International Journal of Business and Technology Management
e-ISSN: 2682-7646 | Vol. 7, No. 3, 138-155, 2025
https://asianscholarsnetwork.com/asnet-journals

Leveraging Fourth Industrial Revolution (IR4.0) Technologies Adoption: Building Firms Competitiveness in the Digital Age

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Received: 30 March 2025 | Accepted: 8 May 2025 | Published: 1 June 2025

DOI: https://doi.org/10.55057/ijbtm.2025.7.3.13

Abstract: *Amid the challenges firms face in adopting Fourth Industrial Revolution technologies such as financial constraints, limited IT competency among employees, and inadequate technological resources. This study investigates key factors driving the IR4.0 adoption and assesses how this adoption is influenced by organizational culture and impacts competitive advantage. The research conducted empirical analyses based on 268 responses from both manufacturing and service-oriented Firms. The findings reveal that the majority of firms in these sectors have made partial strides in the adoption and implementation of IR4.0 technologies, with approximately half of them yet to fully embrace these technological advancements. Additionally, the study highlights a noteworthy negative impact of environmental factors on firms' adoption of IR4.0 technologies. This study significantly contributes to the ongoing discourse of digitalization in developing economies by establishing measures aimed at facilitating the rapid acquisition, adoption, implementation, and integration of digital technologies among businesses.*

Keywords: Digitalization, Technology Adoption, Fourth Industrial Revolution, Diffusion of Innovation, Competitiveness, Organizational Culture

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1. Introduction

The establishment of Intel Malaysia paved the way for numerous technology companies to establish digital hubs in the country, generating over 8,000 jobs for its citizens (MDEC, 2021). Malaysia embarked on a journey up the value chain, emphasizing the development of a robust digital economy with high-tech exports. This remarkable economic transformation, from a low-income economy to an upper-middle-income economy, was propelled by rapid industrialization driven by technological advancements (MDEC, 2021; Idris, 2019). Since the advent of the 1st Industrial Revolution, Malaysia has consistently maintained an impressive average growth rate of over 6.4% per year from 1970 to 2016 (OECD, 2016). According to the Malaysia National Budget (2020) report, the digital economy experienced an average growth rate of 9% from 2010 to 2016 in terms of value-added. However, the COVID-19 pandemic exposed the lack of technological readiness among firms in both manufacturing and service industries. Many enterprises grappled with digitalization due to a dearth of fundamental and advanced technologies. Several businesses suffered substantial revenue losses due to their inability to adapt swiftly to this transition process.

The pandemic has underscored the critical need for digital transformation among businesses. According to the Malaysia Digital Economy Corporation (MDEC) (2021), over 30,000 businesses were affected by the impact of the pandemic. Among the firms that attempted to survive, more than 10,000 suffered substantial revenue losses and ultimately collapsed (Loh et al., 2021). A key factor behind this failure was the lack of technological capabilities necessary to transition swiftly to digital platforms to meet customer demands. This highlights the urgent need for businesses to embrace digitalization and technological adoption to ensure resilience against future disruptions (Tham & Atan, 2021). Despite the advantages of digitalization, a significant number of firms remain hesitant to adopt Fourth Industrial Revolution (IR4.0) technologies, especially in the manufacturing and service sectors, due to financial constraints, outdated infrastructure, and a shortage of skilled professionals (Shahzad et al., 2023).

Malaysia faces a persistent “digital divide,” which hinders firms’ technological adoption and innovation (World Bank, 2019; 2020). This divide stems from inadequate digital infrastructure, insufficient digital governance, and disparities in access to the latest technologies (OECD, 2021). The impact of these challenges is evident, as firms struggle to implement digital solutions effectively, limiting their ability to compete both locally and internationally. A report by MDEC (2021) reveals that only 26% of firms in Malaysia have fully adopted digitalization, while 57% have yet to begin the process, and 17% are still in the early stages. The study also found that 74% of firms face obstacles in digital management, including weak organizational culture, limited infrastructure, and a lack of digital skills, which further impede their ability to innovate and gain a competitive edge (Loh et al., 2021).

Moreover, the lack of structured digital training programs and the shortage of IT expertise contribute to the slow pace of digital adoption, particularly in manufacturing and service firms (World Bank, 2019; 2020). Despite the growing demand for digital skills, many firms struggle to equip employees with the necessary knowledge to facilitate technological integration. Additionally, cultural factors play a role in shaping innovation capabilities. In Malaysia, firms often face conflicts between religious beliefs, traditional values, and organizational culture, which can hinder the adoption of IR4.0 technologies (Vasudevan et al., 2021). These challenges collectively limit the potential for digital transformation and innovation, emphasizing the need for firms to develop strategic initiatives to overcome technological and organizational barriers (Hanifah et al., 2019; Shah et al., 2020).

Given the slow economic growth, the government has advocated for digital transformation to instil micro and macroeconomic stability across sectors. Hence, technological reforms are being promoted to encourage firms’ adoption of industrialized technologies (MDEC, 2021). However, the continuous rapid business establishments pose critical challenges to the limited skilled professionals and financial and technological resources. Amid this growing challenge, it becomes imperative for firms to fully digitalise their business processes by navigating future challenges effectively. Consequently, this study aims to comprehensively examine and analyse the key factors (technological, organizational and environmental) influencing firms’ adoption of IR4.0 technologies, shedding light on the future of digitalization.

1.1 Significance of the Study

The findings will emphasize the crucial need for transformative policy amendment, development and enforcement aimed at promoting the acquisition, adoption, implementation, and integration of digital technologies, including smart technologies, into business management operations for enhanced digitalization. This imperative will extend to micro, small, and medium enterprises, fostering their familiarity with advanced technologies.

