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Investigating the Impact of Industry 4.0 Technology through a TOE-Based Innovation Model

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Abstract: Technological change has drastically shaped developments in the manufacturing and service industries. Integrating Industry 4.0 technologies in business practice is an emerging trend for future-oriented enterprises. By linking the TOE (technology-organization-environment) framework with product innovation, process innovation, and company performance, this research proposes a TOE-based innovation model to investigate Industry 4.0. The test results identified that Industry 4.0 technology adoption can be determined by compatibility, top management support, and competitive pressures, unexpectedly, not cost or employee capability; technology adoption can only indirectly influence company performance through mediation effects of product and process innovation. Results also revealed that industry type and global trade could play moderation roles in the technology adoption process: compared to the manufacturing industry, employee capability seems to be more influential on technology adoption in the service industry; global trade activities cannot significantly impact the technology adoption process, but trade companies are more likely to achieve more process innovation after such adoption. This study can enrich the theoretical bases of Industry 4.0 and confer a better understanding of the ongoing technological revolution in developing countries, which may offer some new insights for practitioners and academics.

Keywords: Industry 4.0; innovation; technology adoption; TOE framework; global trade

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1. Introduction

Nowadays, the ways people live, work, and connect with one another are being profoundly changed by a technological revolution. In recent decades, the Fourth Industrial Revolution (also known as Industry 4.0) has emerged across industries and countries. Industry 4.0 was originally derived from the high-tech strategy of the German government, which advocated automation, data exchange, and digitization of manufacturing [1]. The core component of Industry 4.0 consists of digital technologies such as the Internet of Things (IoT), big data, robotics, artificial intelligence (AI), smart sensors, blockchain technology, cyber-physical systems (CPS) and so forth. Industry 4.0 provides a more comprehensive, interconnected, and integrated approach to manufacturing, which can link the physical world with the digital world and enable companies to collaborate better; it also allows businesses to utilize real-time data to boost productivity and drive company growth [2]. In other words, the adoption of the advanced technologies of Industry 4.0 can empower businesses to develop products more efficiently, decrease production costs, and achieve competitive advantages [3]. These advanced Industry 4.0 technologies not only heavily shape the production process but also the delivery of goods and services, which may have far-reaching implications on productivity, labor skills, income distribution, and well-being—even the environment [4].

The changes brought about by Industry 4.0 have fundamentally impacted both the manufacturing and service industries. Even though previous studies have focused more on the effects of Industry 4.0 within the manufacturing sector [5,6], changes have occurred simultaneously in the service sector. Industry 4.0 has resulted in vast transformations across industries and countries. China, as one of the largest emerging economies, has fully embraced such transformation by implementing Industry 4.0 technologies across industries. On the one hand, in order to catch up with the so-called Fourth Industrial Revolution, the Chinese government proposed Made in China 2025, a ten-year plan that aims to promote the transformation of the manufacturing industry. Currently, Chinese manufacturing companies are facing challenges both internally and externally. From the internal perspective, there are numerous problems that need to be resolved urgently within the industry such as rising production costs, insufficient investment into research and development, and production method limitations; from the external perspective, consumers have greater decision-making dominance, leading the manufacturing industry to become more service-oriented. While the development of big data, cloud computing, 3D printing, robots, and other technologies will subvert the previous manufacturing model and motivate cross-industry integration [7]. On the other hand, industrial transformation has also progressed extensively in the Chinese service industry. According to People's Daily (2019) [8], integration of the new generation of information technologies including the Internet of Things, big data, cloud computing, and artificial intelligence will enable the Chinese service industry to be smarter. It will also function to renew the content, models and distribution of service, and provide customers with intelligent, personalized, and high-value-added services. This transformation in the service industry includes the creation of new service elements and the upgrading of the traditional service industry through new technology adoption.

In recent years, an increasing number of studies have applied different technology acceptance models to study new technology implementation. In this study, our model is based on the TOE framework originally designed by Tornatzky and Fleischer (1990) [9]. This framework is said to be extremely suitable for analyzing different types of company-level innovation adoption [10]; ergo, it should be one of the most appropriate frameworks to study Industry 4.0 technology adoption. The TOE framework includes three aspects: technological, organizational, and environmental contexts. Technological context places emphasis on the implications of technological practice and structure on technology adoption behavior; organizational context represents attributes of organizations that can encourage or discourage technology adoption; environmental context concentrates on companies' surroundings, including their competitors, government, and other external factors that may influence technology [9]. TOE has been applied to investigate the adoption of different types of high technologies in many studies, such as RFID technology [11], information and communication technologies [12], cloud computing [13], smart farms [14], and so forth. The adoption and commercialization of information technologies can bring new opportunities and generate benefits for business; thus, a great number of companies have been seeking continuously to increase productivity and strengthen their competitive advantages through technological innovation [15]. As technology is the main driver of improvement in productivity and product (service) development, the introduction of Industry 4.0 technologies can be regarded as the key to innovation. For example, a product innovation that improves the technical specifications of existing products may meet consumer needs more suitably; process innovation that improves current methods of producing or delivering products may create greater value for stakeholders [16]. Both product and process innovation are significant to market expansion and can provide new opportunities for profit generation [17]. Many companies, in fact, lean towards adopting several Industry 4.0 technologies simultaneously, and by combining these technologies, they can trigger product and process innovation to generate additional benefits. Integrating Industry 4.0 technologies (IoT, ICT, big data and AI, robotics, and RFIDs etc.) in operational activities can bring about more sustainable ways of doing business, accelerate product development, decrease costs, and create competitive advantages in the market [4].

Therefore, it is of paramount importance to investigate Industry 4.0 technology adoption by linking it with product innovation and process innovation to build a TOE-based innovation model. This study intends to address the following research gaps: (1) Previously, the majority of studies examined the technological transformation of Industry 4.0 only in developed counties such as Germany, Italy, and South Korea [5,18,19], and many of them focused solely on the manufacturing industry in developed counties. However, few studies have compared whether innovation (such as product and process innovation) and antecedents of Industry 4.0 technology adoption are different across service and manufacturing sectors, especially in emerging economies such as China. (2) Insufficient empirical studies have tested whether trading activities can serve to promote Industry 4.0 technology adoption, its innovation processes and firm performance. (3) The majority of studies paid more attention to the investigation of the antecedents of technology adoption [12,13,18–20], but there is limited empirical evidence showing how product and process innovation can play mediating roles between Industry 4.0 technology and company performance. However, it is vital to investigate Industry 4.0 in both manufacturing and service industries as the service industry has taken up a growing proportion of national GDP and the digital transformation of the service industry may have become equally important to economic growth in many countries. Along with the growing number of companies being influenced by technological diffusion through global trade and the current rising challenges of global trade (trade protectionism, economic recession etc.), it is also meaningful to examine if such trading activities can actually instigate any positive effects on Industry 4.0 technology adoption, product innovation, process innovation and firm performance. By testing moderation variables such as global trade and industry type in the proposed model, this study can offer a tailored framework to study Industry 4.0 technology adoption more appropriately. Additionally, an examination of the mediation role of product and process innovation will also ultimately enhance understanding of the technological innovation under Industry 4.0. This study aims to link the TOE model (focusing on the adoption process) with firm innovation and performance to establish a new innovation model to study the technological innovation of Industry 4.0 more appropriately.

