstrates that Industry 4.0 readiness exerts a positive influence on both the attitude toward and the actual adoption of Industry 4.0 within SMEs. These findings align with the research by Yang et al. (2015), where readiness is conceptualized as both a precursor and a link between the TOE dimensions and technology integration. In this context, an organization's Industry 4.0 readiness typically serves as a direct predictor of actual implementation. Prior to organizational adoption, the entire deployment process is contingent upon readiness factors that catalyze the decision-making process. Consequently, a higher degree and broader scope of readiness translate into a more extensive level of Industry 4.0 practice within the firm (Jensen et al., 2019).

Giả thuyết H5 được chấp nhận cho thấy thái độ đối với ứng dụng công nghiệp 4.0 có vai trò quan trọng, ảnh hưởng tích cực đến việc ứng dụng công nghiệp 4.0 của các SMEs. Thái độ tích cực của tổ chức đối với công nghiệp 4.0 có thể thúc đẩy mạnh mẽ việc ứng dụng công nghiệp 4.0 của tổ chức. Điều này phù hợp với các tài liệu nghiên cứu trước đây của Bakar và cộng sự (2020); Huynh và Nguyen (2024). Theo nội dung mô hình chấp nhận công nghệ TAM mở rộng (Davis, Bagozzi, & Warshaw, 1989) thái độ đối với việc áp dụng ảnh hưởng đến hành vi sử dụng thực sự. Tổ chức và nhân viên trong tổ chức có nhiều khả năng thực hiện một hành vi nếu họ có thái độ tích cực (Bakar và cộng sự, 2020).

The empirical confirmation of hypotheses H6a and H6b substantiates the significant moderating role of CEO characteristics. These results underscore that Industry 4.0 adoption is not merely a function of resource and technological readiness; rather, it is heavily contingent upon leadership attributes. Specifically, the organization's readiness levels and positive attitudes only achieve their full potential when reinforced by the strategic mindset, professional competence, and steadfast commitment of top leadership. This highlights a synergistic effect where leadership characteristics act as a critical catalyst, amplifying the impact of organizational preparedness on the successful implementation of Industry 4.0.

CHAPTER 5: CONCLUSION AND MANAGERIAL IMPLICATIONS

5.1. Conclusion

The integrated TOE-DOI framework has been validated as an appropriate model for this study and for addressing critical domains related to Industry 4.0 adoption within SMEs. Building upon the scales developed during the qualitative phase, which comprised 66 observed variables, a pilot

quantitative study with 188 samples was conducted for preliminary scale validation. The pilot analysis resulted in the retention of 64 indicators across 15 first-order constructs, with 2 items being excluded. These refined scales served as the foundation for the formal survey instrument. The primary research phase utilized a dataset of 353 SMEs in Ho Chi Minh City. Results from the formal measurement model assessment led to no further item deletions, maintaining a structural framework of 3 second-order constructs and 15 first-order constructs measured by 64 variables. Finally, the structural model estimation confirmed that all 11 proposed hypotheses were supported at a statistical significance level of $p < 0.05$.

5.2. Theoretical Implications

Built upon the integrated TOE and DOI theoretical framework, this study provides robust empirical evidence identifying the causal relationships between technological, organizational, and environmental readiness and their impact on Industry 4.0 readiness, attitudes toward adoption, and actual implementation among SMEs in Ho Chi Minh City. The findings reveal that Industry 4.0 readiness exerts a positive influence on organizational adoption. Furthermore, SMEs demonstrate a genuine preparedness and a favorable attitude toward deployment only when they have attained readiness across all three dimensions: technology, organization, and environment. Notably, when top management exhibits innovativeness, technological expertise, and a supportive mindset, the transition from readiness to actual implementation is significantly amplified. These results contribute to addressing the existing gaps within the TOE and DOI frameworks regarding new technology adoption. Given that environmental factors positively influence organizational readiness, support from community organizations and stakeholders is vital in encouraging SMEs to embrace Industry 4.0. Finally,

policymakers and managers should prioritize employee training programs to enhance organizational competence for successful Industry 4.0 integration.

5.3. Managerial implication

5.3.1. Managerial implications from the results of Technology Readiness influence testing

SMEs exhibit a relatively high level of technological readiness for Industry 4.0 adoption. However, to transition from readiness to effective and sustainable implementation, SME managers must prioritize leveraging relative advantages, ensuring compatibility with existing resources, expanding controlled trialability, and proactively managing security risks. These represent key strategic directions for SMEs to enhance their competitive advantage within the digital transformation and Industry 4.0 landscape. To further bolster technological readiness, Industry 4.0 solutions must be compatible with SMEs' current platforms and resources; companies must also develop a profound understanding of the tangible benefits of Industry 4.0 while addressing perceived data security and safety concerns. Moreover, promoting organizational technological readiness can be achieved by providing pilot versions and trial implementations. Based on these findings, technology providers and developers have a solid foundation to refine and customize their products to better suit the specific needs of SMEs.