Additionally, the study's scope emphasizes the necessity for policymakers to revisit and revise digital policies in alignment with current market dynamics, reflecting the perspective of local firms regarding their technological adoption and management, vision, mission, and the future of sustainable industrial development. From a theoretical perspective, this study extends the TOE model by incorporating key elements including the firm's competitiveness (FC) and organizational culture (OC). It empirically examines how the OC influences the dimension of technology adoption and management, and how FC is influenced by the adoption of technologies.

2. Literature Review

2.1 Diffusion of Innovation (DOI) and TOE model

The application of DOI theory in this study has not only provided the foundation for the adoption of technological innovation but has also undoubtedly contributed to the further exploration of technological inventions through the adoption of innovations in various disciplines. The DOI suggested some key characteristics of innovations that were considered to be conducive to the diffusion of technological innovations. These key properties include relative advantage, compatibility, complexity, trialability and observability (Rogers, 2003). The theory suggests that these characteristics of innovations play a critical role in individuals' attitudes or behaviours toward adopting new technologies. In other words, individuals' decision to adopt the use of smart devices, artificial intelligence, big data, cloud computing, robots, genetic engineering etc., to improve business activities depends on the characteristics of the innovation (Rogers et al., 2014; Rogers, 1995). Rogers (2003) emphasized the discussion on "relative advantage" as the extent to which an innovation is perceived to be better than the idea it replaces. "Compatibility" is the extent to which a technology is perceived to be consistent with existing values, experience, and the needs of potential users. "Complexity" is the extent to which an innovation (such as technology) is perceived as relatively difficult to understand and use. Lastly, trialability and observability as the degree of the trial before the actual use of the innovation and the ability to observe the progress of the technology, respectively (Rogers et al., 2014; Rogers, 2003).

The TOE model, introduced by Tornatzky et al. (1990), is a framework for understanding the factors that impact a firm's adoption of technological innovation. This model identifies three key facets – Technology, Organization, and Environment (TOE) – that collectively influence how organizations adopt technological innovations. Firstly, the technological factor encompasses all relevant technologies, whether already in use within the organization or available in the market for potential adoption. Secondly, the organizational factor takes into account a firm's characteristics and resources, such as its structure, workforce, size, management, and product type, all of which can influence its technology adoption. Lastly, the environmental factors consider industry structure, external support from government entities, market competition, and other external factors (Ghobakhloo & Tang, 2014). This study integrates both the DOI (Diffusion of Innovations) and TOE models as foundational components of its conceptual framework. This integration is crucial for gaining a comprehensive understanding of the existing correlations. DOI enhances TOE's ability to explain and predict technology innovation adoption, ultimately contributing to improved firm performance. Additionally, prior studies (Hameed & Arachchilage, 2020; Ghobakhloo & Tang, 2014) have highlighted the significance of combining DOI and the TOE model, offering a more holistic approach and a robust theoretical framework for investigating how key TOE factors influence the adoption and utilization of digital technologies.

2.2 The Objective of the Study

This study aims to assess how technological, organizational, and environmental factors influence the adoption of IR4.0 technologies by firms. It also investigates the impact of these factors on firms' competitiveness. Furthermore, it examines how organizational culture affects the adoption of IR4.0 technologies for digital transformation and moderates the relationship between technological, organizational, and environmental factors and technology adoption. Finally, the study analyses the effect of firms' IR4.0 technology adoption on their competitiveness.

2.3 Previous Studies & Hypothesis Development

Wang et al. (2016) have posited that relative advantage, process compatibility, complexity and technological readiness are considered significant components for organizations' adoption of technological innovation. The ability of an organization to adopt innovations and build or develop its digital processes depends significantly on the type of positive outcomes expected from such digital development. A study found that technological factors (i.e., relative advantage, process compatibility and complexity) are the key components that influence the adoption of information systems (IS) in companies. This highlights that technological factor has a positive influence on firms' adoption of technologies (Hooi & Chan, 2022). Based on these discussions, we hypothesized the following;

H1a: Technological factors (TFs) predict a positive impact on firms' adoption of IR4.0 technologies.

Lee et al. (2018) have emphasized that organizational factors (i.e., organizational resources, employees' skills, top management etc.) have a significant positive effect on a firm's ability to integrate technologies into their business activities. It further indicates that the integration of information and communication technologies (ICT) into business processes has improved the efficiency of capturing, storing and processing information digitally, significantly improving firms' digitalization. Organizational factors encompass a wide range of elements that collectively contribute to an organization's readiness and capacity to adopt IR4.0 technologies. These factors, when managed effectively, are predictive of a positive impact on a firm's ability to embrace and harness the potential of these transformative technologies, ultimately enhancing its competitiveness in the digital age (Falciola et al., 2020). Based on the above literature discussions, we hypothesized the following;

H1b: Organizational factors (OFs) predict a positive impact on firms' adoption of IR4.0 technologies.

Cruz-Jesus et al. (2019) found that a firm's ability to evaluate the adoption and integration of technological innovations such as information systems (IS), enterprise resource planning (ERP), electronic data interchange (EDI) (Martins et al., 2019), e-business, e-commerce, etc., is determined by the state of environmental factors such as government support, natural resources, competitive pressures, external support and business partners. Schmitt et al. (2019) believe that government support and other elements of environmental factors are critical in promoting digital business process integration through innovation to increase firms' competitive advantage.

H1c: Environmental factors (EFs) predict a positive impact on firms' adoption of IR4.0 Technologies.