Overall, this study can enrich the theoretical basis regarding Industry 4.0 technology adoption in developing countries, offer more practical insights for decision-makers to formulate strategies, and motivate more companies to innovate through new technology adoption. The research purposes are as follows: (1) identify the most important determinants of Industry 4.0 technology adoption; (2) reveal the mediating roles of product innovation and process innovation between technology adoption and firm performance by building a TOE-based innovation model; (3) test whether Industry 4.0 technology adoption process and the following technological innovations can be influenced by global trade and industry type.

2. Literature Review

2.1. The TOE Framework

The TOE framework was originally designed to depict the adoption of various information technologies on an organizational level (Tornatzky & Fleischer, 1990) [9]. TOE contains technological, organizational, and environmental factors, and it is deemed to be more favorable than other adoption models toward technology adoption/use [21]. The TOE framework places more emphasis on social and psychological aspects [20], and has enjoyed stronger empirical and theoretical evidence than other frameworks [22,23]. This framework is relatively appropriate and specific for company-level adoption, which focuses on factors that can offer significant details of organizational technology adoption [24]. By differentiating between internal characteristics and environmental factors, TOE can provide a more comprehensive perspective than other models that overly concentrated on technological aspects [25]. This framework was therefore considered appropriate for investigating adoption and implementation of different innovation practices, and it has received adequate theoretical and empirical support [26].

Based on the TOE framework, organizational technology adoption is dominated by the following three aspects:

- Technological context: this emphasizes both internal and external technology-related elements that can impact organizational technology innovation [27]. In this study, we define it as compatibility or cost of technology adoption.
- Organizational context: this reflects the characteristics, resources, and internal social networks of a company that may influence technology adoption [28]. In this study, we include several organizational variables such as top management support and employee capability.
- Environment context: this refers to external factors that are beyond organizations' control [9], which has been represented by factors such as competitive pressure in this study.

By exploring potential drivers of Industry 4.0 technology adoption and linking the TOE model with technological innovation and firm performance, this study intends to build a new TOE-based innovation model to offer more insights into Industry 4.0 (Figure 1).

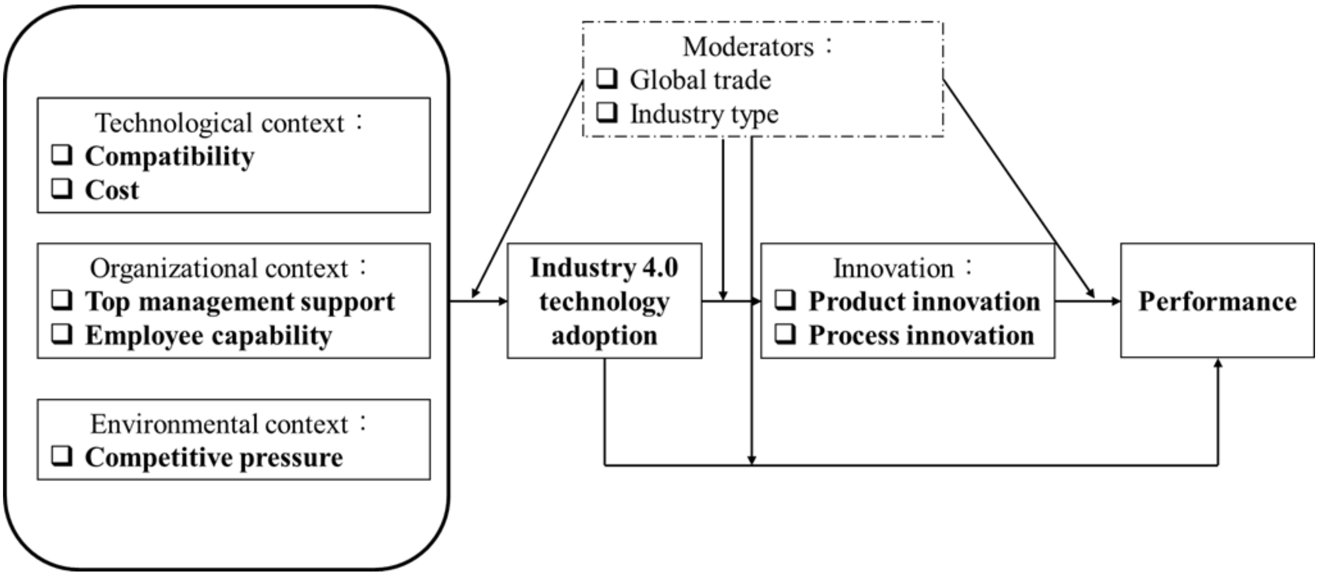

Figure 1. TOE (technology-organization-environment) based innovation Model.

2.2. *Compatibility*

During the adoption of a new technology, businesses may experience huge changes, and such changes may cause resistance and other problems. Thus, it is important to ensure these changes will be compatible with an organization [12]. The issue of compatibility can be divided into technical compatibilities (fit with the current software or hardware) and organizational compatibilities (fit with the current work practices and value system) [29]. Additionally, some scholars have pointed out that it can also be measured by whether a new technology can align with existing norms or structures, infrastructures, and procedures within the business system [20].

If Industry 4.0 technologies are compatible with an existing organizational structure, business system, customer needs etc., this will reduce the difficulties and uncertainties of adoption. As a result, companies may be more willing to adopt such Industry 4.0 technologies.

2.3. *Cost*

Implementation of new technology may be expensive for many companies. Company-level adoption of technology can be accompanied by exorbitant costs including huge startup costs and software costs [30]. Such costs can be defined as the assessment of potential loss during new technology adoption, which is continuously evaluated over time [31]. It may also include direct costs and indirect costs. Direct costs may be caused by the implementation of a new technology, the initial cost of implementing software or hardware, and employee training; while indirect costs may be associated with temporary productivity loss, operational costs of system transformation, and other relative costs resulting from business system/procedure changes [30]. These can noticeably hinder the behavioral intention to adopt an innovation [32,33].

Even though in recent years the prices of hardware and software products have decreased greatly and these products have become more affordable to users, it is still challenging to properly evaluate the benefits versus the costs of IT adoption. According to Ngah et al.'s (2017) [10] research on Halal warehouse adoption, adoption costs can negatively impact companies' decisions regarding technology usage. However, such findings can be contradictory with other studies, for example, Bhattacharya et al. (2018) [34] have suggested that cost is not significantly associated with RFID adoption. It seems that the relationship between cost and new technology adoption remains uncertain. This study intended to further reveal whether higher anticipated costs of adoption can reduce companies' willingness to adopt Industry 4.0 technologies.

2.4. Employee Capability

Companies' employees are extremely significant to the survival and success of businesses [30]. It is of paramount importance to have highly qualified employees in order to appropriately carry out technological innovation [32]. If organizations have highly qualified human resources, they can take the lead in new technology implementation and technological innovation, because qualified personnel with adequate education and innovative ability is indispensable to technical innovation, and it is particularly significant in labor-intensive sectors where improvements and training in tacit skills are heavily reliant on the involvement of employees [35].

