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Technology-pushed, market-pulled, or government-driven? The adoption of industry 4.0 technologies in a developing economy

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Abstract

Purpose – This study aims to investigate the motivations for the adoption of Industry 4.0 technologies among manufacturing firms in developing economies. Specifically, the effects of relative advantage of the technologies, competitive pressure, and government support on the adoption are explored. Moreover, the mediating role of top management support between environmental factors (government support and competitive pressure) and the adoption of Industry 4.0 technologies is examined.

Design/methodology/approach – A research model is developed based on the technology-organization-environment (TOE) framework strengthened by institutional theory. Structural equation modeling (SEM) approach is employed to evaluate the model using data obtained from 215 manufacturing firms through a cross-industry survey. Additionally, a *post-hoc* analysis is conducted using cluster analysis and ANOVA.

Findings – The results show that competitive pressure and government support significantly promote top management support, which in turn contributes to the adoption of Industry 4.0 technologies. Relative advantage of the technologies is not significantly related to the adoption.

Research limitations/implications – This study does not explore the relationship between technology type and the specific needs of manufacturing firms. Future researchers can conduct a more comprehensive analysis by examining how different technology types align with the unique needs of individual companies.

Practical implications – The findings of this study have implications for both policymakers and managers. Policymakers can leverage these insights to understand the underlying motivations behind manufacturing firms' adoption of Industry 4.0 technologies and develop promoting policies. In turn, managers should keep an eye on government policies and utilize government support to facilitate technology adoption.

Originality/value – This study uncovers the underlying motivations—government support and competitive pressure—for the adoption of Industry 4.0 technologies among manufacturing firms in developing economies. Meanwhile, it complements previous research by showing the mediating role of top management support between environmental factors (government support and competitive pressure) and the adoption of Industry 4.0 technologies.

Keywords Industry 4.0 technologies, Technology adoption, Technology-pushed, Market-pulled, Government-driven, Top management support

Paper type Article

1. Introduction

The term "Industry 4.0" was introduced at the Hannover Fair in 2011. It was officially announced in 2013 as a German strategic initiative to take a leading role in the manufacturing

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industry (Kagermann *et al.*, 2013; Xu *et al.*, 2018). Now it sometimes refers to digital transformation or the "Fourth Industrial Revolution" (Hofmann and Rüsch, 2017; Klingenberg *et al.*, 2022). Mostly, Industry 4.0 refers to the digitalization or digital transformation of the manufacturing industry (Ghobakhloo and Ching, 2019; Horváth and Szabó, 2019). It is built upon the integration of information and communication technologies (ICT) and industrial technologies (Alcácer and Cruz-Machado, 2019; Zhou *et al.*, 2015). These technologies are the backbone of Industry 4.0 (Bartodziej, 2017; Choi *et al.*, 2022).

A variety of advantages/benefits of Industry 4.0 technologies have been claimed by researchers (Hofmann and Rüsch, 2017). Empirical research showed that Industry 4.0 technologies contribute to the improvement of organizational performance, such as product and innovation performance (e.g. improvement of product customization, reduction of product launch time) (Cugno *et al.*, 2021; Dalenogare *et al.*, 2018; Sarbu, 2022), operational performance (e.g. increased productivity, reduction of operational cost) (Calış Duman and Akdemir, 2021; Cugno *et al.*, 2021; Dalenogare *et al.*, 2018; Sony *et al.*, 2021; Tortorella *et al.*, 2020), sustainability (Bag *et al.*, 2021), and profitability (Calış Duman and Akdemir, 2021).