Chu et al. (2019) discussed that organizational culture has either a negative or positive effect on a firm capacity to adopt and implement key technological innovations through the adoption of (IR4.0) to promote digitalization. If organizational culture values do not align with its business development strategies such as innovation culture, this would have a negative impact on firms' adoption of IR4.0 technologies. Another study connotes that the integration of technology into business activities is influenced by organizational culture elements including the firm's values, beliefs, norms and practices (Falciola et al., 2020). Therefore, based on these discussions, we hypothesized the following;

H1d: Organizational Culture (OC) predicts a negative impact on firms' adoption of IR4.0 technologies.

Fernando et al. (2022) posited that the adoption of advanced technologies plays a pivotal role in enhancing a business's competitiveness. Embracing technological advancements enables companies to innovate, and create new products, services, and business models, ultimately gaining a competitive edge. Businesses that leverage technology can increase productivity, streamline processes, and reduce costs, positioning themselves ahead of rivals who lag in technology adoption. Additionally, technology facilitates effective collaboration among geographically dispersed teams, improving decision-making and responsiveness to market changes according to Tang et al. (2018). Based on these discussions, we hypothesized the following;

H3a: Technological factors (TFs) have a positive effect on firms' Competitiveness.

A skilled and innovative workforce is a driving force behind a company's competitiveness. Organizational factors, such as fostering a culture of learning and development, investing in employee training, and attracting top talent, directly contribute to a firm's competitive advantage (Lok et al., 2022). Fernando et al. (2022) instigated that a workforce equipped with the necessary knowledge and skills can drive innovation, deliver exceptional products and services, and provide outstanding customer experiences. Cultivating an organizational environment that prioritizes continuous improvement and talent acquisition enhances a company's competitive position. Based on these discussions, we hypothesized the following;

H3b: Organizational factors (OFs) have a positive effect on firms' Competitiveness.

Environmental factors can stimulate businesses to develop sustainable solutions, leading to competitive advantages. Investing in research and development focused on green innovation allows companies to create environmentally friendly products, processes, and technologies (Chuang & Huang, 2018). This positions them as leaders in sustainability, setting them apart from competitors and appealing to stakeholders and customers who value eco-conscious practices. Consequently, environmental considerations can positively impact a company's competitiveness by driving innovation in sustainable practices and products. Based on these discussions, we hypothesized the following;

H3c: Environmental factors (EFs) have a positive effect on firms' Competitiveness

Automation, robotics, and advanced data analytics are examples of IR4.0 technologies that can increase operational effectiveness, decrease errors, and increase productivity. Businesses can enhance their overall performance and gain a competitive advantage by streamlining processes, optimizing resource allocation, and enabling real-time data-driven decision-making (Lok et al., 2022). Fernando et al. (2022) claim that IR4.0 technologies give businesses new opportunities for innovation because machine learning (ML) and artificial intelligence (AI) can help businesses create novel goods, services, and business models. By utilizing these technologies, businesses can respond to customer demands, quickly adapt to shifting market dynamics, and maintain an advantage over rivals. Based on these discussions, we hypothesized the following (see Figure 1);

H3d: Firms' adoption of IR4.0 has a negative effect on firms' Competitiveness.