As the main IT users within an organization, the knowledge, participation, and involvement of employees in adopting a specific technology can impact the acceptance of technology, but a lack of related training or skill with respect to new technology may discourage technology usage [30]. The employee technology acceptance level can be influenced by proper technical training and courses, and such training providing relative knowledge of technology use can be beneficial for technology implementation [15]. Employee knowledge and skill for technology innovation or implementation are crucial components of organizational adoption behavior [18,36]. If employees are willing to improve their skills/knowledge, engage in training, and actively use Industry 4.0 technologies, it can strengthen organizational technology adoption.

2.5. Top Management Support

Top management, as the decision makers of an organization, plays a vital role in encouraging employees to adopt new technology. Convincing them that the adoption can attract more resources and be beneficial to the organization is enormously important [29]. Meanwhile, their attitudes and degree of support toward organizational change are also considerably influential in technological innovation adoption, because their engagement, plus the allocation of sufficient resources for new technology implementation, are critical; they can also send positive signals to other organizational members and educate them about the significance of adoption [24]. Their support is highly influential in creating a supportive environment and offering relative resources to facilitate new technology adoption [32].

Several studies have emphasized the importance of top management support and also suggested that it can serve as a primary predictor of organizational adoption behavior [13,20,32]. If top management believes that Industry 4.0 technologies are beneficial to the organization, they may be more willing to participate in adoption by building a supportive environment, which may ultimately motivate the acceptance of the Industry 4.0 technologies internally. Therefore, we believe that top management support is an indispensable variable which can impact organizational adoption decisions and reduce the barriers to new technology implementation.

2.6. Competitive Pressure

Companies' competitive pressure mainly comes from the perception that competitors may achieve competitive advantages by implementing a new technology [28]. Such pressure has been regarded as a key motivator in new technology adoption, because by adopting new technologies, companies can change the rules of competition as well as the internal structure within an industry and find new ways to surpass their peers, and as such, put themselves in a more favorable position [37]. Non-adopter companies, however, may experience a lower level of organizational performance [29]; thus, they tend to adopt new innovations to reduce the risks of being exposed to any competitive disadvantages [38]. The business environment is quite dynamic, in order to maintain their competitive advantages, companies will have to closely monitor competitors' actions and adjust their strategies to fit in with current business practices [20]. Facing up to increasing competition, organizations always seek to remain competitive through technological innovation.

Competitive pressure was found to be a decisive predictor of new technology adoption that can positively influence the adoption of various technologies [28,39]. New Industry 4.0 technologies can bring about greater opportunities for businesses that have taken the lead in adopting such technologies and help them to achieve competitive advantages within industries; thus, in order to achieve substantial success, companies will actively engage in new technology adoption.

2.7. Product Innovation and Process Innovation

Any practice that is new to an organization can be regarded as an innovation, including the introduction of new facilities, products, services, or processes [40]. New technologies enormously drive productivity improvement in service companies [16]. Additionally, continuous technological innovation will also enhance product performance in the manufacturing industry [7]. Companies can achieve innovation through the usage of new technology to provide products (services) with more competitive advantages, which usually means a lower cost or improved existing product (service) attributes [40].

Product (service) innovation is a process of introducing new products (services) that is usually accompanied by improved technical specifications or software performance in comparison to current products, through which consumer demand may be satisfied to a greater extent [41]. It can bring about opportunities to enhance organizational performance through operational efficiency improvement, new market expansion, and profit growth [16]. Product(service) innovation has frequently been carried out by those companies that have fully embraced technological transformation. By introducing new and advanced Industry 4.0 technologies, product innovation can contribute to noticeably improved performance of existing products or services and, consequently, drive market expansion or sales growth.

Technological innovation includes introducing a new idea into current product (service) lines as well as adding new elements to the production or service process [42]. Thus, not only product innovation but also process innovation can play an indispensable role when it comes to technological innovation. Process innovation can be defined as the introduction of production/delivery methods that are novel or significantly upgraded, and it is closely connected with changes in the use of tools, working style, or installation of new software [16]. Process innovation may bring about growth in productivity [17]. Both product and process innovation have been confirmed to be significant in terms of improvements in sales and profits [43]. The fourth industrial revolution has been comprehensively and profoundly changing production and service processes. Through the implementation of Industry 4.0 technologies, companies can enjoy more efficient ways to deliver services and significantly increase the productivity of production (eg. using robots to produce goods or serve customers).

2.8. Technology Adoption and Mediation Effects of Innovation

Innovation-leveraged company performance has been discussed by many studies before [16,44]. However, the correlations of Industry 4.0 technology adoption, innovation (especially process and product innovation), and company performance have not adequately been verified and remain relatively unclear. In this study, we assumed that the adoption of advanced technology can have effects on company performance because new technology adoption may enhance productivity or reduce production costs by replacing old and costly technologies. It may bring about opportunities to improve company performance through such means as customer satisfaction, sales volume, and so on. Meanwhile, few studies have investigated the mediation effects of innovation between Industry 4.0 technology adoption and firm performance. As such, it is necessarily critical to provide empirical evidence to unveil the internal relationships by exploring the mediation effects of process and product innovation.

2.9. Moderation Role of Global Trade

Increasing usage of digital technologies can greatly decrease costs and bring firms trade opportunities [45]. Using new technologies in the manufacturing process can boost productivity, drive down costs, and accelerate technological diffusion [45]. The development of the internet and digital technologies has leveraged the use of artificial intelligence (AI), Internet of Things (IoT) and blockchain technology, which has created more opportunities for businesses to enter new markets and participate in international trade [46]. In other words, all enterprises can enjoy new opportunities for international trade through technological innovation, which will make importers and exporters more likely to actively adopt Industry 4.0 technology than companies with fewer needs to participate in global trade.

Furthermore, when buyers and suppliers are doing business with each other, they are inclined to exchange not only goods or services but also technical expertise and advanced technology [45]. Companies that engage in global trading activities will be greatly motivated to keep up with foreign trade partners in terms of technological innovation, and they may have greater awareness and more up-to-date knowledge regarding new technology. Having a higher propensity to be influenced by technological diffusion, trading companies are more likely to adopt Industry 4.0 technologies that have been used by their overseas partners. With the advantages of accessing foreign technological resources directly through international trade, both importers' and exporters' (defined as global trade companies) technology adoption processes and company performance may differ from those companies only doing business within their home countries (defined as non-global-trade companies).

Previously, insufficient studies have examined whether global trade companies act differently in the adoption of Industry 4.0 technology compared to non-global-trade companies, and there is insufficient evidence showing how such differences may affect product innovation or process innovation of Chinese companies. In this study, participation in global trade is considered a significant company characteristic that may have moderation effects on Industry 4.0 technology adoption and innovation behavior, which is also newly integrated with the TOE framework. Meanwhile, as the recent trade protectionism and economic recession have brought huge barriers for international trade after the pandemic, it is significant to validify the vital role of trade in promoting technology innovation and it may encourage more companies to participate in global trade and boost the economic recovery.