With its promising advantages/benefits, Industry 4.0 has aroused researchers' interest in its adoption (Frank *et al.*, 2019; Khin and Kee, 2022; Tortorella *et al.*, 2022). Although plenty of work has been done, there are some research gaps regarding the motivations for the adoption of Industry 4.0 technologies among manufacturing firms in developing economies. Relative advantage has been identified as a factor that affects the adoption of Industry 4.0 technologies (Arnold *et al.*, 2018; Chen *et al.*, 2015; Hsu *et al.*, 2014). However, manufacturing firms are still hesitant to embrace Industry 4.0 technologies despite the advantages/benefits (Khin and Kee, 2022). Most manufacturing firms are non-adopters or low to moderate adopters, especially in developing economies (Frank *et al.*, 2019; Ghobakhloo and Ching, 2019). This brings us to the first research question:

RQ1. Is relative advantage a motivation for the adoption of Industry 4.0 technologies among manufacturing firms in developing economies?

Along with the push power from technology advantage, the market can be the pull force for the adoption of new technologies (Brem and Voigt, 2009; Munro and Noori, 1988). The study by Arnold *et al.* (2018) showed that market competition is positively related to Industry 4.0 adoption in Germany. However, the study by Ghobakhloo and Ching (2019) conducted among SMEs in Malaysia and Iran showed that competitive pressure is not related to the adoption of smart manufacturing technologies. The effects of competitive pressure from the market seem to be different in developed and developing economies. The second research question is,

RQ2. Is competitive pressure a motivation for the adoption of Industry 4.0 technologies among manufacturing firms in developing economies?

Besides market mechanisms, governments play an important role in the strategic choices of organizations, although some developing economies have been undergoing an institutional transition from a relationship-centered to a market-centered structure (Peng, 2003). Governments of developing economies have initiated national programs to provide support to domestic enterprises to promote Industry 4.0, such as "Made in China (2025)", "Make in India", "Thailand 4.0 plan", and "National Policy on Industry 4.0" of Malaysia (Li, 2018; Majstorovic and Mitrovic, 2019). The effects of government support can be different in developed and developing economies whose institutional contexts are different (Zhu *et al.*, 2006). Studies conducted in Portugal and Taiwan have found that government support is not significantly related to the adoption of cloud computing (Hsu *et al.*, 2014; Oliveira *et al.*, 2014), but an exploratory study on the Chinese automotive industry's response to Industry 4.0 revealed that government support positively affects the intention to use advanced production technologies (Lin *et al.*, 2018). The third question is, *RQ3.* Is government support a motivation for the adoption of Industry 4.0 technologies among manufacturing firms in developing economies?

Environmental factors (e.g. government support and competitive pressure) affect the behaviors of an organization through human agents by exerting pressures on the top management, which in turn affects the adoption decision (Gholami *et al.*, 2013; Hsia *et al.*, 2019; Liang *et al.*, 2007). However, the mediating role of top management support between environmental factors and the adoption has been overlooked in the literature on Industry 4.0. Therefore, investigating the mediating of top management support is another purpose of this study.

In summary, this study aims to investigate whether the adoption of Industry 4.0 technologies is technology-pushed, market-pulled, or government-driven among manufacturing firms in developing economies. The mediating role of top management support between environmental factors (government support and competitive pressure) and the adoption is also explored.

The technology-organization-environment (TOE) framework is employed to develop the research model. The TOE framework takes a broad perspective by considering technological, organizational, and environmental factors simultaneously in the adoption and implementation of technological innovations (Baker, 2012; Tornatzky and Fleischer, 1990). Structural equation modeling (SEM) approach is employed to evaluate the research model, using data obtained from 215 manufacturing firms through a cross-industry survey. Additionally, a post-hoc analysis is conducted using cluster analysis and ANOVA.

The rest of the paper is structured as follows. Section 2 provides the theoretical background and the literature review. In Section 3, the research model and hypotheses are proposed. Section 4 and Section 5 present the method and results respectively. Discussion is provided in Section 6, followed by conclusions and limitations in Section 7.

2. Theoretical background and literature review

2.1 Industry 4.0 technologies

The emerging new technologies are the backbone of Industry 4.0 (Bartodziej, 2017; Chae and Olson, 2021). Industry 4.0 is built upon the integration of information and communication technologies (ICT) and industrial technologies (Alcácer and Cruz-Machado, 2019; Zhou *et al.*, 2015). However, so far there is no consensus on a definite list of Industry 4.0 technologies (Cifone *et al.*, 2021). Different researchers have different technology lists. To obtain a proper list, we collected 27 Industry 4.0 papers. Each paper has its list of Industry 4.0 technologies. A summary of the technology lists is presented in Table 1.