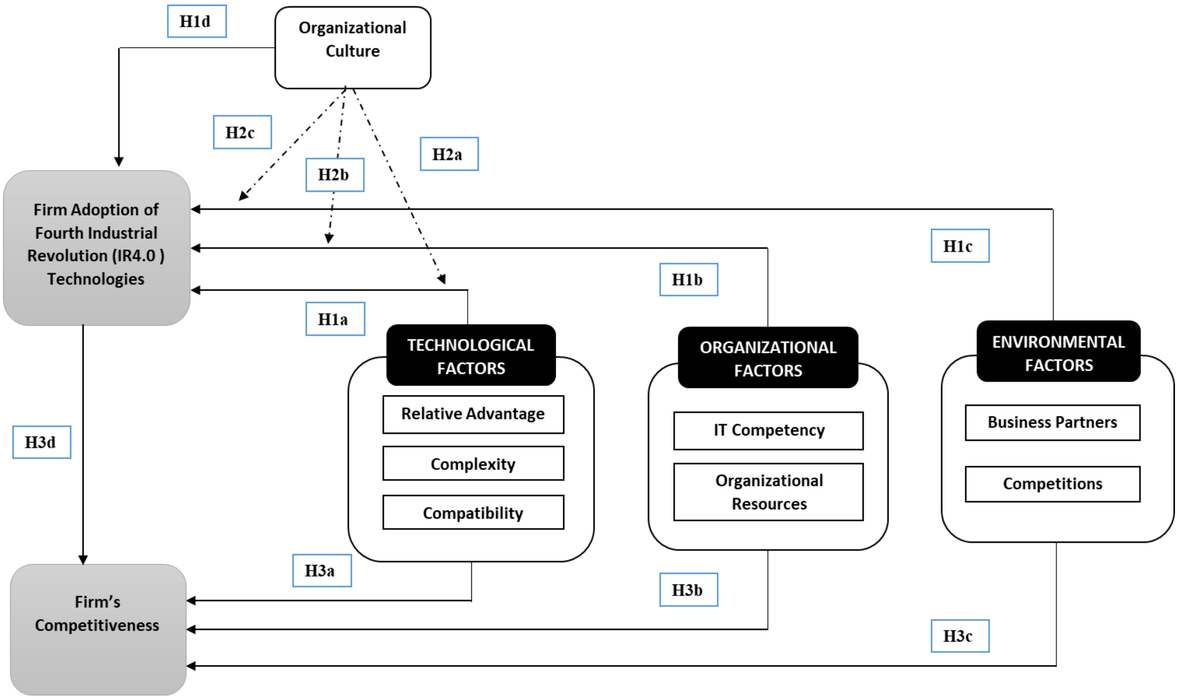

Figure 1: Research Framework
Source: Authors' Analysis

According to Tang et al. (2018), an organization with the values and norms to innovate digital capabilities directly creates a culture of innovation that has a positive influence of technological factors (i.e., relative advantage, compatibility and complexity of technology application) on the firm's ability to not only adopt the application of advanced technologies but also to be able to integrate the technologies into its business activities. A study by Falciola et al. (2020) discussed that it is significant for organizational factors such as resources, product characteristics, employee competency etc., to align its development with the organizational values and norms. For instance, when employees' IT training and development activities are consistent with the company's values and tradition, the influence of organizational culture (OC) becomes important to determine the firm's ability to easily adapt and integrate IR4.0 technologies such as AI, robots, genetic engineering, automation etc., into business activities. Another study (Crus-Jesus et al., 2019) also emphasized that environmental factors like business partners, government support and market competition, are all significant elements that can be influenced by OC to ensure companies necessitate the technology adoption. Although companies would always ensure compliance with their business values, the direction of the market competition can directly influence firms to adjust their values on technology adoption to survive and remain relevant. Therefore, based on the above literature discussions, we hypothesized the following;

H2a: OC moderates the relationship between Technological Factors and firms' adoption of IR4.0 technologies.

H2b: OC moderates the relationship between Organizational factors and firms' adoption of IR4.0 technologies.
H2c: OC moderates the relationship between Environmental factors and firms' adoption of IR4.0 technologies.

3. Research Design

This study employed a quantitative research approach and conducted primary data collection using survey questionnaires. The data collection process encompassed both face-to-face and online methods due to data availability constraints. Face-to-face interactions allowed researchers to elucidate the study's objectives and intended contributions to participants. In contrast, online distribution not only ensured compliance with pandemic-related safety measures but also facilitated access to a broader sample without incurring transportation costs. The questionnaire distribution was a collaborative effort involving four researchers, each responsible for administering approximately 73 questionnaires. To determine the sample size, Krejcie and Morgan's formula was applied, considering a total population of 1,043,082 firms in the manufacturing and services sectors. The study aimed to secure a minimum of 300 responses from various stakeholders, including CEOs, directors, presidents, entrepreneurs, owners and top management executives. In practice, 1,398 survey questionnaires were disseminated to respondents in strategic locations within five states: Kuala Lumpur, Penang, Johor, Perak, and Selangor. These states were chosen due to their concentration of over 60% of the total business establishments (DOSM, 2020).

The research tool is carefully constructed to investigate how TOE factors affect a firm's adoption of IR4.0 technologies, with the influence of firms' competitiveness. The structure of the survey is divided into four sections: A, B, C, and D. Age, gender, education, and position are among the demographic data that are gathered in Section A. Section B covers firms' profiles including category of industry, activity, revenue, etc. Section C explores firms' adoption of technology elements. Finally, Section D incorporates TOE factors, organizational culture and firm competitiveness elements. In this section, a 5-point Likert-type scale with options ranging from "Strongly Disagree" (1 point) to "Strongly Agree" (5 points) is used by respondents to express their opinions. Face evaluation of the instrument's reliability test was applied in this study. The reliability test was observed to ensure that the participants were conformable in choosing the right answers for the questionnaire.

3.1 PLS-SEM Analysis

This study employed the Partial Least Square Structural Equation Modeling (PLS-SEM) approach, a variance-based method analysis. The analysis comprised two main stages: 1) the measurement model and 2) the structural model. In the measurement model, the PLS algorithm was used to assess each indicator's contribution to the composite score of each construct, ensuring model reliability, convergent validity and discriminant validity (HTMT). The structural model involved bootstrapping analysis to examine correlation effects, r-square, f-square, and q-square. The PLS-SEM analysis incorporates lower-order, first-order and higher-order constructs to examine construct relationships. The analysis initially focused on the first and lower-order constructs directly linked to the dependent variable and then assessed the higher-order constructs' direct impact on the dependent construct, this procedure is emphasized by Sarstedt et al. (2019) and Hair et al. (2019).

4. Analysis

4.1 Firm Adoption of Technologies

Based on 268 response data, the statistical breakdown of firms across manufacturing and service sectors reveals that 69.8% are from manufacturing, while 30.2% belong to the services sector. The analysis shows that 2% of these firms have not adopted any of the key IR4.0 technologies yet, while 20.37% have taken initial steps towards adoption. A significant portion, 53.10% have partially adopted IR4.0 technologies. In contrast, 22.10% of the firms have made substantial advancements in technology integration, with 2.42% achieving full adoption. In summary, the majority of both manufacturing and services businesses have made partial strides in adopting IR4.0 technologies, with almost half of them yet to fully incorporate technologies such as artificial intelligence, cybersecurity technology, big data, cloud computing, and genetic engineering. Notably, many manufacturing firms have excelled in incorporating automation and smart technologies while partially integrating AI. This indicates that most firms are in the early stages of adopting and developing capabilities to support IR4.0 technologies integration, also reiterated by Islam et al. (2020) findings.

4.2 PLS-SEM Analysis

4.2.1 First-Order Constructs

The PLS-SEM analysis encompasses both first-order and higher-order constructs, following the established PLS-SEM procedure. Starting with the first-order constructs, each factor's analysis is significant, will all leading items having t-statistics exceeding the minimum threshold of 1.96. After conducting the analysis, all lower-order and higher-order constructs are independently examined, and their loadings are statistically significant. For example, factor leadings under organizational culture include OC1 (12.347), OC2 (34.106), and so forth, while organizational resources feature OR1 (8.949), OR (17.663), OR (16.773). The analysis assesses internal reliability, including Cronbach's alpha and Composite reliability, convergent validity, and discriminant validity for all constructs, all of which are found to be significant. Notably, Variance Inflation Factors (VIFs) for each item reveal no indications of multicollinearity issues, as all values are < 5.0 (see Table 1) (Hair et al., 2019).