2.10. Moderation Role of Industry Type

The industry to which a business belongs can be influential in technology adoption. The industrial environment, along with other factors such as organizational conditions, technological features, and business structures, are remarkably important to organizational adoption behaviors [20]. Because different industries have different requirements for information processing, these differences may influence company-level technology adoption [47]. Meanwhile, companies tend to seek innovation and technology adoption due to the pressure of losing advantages within an industry. Different industries may experience different levels of competitive pressure, resource access, and so forth, which could also affect such adoption.

In the case of the service industry, this heavily depends on information processing systems, while the manufacturing industry may rely more on material planning or resource planning systems [12,47]. Salmeron and Bueno (2006) [48] argued that companies in the same industry are more likely to adopt the same information systems or technologies, share similar attitudes regarding technological changes, and their employees may also have similar attitudes towards new technology usage. Other scholars have pointed out that organizational investment in information technologies is not exactly the same across industries, and companies in less information-intensive industries are less willing to implement information technologies [30]. In other words, the significance of new technology adoption can be perceived at different levels across industries because of differences in company characteristics and information intensity [49].

There may be a large number of differences across service and manufacturing industries in the adoption of Industry 4.0 technology. Consequently, companies from different industries may engage in different innovation activities which lead to different levels of firm performance. Some scholars suggested that product innovation may exhibit differences in intensity between service and manufacturing sectors under Industry 4.0 [50]. However, it still remains unclear how the service and manufacturing industries differ from each other in other types of innovation (process innovation), Industry 4.0 technology adoption, and firm performance.

Therefore, based on the aforementioned literature, we proposed the hypotheses as shown in Table 1.

Table 1. Hypothesis.

Hypothesis
H1: Compatibility can positively impact upon Industry 4.0 technology adoption.
H2: Cost can negatively impact upon Industry 4.0 technology adoption.
H3: Employee capability can positively impact upon Industry 4.0 technology adoption.
H4: Top management support can positively impact upon Industry 4.0 technology adoption.
H5: Competitive pressure can positively impact Industry 4.0 technology adoption.
H6: Adoption of Industry 4.0 technology can positively impact upon product innovation.
H7: Product innovation can positively impact upon company performance.
H8: Adoption of Industry 4.0 technology can positively impact upon process innovation.
H9: Process innovation can positively impact upon company performance.
H10: Adoption of Industry 4.0 technology can directly impact upon company performance.
H11: Product innovation (a) and process innovation (b) mediate the relationship between technology adoption and company performance
H12: Participation in global trade can moderate relationships in the proposed model.
H13: Industry type can moderate relationships in the proposed model.

3. Methodology

3.1. Questionnaire

This study intended to investigate the determinants of Industry 4.0 technology adoption and how such adoption can lead to innovation and better company performance. To test the proposed hypotheses, we conducted a survey in China to collect research data. Most of the survey items were designed according to the previous studies (Table 2), but a few were slightly modified to fit the research purpose. To measure 9 variables as shown in Figure 1 (competitive pressure, top management support, employee capability, cost, compatibility, technology adoption, product innovation, process innovation, company performance), a five-point Likert scale from “1 = strongly disagree” to “5 = strongly agree” was used.

Table 2. Factor Loading and Questionnaire Items.

Items	Content	Factor Loading	Source
AD1	Our company holds a positive attitude towards the adoption of Industry 4.0 technologies	0.797	Maduku et al. (2016) [32]
AD2	Our company are willing to continue to use these Industry 4.0 technologies	0.834	
AD3	Our company are willing to continue applying these Industry 4.0 technologies across the business	0.873	
AD4	Our company are willing to use these Industry 4.0 technologies to expand our scope of business	0.868	
AD5	Our company is satisfied with the newly adopted Industry 4.0 technology	0.851	
CT1	Adopting these Industry 4.0 technologies may bring a financial burden to the company	0.764	Maduku et al. (2016) [32]
CT2	Applying these Industry 4.0 technologies widely in business may require great investment	0.835	
CT3	Providing technical support for these Industry 4.0 technologies may require a lot of funding	0.836	
CT4	Training employees to be proficient in using these Industry 4.0 technologies requires lots of investment	0.822	
CT5	It takes a lot of time to train employees to use these Industry 4.0 technologies proficiently	0.734	
CP1	The adopted technology fits with the needs of the existing production/service process	0.734	Yoon et al. (2020) [14]
CP2	The adopted technology fits with the needs of the existing management system	0.786	
CP3	The adopted technology fits with the company’s existing organizational structure	0.781	
CP4	The adopted technology fits with the company’s existing technical needs	0.762	
CP5	The adopted technology fits with the company’s current business needs	0.771	
CP6	The adopted technology fits with the needs of the company’s existing customers	0.803	
CPP1	The adoption of advanced technology is due to pressure within the industry to upgrade technology	0.727	Jia et al. (2017) [28]
CPP2	The adoption of these Industry 4.0 technologies is to improve competitiveness in the industry	0.833	
CPP3	Adopting these Industry 4.0 technologies is an important strategy to compete in the current market	0.845	
CPP4	If these Industry 4.0 technologies are not introduced, customers may choose competitors’ products	0.815	
CPP5	If these Industry 4.0 technologies are not introduced, the company may suffer competitive disadvantages	0.752	
EC1	Most employees of the company are aware of the importance of introducing advanced technology	0.778	Maduku et al. (2016) [32]
EC2	Most employees are willing to use these Industry 4.0 technologies	0.853	
EC3	Most employees are willing to learn to use these Industry 4.0 technologies	0.864	
EC4	Most employees are willing to actively use these Industry 4.0 technologies in their daily work	0.854	
EC5	Most employees are able to use these Industry 4.0 technologies after training	0.744	
PF1	After adopting these Industry 4.0 technologies, customer satisfaction has increased	0.826	Akgün et al. (2009) [51]
PF2	After adopting these Industry 4.0 technologies, the number of company transactions has increased	0.795	
PF3	After adopting these Industry 4.0 technologies, market expansion has accelerated	0.844	
PF4	After adopting these Industry 4.0 technologies, the company’s market share has increased	0.770	
PF5	After adopting these Industry 4.0 technologies, the company’s total sales have increased	0.814	

Table 2. *Cont.*

Items	Content	Factor Loading	Source
PCI1	After adopting these Industry 4.0 technologies, it is beneficial to the collection and processing of product- or service-related information	0.784	Rajapathirana & Hui (2018) [11]
PCI2	After adopting these Industry 4.0 technologies, it provides production- or service-related technical convenience	0.820	
PCI3	After adopting these Industry 4.0 technologies, the production process or service process has been simplified	0.795	
PCI4	After adopting these Industry 4.0 technologies, the existing production process or service process has been improved	0.809	
PCI5	After adopting these Industry 4.0 technologies, the production process or service process upgrade has been promoted	0.832	
PCI6	After adopting these Industry 4.0 technologies, the cost of labor and resources has reduced	0.730	
PDI1	After adopting these Industry 4.0 technologies, deficiencies in existing products or services have been improved	0.770	Rajapathirana & Hui (2018) [11]
PDI2	After adopting these Industry 4.0 technologies, the company is providing better quality products or services	0.805	
PDI3	After adopting these Industry 4.0 technologies, the company is providing more valuable products or services	0.832	
PDI4	After adopting these Industry 4.0 technologies, the company is providing more competitive products or services	0.812	
PDI5	After adopting these Industry 4.0 technologies, the company is providing products or services that are more in line with new customer needs	0.799	
PDI6	After these Industry 4.0 technologies, the company is providing products or services that are more in line with new market trends	0.764	
TS1	Top management believes that introducing Industry 4.0 technologies is strategically important	0.812	Maduku et al. (2016) [32]; Wang et al. (2010) [52]
TS2	Top management is willing to invest in the introduction of advanced technology	0.843	
TS3	Top management is willing to take responsibility in the process of introducing technology	0.828	
TS4	Top management encourages the updating of the company's technology to improve competitiveness	0.837	
TS5	Top management actively encourages the use of advanced technology to gain competitive advantages	0.826	
TS6	Top management is willing to provide relevant training	0.808	