Each of the 11 technologies in Table 1 appeared seven or more times in the 27 Industry 4.0 technology lists. Technologies such as virtual reality (VR), blockchain, and manufacturing execution system (MES), which are not included in Table 1, occurred less than seven times. After consulting with two experts on Industry 4.0, we included them in our list of Industry 4.0 technologies, as they were considered important within the context of Industry 4.0. Therefore, our final list comprises 14 technologies, namely cloud computing, IoT, big data and analytics, 3D printing, autonomous robots, augmented reality (AR), simulation, CPS, cyber security, AI, mobile technology, VR, blockchain, and MES. The list is used to measure the adoption of Industry 4.0 technologies in this study.

2.2 TOE framework and institutional theory

2.2.1 TOE framework. Tornatzky and Fleischer (1990) developed the TOE framework to study the affecting factors for the adoption and implementation of technological innovations at an organizational level. Taking into consideration technological, organizational, and

No	Source	Technologies A	B	C	D	E	F	G	H	I	J	K
1	Dalenogare *et al.* (2018)	✓		✓	✓			✓				
2	Tortorella *et al.* (2020)	✓	✓	✓								
3	Yu and Schweisfurth (2020)	✓	✓	✓	✓	✓	✓	✓		✓		
4	Moeuf *et al.* (2017)	✓	✓	✓		✓		✓	✓	✓		
5	Schmidt *et al.* (2015)	✓	✓	✓					✓			✓
6	Stentoft and Rajkumar (2019)	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
7	Rossini *et al.* (2019)	✓	✓	✓	✓	✓	✓				✓	✓
8	Liao *et al.* (2017)	✓		✓	✓			✓			✓	
9	Vaidya *et al.* (2018)	✓	✓	✓	✓	✓	✓	✓	✓			
10	Zhou *et al.* (2015)	✓	✓	✓					✓			✓
11	Bartodziej (2017)	✓	✓	✓	✓	✓			✓	✓		✓
12	Kang *et al.* (2016)	✓	✓	✓	✓				✓			
13	Zheng *et al.* (2021)	✓	✓	✓	✓	✓	✓	✓	✓		✓	
14	Lu (2017)	✓	✓	✓								✓
15	Büchi *et al.* (2020)	✓	✓	✓	✓		✓	✓		✓		
16	Wang *et al.* (2016)	✓	✓	✓							✓	
17	Da Silva *et al.* (2020)	✓	✓	✓		✓	✓	✓	✓	✓		
18	Oztemel and Gursev (2020)	✓	✓	✓		✓	✓	✓	✓			
19	Xu *et al.* (2018)	✓	✓						✓			
20	Pacchini *et al.* (2019)	✓	✓	✓	✓	✓	✓		✓		✓	
21	Pollak *et al.* (2020)	✓	✓	✓	✓	✓	✓					
22	Ghobakhloo (2018)	✓	✓	✓	✓	✓	✓	✓	✓	✓		
23	Zhong *et al.* (2017)	✓	✓	✓					✓			
24	Tang and Veelenturf (2019)		✓		✓	✓					✓	
25	Alcácer and Cruz-Machado (2019)	✓	✓	✓	✓	✓	✓	✓		✓		
26	Nayernia *et al.* (2022)	✓	✓	✓	✓	✓	✓	✓		✓	✓	
27	Choi *et al.* (2022)		✓		✓	✓	✓				✓	✓
	Frequency	25	25	24	17	16	14	13	13	9	9	7

Note(s): A: Cloud computing; B: IoT; C: Big data and analytics; D: 3D printing; E: Autonomous robots; F: AR; G: Simulation; H: CPS; I: Cyber security; J: AI; K: Mobile technology
Source(s): Authors work