Table 1: Multicollinearity Statistics (VIF) for Indicators

Variance Inflation Factor (VIF)							
IR4.01	1.995	OC1	1.782	PCH3	1.907	BP2	1.587
IR4.010	3.128	OC2	1.742	PCH4	1.656	BP3	2.210
IR4.02	1.703	OC3	1.705	PRA1	2.615	BP4	2.173
IR4.03	1.945	OR1	1.327	PRA2	2.414	MC1	1.593
IR4.04	2.009	OR2	1.219	PRA3	2.277	MC2	1.692
IR4.05	2.003	OR3	1.289	PRA4	2.889	MC3	1.620
IR4.06	2.006	PC1	2.733	PRA5	2.741	MC4	1.585
IR4.07	2.510	PC2	1.742	PRA6	3.010	FC1	1.262
IR4.08	2.778	PC3	2.092	TMS1	1.737	FC2	1.195
IR4.09	2.838	PC4	2.198	TMS2	1.714	FC3	1.282
PX1	1.863	PC5	3.237	TMS3	1.750		
PX2	1.437	PC6	3.272	TMS4	1.929		
PX3	1.758	PCH1	1.394	TMS6	1.784		
PX4	1.896	PCH2	1.780	BP1	1.592		

Note: IR4.0 (4th Industrial Revolution Technology), Relative Advantage (PRA), Complexity (PX), Compatibility (PC), Product Characteristics (PCH), Organizational Resource (OR), Organizational Culture (OC), Business Product (BP), Market Competition (MC).
Source: Authors' Analysis

4.2.2 Higher-Order Constructs

The measurement model assessment includes the validation of higher-order constructs (TFs, OFs, and EFs) depicted in Figure 1. Each of these constructs undergoes evaluation for reliability and convergent validity. Additionally, their discriminant validity with other first-order constructs in the model, as recommended by Sarstedt et al. (2019), is examined. The results confirm the reliability and validity of the higher-order constructs, with reliability values > 0.70 and AVE values > 0.50 (Table 2). Furthermore, the discriminant validity of the higher-order construct with other first-order constructs is established, as all HTMT values are < 0.90 (Table 4). Firms' adoption of IR4.0 technologies and competitiveness is significantly influenced by the independent constructs, with an r-square of 0.498 and 0.364 respectively, indicating a good predictive influence. The Q2 predictive relevance of dependent constructs stands at 0.286, signifying substantial predictive relevance (Hair et al., 2019).

Table 2: Construct Reliability and Validity

	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)	VIF Values	R Square	f2	Q2
A.IR4.0 Tech	0.927	0.938	0.603	1.212	0.498	0.084	0.286
EFs	***0.806***	***0.802***	***0.669***	***1.243***		***0.118***	
TFs_OC_IR4.0	1.000	1.000	1.000	1.096		0.061	
OFs_OC_IR4.0	1.000	1.000	1.000	1.171		0.009	
EFs_OF_IR4.0	1.000	1.000	1.000	1.094		0.212	
OC	0.805	0.868	0.689	1.264		0.127	
OFs	***0.753***	***0.768***	***0.525***	***1.261***		***0.071***	
TFs	***0.755***	***0.889***	***0.801***	***1.212***		***0.084***	
FC	0.740	0.794	0.577	1.022	364	0.073	

Note: Bold and Italic values represent the Higher-Order Construct statistics. TFs (Technological Factors), OFs (Organizational Factors), EFs (Environmental Factors), FC (Firms' Competitiveness), OC (Organizational Culture), (M) Moderation, and (A. IR4.0 Tech) Adoption of Fourth Industrial Revolution Technologies
Source: Authors' Analysis

Table 3: Fornell-Larcker Criterion

	A. IR4.0 Tech	EFs	FC	M1	M2	M3	OC	OFs	TFs
A.IR4.0 Tech	0.797								
EFs	***-0.199***	***0.816***							
FC	0.012	0.214	0.750						
M1	-0.148	-0.107	-0.006	1.000					
M2	-0.088	0.115	-0.013	0.073	1.000				
M3	0.140	-0.205	-0.002	0.255	-0.107	1.000			
OC	0.115	0.008	0.103	-0.116	-0.159	0.142	0.848		
OFs	***0.151***	***0.294***	***0.098***	***0.007***	***-0.102***	***0.117***	***0.219***	***0.723***	
TFs	***0.267***	***0.193***	***-0.083***	***-0.365***	***0.009***	***-0.140***	***0.077***	***0.219***	***0.892***

Note: Bold and Italic values represent the Higher-Order Construct statistics
Source: Analysis

Table 4: Heterotrait-Monotrait Ratio (HTMT)

	Adoption_4 IR TECH	EFs	FC	M1	M2	M3	OC	OFs	TFs
Adoption_4IR TECH									
EFs	***0.296***								
FC	0.067	0.324							
M1	0.148	0.135	0.031						

M2	0.087	0.159	0.095	0.073				
M3	0.147	0.292	0.055	0.255	0.107			
OC	0.136	0.060	0.142	0.127	0.177	0.159		
OFs	***0.200***	***0.522***	***0.184***	***0.141***	***0.180***	***0.169***	***0.325***	
TFs	***0.296***	***0.333***	***0.128***	***0.430***	***0.027***	***0.176***	***0.088***	***0.351***

Note: Bold and Italic values represent the Higher-Order Construct statistics
Source: Analysis