Note: AD = adoption; CP = compatibility; CPP = competitive pressure; CT = cost; EC = employee capability; PCI = process innovation; PDI = product innovation; PF = company performance; TS = top management support; all the respondents were asked to answer the survey based on the Industry 4.0 technologies that were selected at the beginning.

3.2. Data Collection and Sampling

In order to gain sufficient samples, the survey was created by using the Tencent online survey system and randomly delivered to potential participants of manufacturing and service firms only in the database through WeChat, one of China's largest SNS (Social Networking Services) platforms. It took about two months, from October to November 2020, more than 700 surveys were delivered but only a total of 340 completed questionnaires were collected and later used in the data analysis. In order to test the conceptual model and the significance of the hypotheses, we conducted a confirmatory factor analysis and structural equation analysis (using SmartPLS3.2.8).

All participants had been working in companies that had applied at least one core Industry 4.0 technology (or companies that are in the process of adoption). Managers and company representatives who have some experience with adopting/using the Industry 4.0 technologies participated in the survey. Actually, Industry 4.0 has included more than 1200 enabling technologies and there is no universal definition of Industry 4.0 [5], but in this study, core Industry 4.0 technologies refers to smart factories, big data, driver-less cars/equipment, AI, cloud computing, 3D printing, robotics, 5G, augmented reality, virtual reality, sensors/automatic identification tech, Internet of Things, blockchain, cyber-physical systems, and smart management systems, and participants were asked to choose the adopted technology from multiple choices. According to the demographic characteristics of the samples, around 70% of the companies had utilized more than one of the aforementioned Industry 4.0 technologies and around 90% of them had introduced those advanced technologies in 5 years. Among the samples, 57.65% represented service companies from sectors such as Logistics, Wholesale and Retail, Tourism, Catering, Software and Information Services, etc., and 42.35% were manufacturing companies from sectors such as Textile and Garment, Biomedicine, Food and Beverage, Automobile, Electronic Appliance Manufacturing, etc. In terms of participation in global trade, the survey subjects consisted of exporting companies (23.24%), importing companies (12.94%), export and import companies (18.53%) and non-global-trade companies (45.29%) (Table 3).

Table 3. Sample Profile.

Demographic Variables		Frequency	Percent
Time of using this technology	≤12 months	201	59.11
	13–24 months (2 years)	68	20.00
	25–36 months (3 years)	22	6.47
	37–60 months (5 years)	16	4.71
	>60 months (5 years)	33	9.71
Employee number	1–50	85	25.00
	51–150	96	28.24
	151–300	75	22.06
	301–450	19	5.59
	451–600	21	6.18
	above 600	44	12.93
Industry type	Service industry	196	57.65
	Manufacturing industry	144	42.35
Participation in global trade	Export company	79	23.24
	Import company	44	12.94
	Export and import company	63	18.53
	Non-global-trade company	154	45.29

4. Results

In this study, the PLS-SEM (Partial least squares–structural equation modeling) approach was utilized to verify the established hypotheses. This study adopted Structural Equation Modeling (SEM) using SmartPLS3.2.8 software and applied bootstrapping procedure of 5000-subsample suggested by Hair et al. (2016) [53]. The PLS-SEM method has been frequently used in recent business studies. In general, PLS is suitable for analyzing complex relationships because it minimizes factor uncertainty [54]. It is also a statistical tool that can simultaneously perform an optimal evaluation of the measurement model and the structural model, and has the advantage of being less constrained by the sample size than the other structural equation program. It is also considered to be more appropriate for exploratory research [14], as is the case in this study. Thus, the PLS-SEM method was considered to be relatively suitable for the study purpose.

4.1. Measurement Model

Reliability was first measured using Cronbach's Alpha. The overall Cronbach's Alpha of each configuration was greater than 0.7. Generally speaking, Cronbach Alpha values range from 0 to 1, and if values are greater than 0.7, it can be concluded that a strong concentration exists between constructs [55]. Moreover, as suggested by Bagozzi and Yi (1988) [56], if the Average Variance Extracted (AVE) level is above 0.5 and the Composite Reliability (CR) level is above 0.7, it indicates good construct reliability of the conceptual model. As shown in Table 4, the AVE and CR levels were all within the recommended levels. Meanwhile, all the item loading levels were higher than 0.5 (Table 2). These all confirmed the appropriate convergent validity of the measurement items in the confirmatory analysis.

For discriminant validity, as shown in Table 5, the AVE's square root of each construct was larger than the inter-construct correlations, meaning that the measurement items enjoyed good discriminant validity [57].

Table 4. Construct Reliability and Validity.

Construct	Cronbach's Alpha	CR	AVE
Adoption	0.900	0.926	0.714
Compatibility	0.865	0.899	0.598
Competitive pressure	0.855	0.896	0.633
Cost	0.858	0.898	0.639
Employee capability	0.877	0.911	0.672
Company performance	0.869	0.905	0.656
Process innovation	0.884	0.912	0.633
Product innovation	0.885	0.913	0.636
Top management support	0.907	0.928	0.682

Table 5. Fornell-Larcker Criterion.

Construct	1	2	3	4	5	6	7	8	9
Adoption (1)	0.845								
Compatibility (2)	0.760	0.773							
Competitive pressure (3)	0.691	0.673	0.796						
Cost (4)	0.557	0.584	0.636	0.799					
Employee capability (5)	0.644	0.581	0.658	0.508	0.820				
Company performance (6)	0.604	0.631	0.594	0.469	0.563	0.810			
Process innovation (7)	0.722	0.698	0.647	0.538	0.599	0.738	0.796		
Product innovation (8)	0.775	0.727	0.709	0.558	0.668	0.711	0.777	0.797	
Top management support (9)	0.692	0.658	0.677	0.546	0.714	0.635	0.640	0.683	0.826

Finally, regarding the identification of CMB (common method bias), this study has checked the variance inflation factors (VIFs) through collinearity statistics. According to Kock (2015) [58], if the VIFs of the inner model based on a full collinearity test are no more than 3.3, the research model can be confirmed as free of CMB. In this study, all of the occurrences of VIFs are equal to or lower than the recommended threshold (range from 1~3.3), suggesting that our model is free of CMB.