5.3.2. Managerial implications from the results of Organizational Readiness influence testing

It is evident that SMEs possess a relatively favorable level of organizational readiness for Industry 4.0 adoption, particularly concerning leadership awareness, commitment, and absorptive capacity. However, to enhance adoption effectiveness and foster sustainable competitive advantages, these enterprises must strengthen the guiding role of top

management, develop high-quality human resources, optimize financial allocation, and incrementally modernize IT infrastructure tailored to their specific characteristics. SME leadership serves as the strategic beacon, motivating and driving the implementation of new technologies. Top management support extends beyond financial provision; it encompasses strategic commitment, change management proficiency, and the cultivation of an environment conducive to Industry 4.0 innovation. Consequently, empowering leaders is essential to accelerating Industry 4.0 deployment. Furthermore, organizations should establish specialized training programs to equip employees with the necessary knowledge and skills for integrating new technological products. Building an innovative culture that encourages experimentation and continuous learning is equally vital. Given that Industry 4.0 implementation requires meticulous preparation of financial and IT infrastructure, SMEs must strategically identify investment priorities based on long-term benefits and financial feasibility. Finally, seeking supplemental resources through government support programs, investment funds, or strategic partnerships is highly recommended.

5.3.3. Managerial implications from the results of Environmental Readiness influence testing

The empirical findings indicate that the external environment in Vietnam presents a dual landscape of opportunities and pressures for Industry 4.0 adoption among SMEs. Consequently, SMEs must adopt a proactive and agile approach to effectively leverage government support policies, while recontextualizing competitive pressure as a catalyst for innovation and maximizing external assistance. Such a strategic posture will enable Vietnamese SMEs to enhance their environmental readiness, thereby facilitating an efficient and sustainable Industry 4.0 transition. External resources and government interventions play a pivotal role in bolstering

organizational readiness and fostering a favorable attitude toward adoption. Specifically, technology firms and solution providers-offering both software and hardware-can provide essential technical support, strategic consultancy, and deployment expertise. Furthermore, research institutes, industry associations, and business communities serve as vital knowledge hubs that facilitate organizational learning and successful implementation. Ultimately, market-driven competitive pressure functions as a critical driver, compelling SMEs to integrate Industry 4.0 technologies to maintain their market position.

5.3.4. Managerial implications of Industry 4.0 Readiness effects

Drawing from the empirical findings regarding Industry 4.0 readiness, the primary managerial implication is that enterprises must adopt a holistic and synchronized approach to adoption. Beyond merely focusing on financial capital, SMEs should prioritize human capital development, foster an organizational culture centered on innovation and risk tolerance, and proactively adapt to external environmental pressures. Crucially, within the SME context, enhancing Industry 4.0 readiness must be intrinsically linked to the strategic vision, commitment, and professional competence of leadership. This synergy ensures that available resources are effectively leveraged and translated into tangible Industry 4.0 implementation practices.

5.3.5. Managerial implications of Attitude Towards Industry 4.0 Adoption effects

Drawing from the empirical results regarding attitudes toward Industry 4.0 adoption, a critical managerial implication emerges: to accelerate Industry 4.0 integration, enterprises must prioritize cultivating and sustaining a positive attitude at both the leadership and organizational levels. Specifically, firm leaders should manifest a clear strategic commitment through investments in training, internal communications, and the

establishment of organizational confidence in the feasibility of Industry 4.0 implementation. Furthermore, businesses should foster a culture of continuous learning and agility, thereby translating favorable attitudes into decisive actions and practical deployment. Especially within the SME context, the leader's attitude plays a decisive role, as it dictates the framework for perception, resource allocation, and risk appetite throughout the entire Industry 4.0 transformation process.

5.3.6. Managerial implications from the results of testing the moderating role of CEO Characteristics

Leadership characteristics serve as a significant positive moderator in the relationships between Industry 4.0 readiness, attitudes toward adoption, and actual implementation. Leveraging their inherent strengths, leaders should act as inspirational figures, fostering creativity, stimulating innovative ideas among subordinates, and cultivating a dynamic working environment. Furthermore, leadership must demonstrate proactive support and a high tolerance for risk when experimenting with novel technological solutions. A steadfast commitment from top management functions as a vital organizational driver, mobilizing the entire enterprise to integrate and exploit the scientific advancements of Industry 4.0.

5.4. Limitations and suggestions for further research

Firstly, regarding the research scope, this study investigated the factors influencing Industry 4.0 adoption among SMEs but was geographically constrained to Ho Chi Minh City. This regional focus may limit the generalizability of the findings to other areas with different economic structures. Future research could expand the scope of data collection to diverse regions or across the country to re-validate the causal relationships between these factors and enhance the model's external validity.

Secondly, there are inherent limitations in the sampling methodology. This study utilized a convenience sampling technique, which may restrict the generalizability of the empirical findings. Consequently, the results may not fully represent the broader population of SMEs. Future research could benefit from integrating multi-stage sampling techniques or employing probability sampling methods to enhance the representativeness of the sample and ensure a more robust generalization to the entire population.

Thirdly, the mediation analysis results confirm the existence of significant mediating pathways between technological, organizational, and environmental readiness and Industry 4.0 adoption. Consequently, future research should conduct a more granular investigation into the mediating roles of Industry 4.0 readiness and adoption attitudes. Specifically, scholars could explore the sequential or parallel mediation mechanisms through which TOE readiness dimensions influence the actual implementation of Industry 4.0 within the SME sector to further refine the theoretical framework.