4.2.3 Direct Effect Analysis & Discussions

The results from Table 5 reveal that EFs have a significant negative impact on firms' adoption of IR4.0 technologies *at (t-3.850 & p-0.000), hence, we reject hypothesis H1c.* EFs, including business partners, government policies, and market competition, directly hinder firms from adopting and utilizing IR4.0 technologies such as genetic engineering, AI robotics, etc., in their business operations. Challenges such as inadequate technological resources and limited competition, contribute to the slow adoption of technology among firms in the country. This divide in technological capabilities between Firms and larger companies allows the latter to dominate the market, leaving smaller firms with a limited customer base (Alam et al., 2022; Aziz & Wahid, 2020). The analysis shows that OC does not predict any significant effect on firms' adoption of fourth industrial revolution (IR4.0) technologies, *at (t-0.439 & p-0.000), therefore, we reject hypothesis H1d.* This finding discovers that in the Malaysian context, organizational culture such as a firm's values, beliefs, practices, innovation, etc., does not directly influence a firm's ability to effectively adopt and integrate advanced technologies in businesses. Several studies (Yusof & Jamal, 2022; Low et al., 2020) have found that organizational culture like innovative culture among local firms in Malaysia to promote the application of digital technologies is still limited, hence, hinders the rapid digitalization progress.

Table 5: Path Coefficient

	Original Sample (O)	**T Statistics (|O/STDEV|)**	**P Values**
Direct Effect			
EFs -> Adoption_IR4.0 Tech	-0.286	3.850	0.000
Organizational Culture -> Adoption_IR4.0 Tech	0.041	9.439	0.000
OF -> Adoption_IR4.0 Tech	0.166	2.006	0.045
TFs -> Adoption_IR4.0 Tech	0.268	3.841	0.000
EFs -> FC	-0.012	0.116	0.907
Adoption_IR4.0 Tech -> FC	0.143	2.020	0.041
OFs -> FC	0.226	1.688	0.092
TFs -> FC	-0.193	2.764	0.006
Moderation Effect			
M1	-0.059	0.836	0.403
M2	-0.021	5.306	0.000
M3	0.076	0.788	0.431

Note: TFs (Technological Factors), OFs (Organizational Factors), EFs (Environmental Factors), FC (Firms' Competitiveness), OC (Organizational Culture), and (M) Moderation, and (A. IR4.0 Tech) Adoption of Fourth Industrial Revolution Technologies
Source: Analysis

The findings in Table 5 indicate that OFs significantly and positively influence firms' adoption of IR4.0 technologies *at (t-2.006& p-0.045), hence, we accept hypothesis H1b.* These factors encompass elements such as firm activities, product characteristics, and organizational resources, which not only promote the adoption of industrial technologies but also facilitate the integration of advanced technologies. This integration is fundamental for enhancing the overall structure and development of firms. The results support hypothesis H1b and reject the null hypothesis. Despite challenges, including financial constraints, many Firms have made substantial progress in technology adoption since the onset of the COVID-19 pandemic, contributing to improved innovation through the adoption of IR4.0 technologies (Pu et al., 2021). The results highlight that TFs significantly and positively influence firms' adoption of IR4.0 technologies *at (t-3.841 & p-0.000), therefore, we accept hypothesis H1b.* TFs encompass available technology sets and innovation attributes, playing a crucial role in enabling firms to incorporate advanced technologies into their operations. This ease of technology application expedites adoption and integration, fostering technological innovation within organizations (Pu et al., 2021). Moreover, the expected positive outcomes from technology integration drive firms to embrace digitalization, a trend accelerated by the impact of COVID-19, propelling many Malaysian firms toward digital transformation (Rpir et al., 2019).

OFs do not significantly impact FC, with statistical significance *at (t-1.688 & p-0.092), therefore, we reject hypothesis H3b.* This suggests that in certain scenarios, OFs have limited influence on a firm's competitive advantage, especially when markets are dominated by a single major player or a few large entities, limiting the capacity of OFs to reshape competitiveness (Aziz & Wahid, 2020). Similarly, EFs exhibit no significant impact on FC *at (t-0.116 & p-0.907), hence, we reject hypothesis H3c.* However, governmental regulations and industrial policies can shape the competitive landscape. Companies that proactively adhere to regulations, particularly in areas like environmental compliance, can mitigate legal risks and enhance their reputation, attracting sustainability-conscious customers and fostering trust among stakeholders (Lok et al. 2022; Chuang & Huang, 2018).