4.2. Structure Model Results

4.2.1. Hypotheses Testing Results

Table 6 and Figure 2 present the test results for all the hypotheses. Seven out of ten hypotheses were confirmed to be significant. According to the results, hypothesis H1 was accepted because compatibility (ß = 0.430, $p < 0.001$) is the most influential determinant of adoption. As expected, top management support (ß = 0.176, $p < 0.05$) and competitive pressure (ß = 0.170, $p < 0.05$) were found to be important to adoption, meaning H4 and H5 were accepted. However, the cost of the technology (ß = 0.030, $p > 0.05$) and employee capability (ß = 0.142, $p > 0.05$) did not have significant effects on technology adoption, so H2 and H3 were rejected.

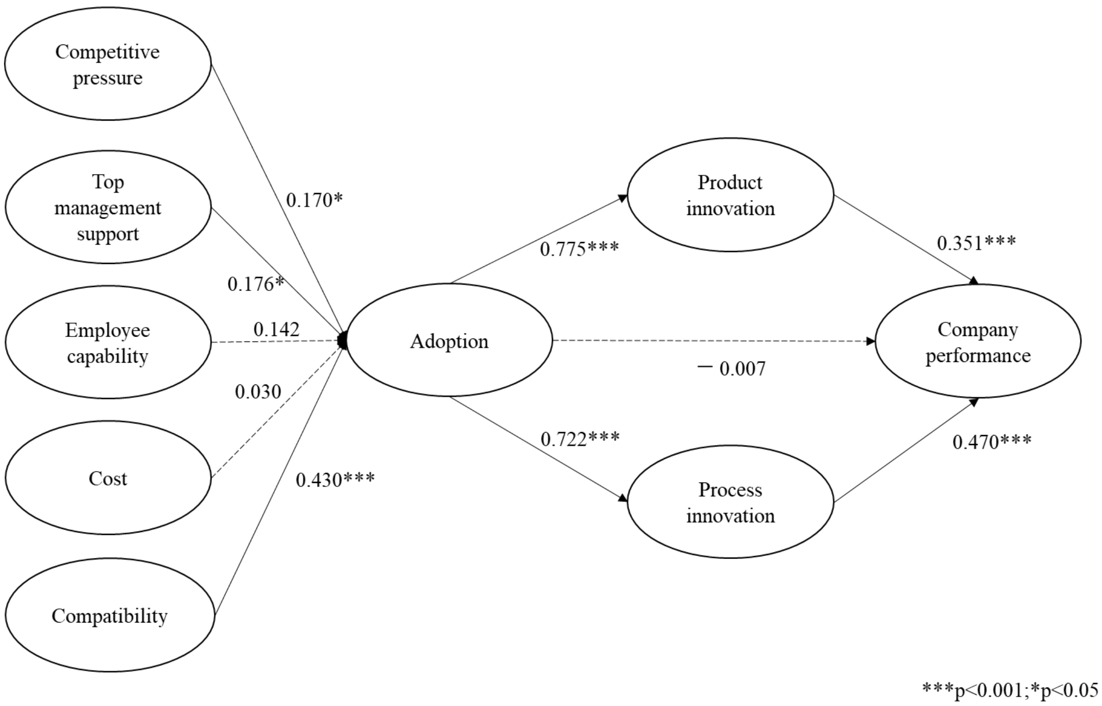

Figure 2. Model Testing Results.

Table 6. Hypotheses Testing Results.

	Hypotheses	β	Standard Deviation	T Statistics	*p* Values
H1	CP → AD	0.430	0.079	5.447	0.000
H2	CT → AD	0.030	0.055	0.550	0.582
H3	EC → AD	0.142	0.074	1.904	0.057
H4	TS → AD	0.176	0.079	2.228	0.026
H5	CPP → AD	0.170	0.077	2.218	0.027
H6	AD → PDI	0.775	0.030	25.592	0.000
H7	PDI → PF	0.351	0.089	3.940	0.000
H8	AD → PCI	0.722	0.039	18.437	0.000
H9	PCI → PF	0.470	0.099	4.742	0.000
H10	AD → PF	−0.007	0.104	0.070	0.945

In addition, technology adoption was found to have direct effects on product innovation (ß = 0.775, $p < 0.001$) and process innovation (ß = 0.722, $p < 0.001$), supporting H6 and H8. Company performance could be positively influenced by product innovation (ß = 0.351, $p < 0.001$) and process innovation (ß = 0.470, $p < 0.001$), which would support

H7 and H9, but technology adoption (ß = −0.007, $p > 0.05$) showed no direct implications for company performance, meaning H10 was rejected.

4.2.2. PLS-MGA Moderation Test

This study selected participation in global trade and industry type as moderators. In order to find out whether these had effects on the technology adoption process, innovation, and company performance, this study applied Partial Least Squares Multi-Group Analysis (PLS-MGA) for the group comparison. PLS-MGA is a non-parametric significance test for group differences based on PLS-SEM bootstrap results. If the p-value should be less than 0.05 or greater than 0.95, the difference in specific path coefficients across groups is regarded as significant at the 5% probability of error level [59].

According to the results shown in Table 7, after adoption, global trade companies seemed to experience greater process innovation than non-global-trade companies. Companies in different industries also exhibited some differences in their technology adoption processes. Employee capability in the service industry can play a more vital role in the adoption decision. These findings indicated that H12 and H13 were partially supported.

Table 7. Multi-Group Analysis Results.

	Hypotheses	β (TR)	β (NTR)	*p*-Value (TR vs. NTR)	β (M)	B (S)	*p*-Value (M vs. S)
H1	CP → AD	0.488	0.352	0.195	0.572	0.363	0.075
H2	CT → AD	0.069	0.013	0.300	0.102	−0.028	0.104
H3	EC → AD	0.057	0.240	0.897	−0.092	0.263	0.998
H4	TS → AD	0.178	0.186	0.539	0.263	0.113	0.145
H5	CPP → AD	0.182	0.126	0.362	0.083	0.239	0.885
H6	AD → PDI	0.767	0.781	0.592	0.769	0.773	0.514
H7	PDI→ PF	0.387	0.329	0.374	0.314	0.364	0.612
H8	AD → PCI	0.789	0.631	0.021	0.760	0.703	0.224
H9	PCI → PF	0.545	0.416	0.247	0.574	0.413	0.233
H10	AD → PF	−0.086	0.020	0.694	−0.055	0.021	0.647

Note: NTR = non-global-trade company; M = Manufacturing industry; S = Service industry; TR = global trade company.

4.2.3. Mediation Test

This study intended to find out whether product innovation and process innovation could have mediating effects on the relationship between technology adoption and company performance. Mediation testing results, as shown in Table 8, indicated that technology adoption could not be directly linked with company performance but through the mediation of product innovation (indirect effects: $\beta_{\text{adoption} \rightarrow \text{product innovation} \rightarrow \text{company performance}} = 0.272$, $p < 0.001$) and process innovation (indirect effects: $\beta_{\text{adoption} \rightarrow \text{process innovation} \rightarrow \text{company performance}} = 0.340$, $p < 0.001$), it could significantly and indirectly influence company performance (Figure 3). Thus, it could be said that product innovation and process innovation can act as mediators between technology adoption and company performance, meaning H11(a) and H11(b) were accepted.