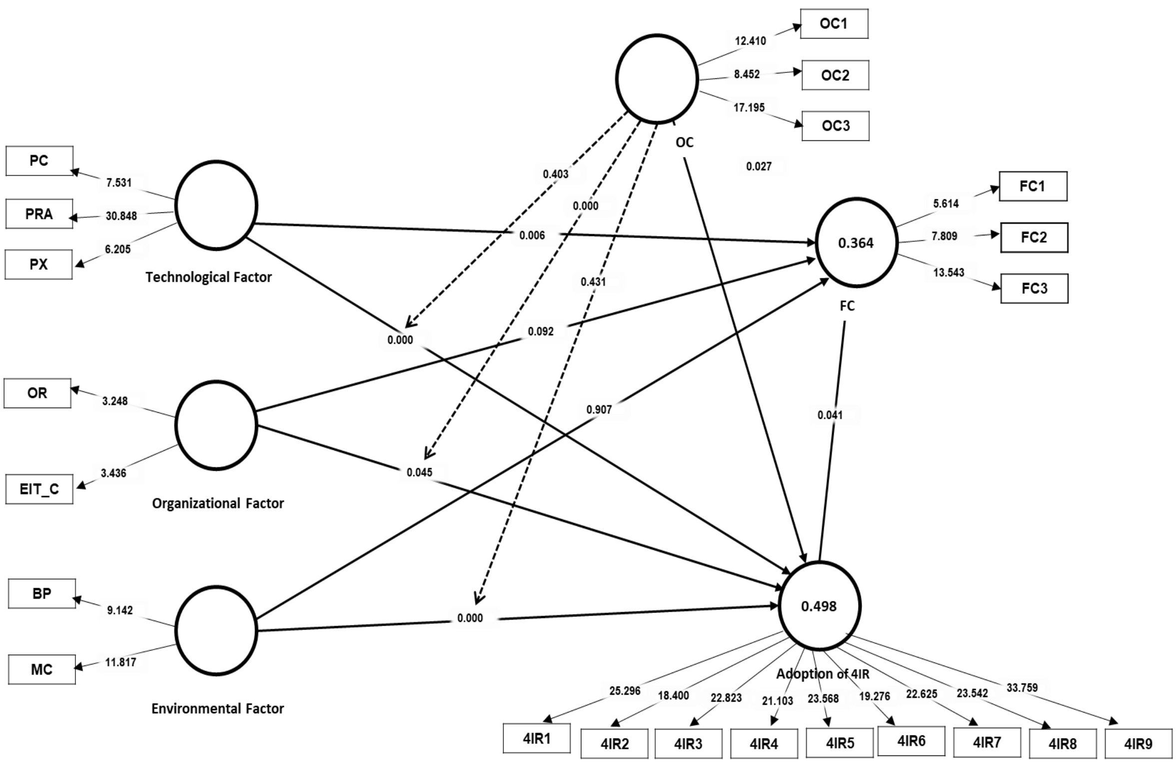

Figure 2: PLS-SEM Structural Equation Modelling
Source: Analysis

TFs exhibit a negative impact on firms' competitiveness (FC), with statistical significance *at (t-2.764 & p-0.006) see Figure 2, therefore, we reject hypothesis H3a.* According to (Fernando et al., 2022), TFs can have a downsizing effect on FC, signifying that an overemphasis on technology adoption and advancement can, paradoxically, hinder a firm's competitive edge. This might occur if firms prioritize technology at the expense of customer-centric strategies or fail to effectively leverage technology to meet customer needs and enhance overall competitiveness. On the other hand, it reveals that the adoption of IR4.0 technologies positively influences FC, *at (t-2.020 & p-0.041), therefore, we accept hypothesis H3d.* This finding emphasizes how IR4.0 adoption facilitates the creation of new models and revenue streams. Adopting disruptive technologies exploring innovative technologies and exploring innovative business models empowers companies to seize underserved markets and establish new industry niches, thereby gaining a competitive edge (Lok et al., 2022). The analysis indicates that organizational culture (OC) has an insignificant impact on the relationship between technological factors (TF) and the adoption of IR4.0 technologies in firms at *M1-(t-0.836 & p-0.403).* In essence, as digital integration becomes more accepted in business management, OC's influence on technology adoption and innovation decreases. In Malaysia, OC only plays a relevant role when necessary to foster innovation culture and facilitate technology integration in business activities (Hooi & Chan, 2022; Hu & Kee, 2022; Lee et al., 2021). This suggests that AI technologies and smart electronic devices, like robots, primarily follow instruments and calculations, reducing the direct impact of OC in guiding employee actions within firms.

The study finds that OC negatively affects the relationship between organizational factors (OFs) and the adoption of IR4.0 technologies *at M2-(t-5.306 & p-0.000).* According to Hooi and Chan (2022), OC can have both positive and negative impacts on the connection between OFs (e.g., products, employees, resources, firm size, etc.) and technology adoption. The negative impact occurs when a firm struggles to instil an innovative culture in its business operations, hindering the adoption of advanced industrial revolution technologies. In Malaysia, this negative influence of organizational culture is evident in Challenges like poor working conditions and reduced productivity faced by many industry firms (Singh & Chan, 2022). Extensive research (Kamal et al., 2020; Visvanathan et al., 2018; Catalin & Mihaela, 2013) highlight the widespread issue of extended work hours in some Malaysian Firms. Employees are either encouraged or obliged to exceed regular hours for higher pay. While longer hours can boost productivity in some cases, Razali et al. (2018) argue that, in this digital era, their impact on the relationship between firm resources and technology adoption is limited. The introduction of AI has reduced the demand for skilled workers, as firms increasingly use AI to enhance production. COVID-19 has further reduced the need for physical presence and manual labour, with technology and e-commerce playing larger roles (Abidin et al., 2021; Kamal et al., 2020).

The analysis reveals that OC does not impact the relationship between EFs and firms' adoption of IR4.0 technologies, with results at *M3-(t-0.788 & p-0.431).* Abdul-Hamid et al. (2021) emphasize how government and industrial policies significantly shape OC towards technology implementation for rapid digitalization, rather than the reverse. This underscores that aspects of OC, like employees' work ethics, standards, and values, do not directly affect factors such as market competition. Similarly, research by Singh and Chan (2022) suggests that government regulations promoting swift digitalization have a more substantial impact on firms' capacity to adopt advanced technologies for business development, bypassing the influence of OC. Therefore, while OC directly influences technology adoption, the significance of EFs like government and industry policies, market competition, and business partnerships in shaping firms' OC for IR4.0 adoption remains paramount (Hoor & Chan, 2022).