Table 8. Mediation Effects of Product Innovation and Process Innovation.

Path	First Stage		Second Stage		Direct Effects		Indirect Effects		Total Effects AD → PF		Mediation
	β	*p*	β	*p*	β	*p*	β	*p*	β	*p*	
AD → PDI → PF	0.775	0.000	0.351	0.000	−0.007	0.945	0.272	0.000	0.610	0.000	Yes
AD → PCI → PF	0.722	0.000	0.470	0.000			0.340	0.000			Yes

Note: AD = adoption; PCI = process innovation; PDI = product innovation; PF = company performance.

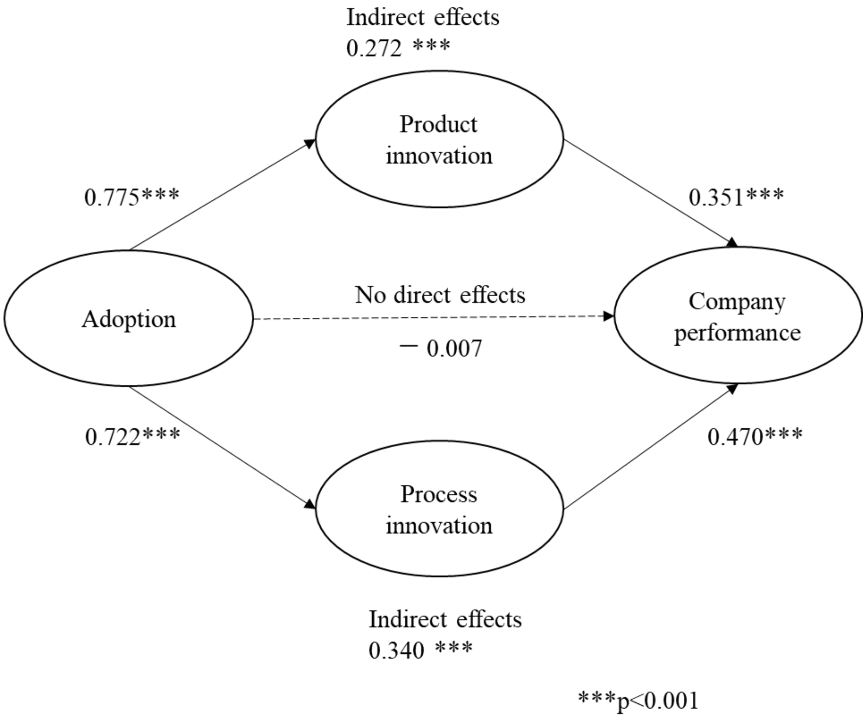

Figure 3. Mediation Testing Results.

5. Conclusion and Discussion

5.1. Discussions and Theoretical Implications

This study intended to investigate the determinants of adoption of Industry 4.0 technology, and how such adoption can drive innovation and company performance. A TOE (technology-organization-environment) based innovation model was established by linking the TOE model with product innovation, process innovation, and company performance. Meanwhile, by testing the moderation effects of industry type and global trade with the conceptual model, this study has served to enrich our understanding of Industry 4.0 technology adoption under a different context.

The findings showed that compatibility is the most influential factor that can positively impact technology adoption, which was similar to Yoon et al.'s (2020) research on smart farm adoption in Korea [14]. It may imply that ensuring that new technology is compatible with existing production/service lines, management systems, technical systems, and so forth is vital in making adoption decisions. This study also found that support from top management is critically necessary to the adoption decision and this finding substantiates Lin's (2014) study on supply chain management system adoption [39]. In other words, only with the support of top management to provide essential resources and training etc., adoption can be carried out successfully. Besides technological and organizational factors, pressures from the external environment were also confirmed to be relatively important in Industry 4.0 technology adoption. Companies may experience customer retention difficulties if they fail to keep up with competitors. According to Bhattacharya and Wamba

(2018) [34], companies may perceive pressure not to lose their competitive advantages over competitors, which will force them to adopt new practices. Thus, we provided evidence showing that compatibility, top management and competitive pressure are decisive drivers of Industry 4.0 technology adoption. In this study, we assumed that cost may negatively affect technology adoption, because using Industry 4.0 technologies may be accompanied by huge costs of set-up, software purchases, or training and other related cost, all of these costs might be regarded as obstacles to technology adoption. However, the results worked against the arguments that cost can hinder technology adoption [14,32,33]. This study indicated that cost might not be the relatively crucial factor in adoption decisions compared with other factors for the surveyed company. In other words, when some companies adopt technologies such as AI, cloud computing, 3D printing, robotics, 5G, augmented reality and so forth, they may lay more emphasis on gaining competitive advantages, production efficiency and profit growth but the cost may play a less dominant role in their adoption decisions. Another possible reason might be the decreasing cost of introducing digital technologies such as IoT and cloud computing [60], which may have made the adoption of new technologies more affordable to some companies. Additionally, testing results of the whole group showed that employee capability overall cannot play a decisive role in adoption either. This differs from the view that having qualified personnel with adequate IT knowledge and skills to participate in the technology adoption process can ultimately stimulate adoption [18,32]. Such results indicated that recently, Industry 4.0 technologies might have already ignited tremendous changes in the workplace and with the help of ongoing technological revolution and automation, there could be a declining need for people's participation, skills, or interaction during work. This finding offered more empirical evidence that the Industry 4.0 technology adoption process has become less demanding on people.

However, employee capability seems to function differently across industries in the adoption process. The moderation testing result revealed that differences exist across industries during Industry 4.0 technology adoption process; industry type can moderate the relationships between employee capability and technology adoption. Although many manufacturing sectors such as furniture, textile and garment manufacturing etc. are intensively relying on labor resources, in this study, the findings suggested that surprisingly, employee capability tends to be less influential in the adoption decisions of manufacturing companies than service companies. It means that Industry 4.0 adoption in the service industry may depend more on employees' skills, knowledge, participation, and abilities. Such findings indicated that appropriate employee capability may be more vital to technology adoption in the service industry than the manufacturing industry. Additionally, according to the moderation test results, international trade activities seem to have no significant effects on the antecedents of technology adoption, but compared to non-global-trade companies, Industry 4.0 technology adoption has stronger effects on process innovation in global trade companies. The overall innovation (combining product and process innovation) of global trade companies also seems to be greater than that of non-global-trade companies. More importantly, this study found that through innovation, the performance of global trade companies was improved on a slightly larger scale than non-global-trade companies. This study may provide empirical evidence showing that participation in international trade can impact Industry 4.0 technology adoption and innovation process. One of the reasonable explanations might be that global trade companies tend to have greater access to foreign resources, Industry 4.0 technologies, and technical expertise. Through knowledge/resource sharing with oversea partners, global trade companies may have a greater propensity to stimulate innovation with newly adopted Industry 4.0 technologies and reinforce firm performance.