5. Conclusion

Based on the data collected from 268 firms, this study reveals that the adoption of Fourth Industrial Revolution (IR4.0) technologies, particularly among Firms, is progressing slowly and is considered to be in an emerging stage within the manufacturing and services sectors. A significant portion of firms in both sectors have only partially adopted IR4.0 technologies including artificial intelligence, cybersecurity, big data, genetic engineering, and cloud computing, with nearly half of them yet to fully integrate those technologies into their production processes. Notably, a majority of manufacturing firms have made significant strides in adopting automation and smart technologies, partially incorporating AI and robotics into their manufacturing processes. However, over 90% of these Firms continue to grapple with challenges related to digitalization, including insufficient financial and technological resources and a shortage of digitally skilled personnel. Despite these challenges, there is potential for firms to enhance the integration of AI and other 'state-of-the-art' technological advancements into their business operations in the near future. The study delves into the key factors (including TFs, OFs and EFs) influencing firms' adoption of IR4.0 technologies, explores how organizational culture moderates these effects, and examines the impact of technology adoption on a firm's competitive advantages. The research indicates that TFs and OFs significantly predict positive outcomes for firms' technology adoption, while EFs have a notably negative influence on the adoption of IR4.0 technologies. Additionally, the findings highlight that organizational culture (OC) has an insignificant impact on the relationship between TFs and EFs with technology adoption, but it exerts a significant negative influence on the correlation between OFs and IR4.0 technology adoption. Furthermore, the study identifies that firms' adoption of IR4.0 technologies successfully mediates the relationship between TFs and EFs, and facilitates conditions. TFs are shown to negatively affect competitiveness.

5.1 Theoretical & Practical Contribution

The findings significantly broaden the dimension of the TOE model which incorporates the influences of OC on technology adoption and its impact on competitiveness. It considers OFs like leadership management, employees' competency, business activities and innovation as fundamental to successful technology integration. Firms with these traits are better equipped to adopt IR4.0 technology, enhancing their competitiveness. This model offers a dynamics perspective, accounting for the evolving interplay of technological, organizational, and environmental factors. It recognizes that IR4.0 adoption is influenced by various variables including employees' IT competency and technological resources. Furthermore, the study extends the body of knowledge emphasizing the mediating role of IR4.0 adoption between EFs and OFs, ultimately shaping firms' competitive advantage positively. The TOE model elucidates the dynamic link between competitiveness and technology adoption management in businesses, with IR4.0 adoption as a crucial mediator.

This study lays the groundwork for future research on critical economic strategies designed to incentivise firms to rapidly adopt and implement state-of-the-art technological innovations, thereby enhancing organizational performance. By advocating for the integration of smart technologies into business production and management processes, the research emphasizes the importance of accelerating digital transformation. A key finding is the necessity to establish and enforce robust laws, particularly in developing economies, that mandate firms to acquire, adopt, and integrate advanced digital technologies. This is essential for improving business management practices and maintaining competitiveness in a rapidly evolving global market. Furthermore, the study emphasizes the need for policymakers to revisit and revise digital policies to align with the growth of the global digital economy. It highlights the importance of incorporating insights from local businesses regarding their vision, mission, and challenges in adopting new technologies. This alignment is crucial for fostering sustainable industrial development and ensuring that businesses are well-equipped to navigate the complexities of the digital era. By addressing these aspects, the research provides a comprehensive framework for driving technological adoption, enhancing business efficiency, and contributing to socio-economic growth through the digital economy.

6. Policy Implications

The slow adoption of technology within Firms poses a significant hindrance to industrial growth and digitalization in the economy. This emphasizes the urgent need for comprehensive policy strategies to address key challenges and facilitate the rapid integration of IR4.0 technologies into local business management operations, ultimately contributing to a robust digital economy. To tackle the issue of slow technology adoption, authorities and stakeholders should consider expanding technological and financial incentives for Firms in developing areas. Providing resources and funding support can encourage the establishment of digital technology sub-firms by large corporations, thereby boosting digitalization efforts. Besides that, policymakers should amend existing policies to mandate local firms to train and develop a more digitally skilled workforce, this is crucial for effective technology integration and business development to enhance competitive advantages. Alternatively, policies that promote increased funding, particularly micro, small and medium firms, enhance research and developed (R&D) activities that can foster technological innovations and digital solutions. These initiatives would reduce the issue of the digital divide in the industry. Furthermore, facilitating partnerships between local businesses and international tech companies, and expanding investment (e.g., 5G infrastructure) would help promote technology transfer and digitalization, benefiting Firms with limited technological capabilities.

7. Limitation and Future Research

The study is coupled with some limitations that could be considered by future researchers. Firstly, cross-sectional research is conducted that involves the collection of data from target respondents (i.e., CEOs, Owners, entrepreneurs, presidents, directors, managing directors and top management officials), from both manufacturing and service sectors. This was done based on a fresh sample of respondents at a time, hence, the result of the study would not reflect on changes in technology adoption among firms in the future. Therefore, with the expected changes in the level of firms' adoption of technology, we recommend a longitudinal research study to be conducted, to capture the outcome of firms' adoption of technology in Malaysia over a while. Other than that, the study applied a PLS-SEM higher-order construct analysis to avoid any issues of multicollinearity and also limit the possible high number of constructs' correlations that could highlight duplication of the result. However, to have another proper dimensional aspect of the PLS-SEM analysis, providing separate comprehensive findings, we recommend only a first-order construct analysis to be conducted and examined. This could provide new information about first-order constructs (such as relative advantage, firm resources, business partner etc.) on how they directly affect firms' adoption of technology instead of only the higher-order constructs (like TFs), using the same model.

Compliance with Ethical Standards
Conflict of Interest: Author 1, Author 2, and Author 3 declare that they have no conflict of interest.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institution

Informed consent: Informed consent was obtained from all individual participants included in the study. Additional informed consent was obtained from all individual participants for whom identifying information is included in this article.

Data Availability Statement

My manuscript contains data that will be made available upon reasonable request.

Acknowledgement

This research work was funded by Universiti Tunku Abdul Rahman under the Research Scholarship UTAR Research Funding (UTARRF); Reference No. UTAR/IPSR/2023/152/RSS/RSS 1+1. The authors expressed their gratitude for their financial support in the publication of this paper. The views expressed herein are those of authors and do not necessarily reflect the views of the UTARRF.

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