More significantly, we confirmed the full mediation effects of product innovation and process innovation. Industry 4.0 technology can promote better product performance, production efficiency and so forth to generate huge product innovation and process innovation. Based on our current knowledge, limited studies have ever verified the mediation of product and process innovation under the Industry 4.0 context. In accordance with the results of the mediation test, technology adoption cannot be directly associated with firm performance; but these adopted technologies could enhance firm performance indirectly through the mediation of product and process innovation. This finding can serve to explain the mechanism between Industry 4.0 technology adoption and firm performance. Thus, after adoption, it is critically essential to apply these Industry 4.0 technologies to boost innovations such as upgrading the current service/production line, reinforcing the efficiency of the existing production (service) process, and providing products (services) with better quality. This result indicated that the effectiveness of adopted Industry 4.0 technologies should be maximized through product and process innovation.

Overall, China has taken the lead in adopting Industry 4.0 among developing countries, with new technology adoption being carried out actively within the country. Investigating the determinants of Industry 4.0 technology adoption and exploring how such technology adoption relates to innovation and company performance in China is extremely significant. This study can offer more empirical evidence of technological transformation in developing countries and proposes a TOE-based innovation model for follow-up research into Industry 4.0 across different types of companies and industries.

5.2. Managerial Implications

Our findings suggested that compatibility, top management support, and competitive pressure are indispensable drivers of Industry 4.0 technology adoption. The result also indicated that product and process innovation can mediate between technology adoption and company performance. Companies in different industries or with global trading experience showed differences in technology adoption and innovation. Based on these findings, we have concluded the managerial implications focusing on the TOE (technology-organization-environment) based innovation model as follows:

First of all, considering the technological aspect, compatibility acts as the strongest predictor of technology adoption. Thus, companies that intend to adopt Industry 4.0 technologies might need to pay more attention to this. In order to generate benefits through adoption, managers should ensure that adopted Industry 4.0 technology fits with the requirements of current production/service processes, management systems, organizational structures, and so forth; otherwise, such adoption may incur extra coordination costs. It is also important to consider technical and customer needs, so as to choose the most suitable technology. Instead of introducing several Industry 4.0 technologies at the same time, companies may consider only adopting one or two technologies that can be integrated easily with current systems to minimize coordination costs at the early stage. Companies can cooperate with early adopters or oversea partners to gather more information about Industry 4.0 adoption and get better prepared. This is helpful for choosing the most appropriate technology and reducing potential coordination costs. Another possible solution is to adopt advanced technologies that can be easily combined together to build digital platforms and form synergies. For example, previous evidence showed integrating the Internet of Things, cloud computing, big data and analytics to build digital supply chain platforms can increase firm performance [61], which suggests that a combination of these Industry 4.0 technologies may encounter fewer compatibility issues.

Secondly, when it comes to the organizational aspect, support from top management is critical to the adoption process. Managers should be aware of the significance of technological innovation and continuously support new technology adoption by all means (offering related resources, financial support etc.). They should also provide adequate training programs for employees and give rewards to those who actively participate in the training to encourage the usage of Industry 4.0 technologies.

Thirdly, referring to the environmental aspect, competitive pressure also plays a key role in organizational technology adoption. Managers should be aware that competitive pressure is not always a negative thing for businesses. Companies that tend to be more sensitive to competitive pressure are more likely to enjoy the privileges of being the first mover in technology adoption and leading technological transformation within their industry. However, companies that are late adopters of these Industry 4.0 technologies may face risks of losing competitive advantages. Thus, companies should monitor technological trends and actively participate in the adoption of Industry 4.0 technologies.

Fourthly, product and process innovation can fully mediate the relationship between new technology adoption and firm performance. Simply adopting Industry 4.0 technologies cannot improve firm performance significantly as expected. The key to improving business performance is to take efforts to use Industry 4.0 technologies to innovate. Companies should introduce the latest technologies with the aim of motivating product and process innovation. It is essential to get familiar with current customer needs and market trends, then use Industry 4.0 technologies to upgrade existing products (services) to offer customers a superior and customized experience to meet their needs more promptly. More importantly, utilizing these smart and automatic technologies to enhance information processing and improve the efficiency of production (service) should also be the ultimate goal after the adoption. Only through using Industry 4.0 technologies to support continuous innovation, it can effectively impact firm performance and lead to market expansion, and sales growth.

Moreover, employee capability showed no significant effects on the adoption process in the full sample model, but testing results of the moderation effects of industry indicated that employee ability is still a comparatively significant factor for companies in the service industry compared to the manufacturing industry. Therefore, service-based companies should make great efforts to educate and stimulate employees' awareness of the significance of new technology adoption. They should also provide sufficient support, relevant education, and customized training to employees before and after the adoption in order to help them become familiar with these Industry 4.0 technologies. Particularly, in the service industry, giving some appropriate guidelines (e.g., an easy-to-understand operation manual) and hiring a few in-house technical experts to help employees use those Industry 4.0 technologies may be extremely necessary at the early stages of adoption.

Finally, in contrast to non-global-trade companies, global trade companies' adoption behavior can lead to greater improvement in the innovation process, especially process innovation. Because global trade companies will likely have more extensive access to various oversea resources and technical expertise, they may also have a higher propensity to adopt Industry 4.0 technologies and leverage greater technological innovation. As a result, technological innovation drives higher productivity, lower production costs, and better product performance, which would help companies to enjoy more sales growth and market expansion compared to non-global-trade companies. Particularly, the pandemic has caused tremendous disruptions for lots of economies, and some countries have turned to trade protectionism [62], but in this study, we confirmed that participating in global trade can actually promote Industry 4.0 technology adoption and its following innovation. Thus, it is necessarily important for companies to participate in global trade and seek ways to build more connections with foreign partners to exchange resources, knowledge, and technical expertise. Eventually, global trade companies might achieve more technological innovation, enjoy better company performance and recover from economic recession through Industry 4.0 technologies.

6. Limitations and Suggestions for Future Studies

All in all, this study provided a more comprehensive understanding of technology adoption and innovation in China during the Industry 4.0 era. In addition, it offered insights for companies through which they could adjust their strategies for new technology adoption. By identifying the implications of industry type and global trade, this study may prominently contribute to the current knowledge of organizational technology adoption.

However, this study also has some limitations. First of all, the sample could be more diverse. It might be interesting to do a comparison study across several countries to generalize the findings. Secondly, this study may be limited to offering a comparatively general perspective on Industry 4.0. Instead of focusing on a single technology, this study tried to be more inclusive and gain insight into the overall patterns of Industry 4.0 technology adoption. Introducing and combining several Industry 4.0 technologies together during adoption has become a common phenomenon for many companies. As such, companies that have adopted (or companies that are in the process of adopting) one or more of the aforementioned Industry 4.0 technologies were included during the sampling process. However, in future studies, it could also be interesting to study the company-level adoption of a specific technology or digital platforms based on the combination of several technologies, which might lead to some different findings. Lastly, this study only discussed process innovation and product innovation, but future studies might also investigate other types of innovations such as organizational innovation, which may produce some other interesting findings.

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Institutional Review Board Statement: Not applicable.

Informed Consent Statement: The survey was collected online. At the beginning, we made a statement that the collected data is confidential and will only be used for academic purposes. If the participants want to participate in the survey, they can continue to complete the following questions by clicking "yes, continue to next question". Thereby, Informed consent was obtained.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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