Table 1.
Industry 4.0 technologies in literature

environmental factors, the TOE framework provides researchers with a broader perspective. The effectiveness of the TOE framework has been verified by numerous empirical studies on the adoption of information systems and other technologies, such as E-business, inter-organizational systems, EDI, open systems, enterprise systems, RFID, etc. (Baker, 2012; Chau and Tam, 1997; Oliveira and Martins, 2011; Wang *et al.*, 2010; Zhu *et al.*, 2006). Its effectiveness can be attributed to its "generic" nature since the framework can be used as an umbrella under which a host of various factors can be placed.

2.2.2 Institutional theory. Institutional theory is effective when explaining the impact of environmental factors on organizational behaviors (DiMaggio and Powell, 1983; Liang *et al.*, 2007). It can strengthen the environmental dimension of the TOE framework by providing it with a more valid theoretical basis (Oliveira *et al.*, 2019). The new institutional theory argues that the practices and forms of organizations tend to be increasingly similar because of institutional pressures from the environment (DiMaggio and Powell, 1983; Teo *et al.*, 2003). These institutional pressures include coercive pressures, mimetic pressures, and normative pressures. Coercive pressures are defined as "formal or informal pressures exerted on organizations by other organizations upon which they are dependent" (DiMaggio and Powell, 1983; Teo *et al.*, 2003). Sources of coercive pressures include the government, industry, parent corporation, competitive market, etc. (Liang *et al.*, 2007; Teo *et al.*, 2003). Mimetic pressures emerge when a practice becomes prevalent among peer organizations or competitors, especially when the adoption of the practice is perceived to be successful (Haveman, 1993; Teo *et al.*, 2003). Normative pressures manifest themselves in the form of norms, rules, and information shared between members of a network (Powell and DiMaggio, 2012). In this study, we investigate the effects of environmental factors as sources of pressures through the lens of institutional theory.

2.3 Literature on industry 4.0 adoption

Researchers often mixed "adoption" with "implementation" (Frank *et al.*, 2019; Ghobakhloo, 2020; Raj *et al.*, 2020). Adoption and implementation are two different but consecutive stages in the process of technology assimilation (Cooper and Zmud, 1990; Fichman, 2000; Grover and Goslar, 1993; Zhu *et al.*, 2006). Adoption is the decision to introduce a technology, and implementation is the deployment and utilization of the technology (Grover and Goslar, 1993; Zhu *et al.*, 2006). As shown in Table 2, the affecting factors for the adoption of Industry 4.0 generally fall into the three dimensions of the TOE framework. In addition to relative advantage, government support, and competitive pressure, which are of particular interest to this study, researchers have also explored other affecting factors for Industry 4.0 technologies.

Technological factors include relative advantage/perceived benefits (Chen *et al.*, 2015; Hsu *et al.*, 2014), complexity (Da Silva *et al.*, 2020; Oliveira *et al.*, 2014), compatibility (Chen *et al.*, 2015; Wang *et al.*, 2010), cost (Raj *et al.*, 2020), etc. The effects of relative advantage, complexity, and compatibility on adoption are inconsistent across studies as shown in Table 2. For example, studies conducted in the US and Taiwan showed that relative advantage is positively related to the adoption of big data and cloud computing (Chen *et al.*, 2015; Hsu *et al.*, 2014), while the study by Wei *et al.* (2015) revealed that relative advantage has no impact on the adoption of RFID in China.

Dimensions	Key factors	Sources
Technological	Relative advantage (0, +)	Chen *et al.* (2015), Hsu *et al.* (2014), Wei *et al.* (2015)
	Complexity (0, −)	Da Silva *et al.* (2020), Wang *et al.* (2010), Wei *et al.* (2015)
	Compatibility (0, +)	Chen *et al.* (2015), Wang *et al.* (2015)
	Cost (−)	Raj *et al.* (2020)
Organizational	Top management support (0, +)	Arnold *et al.* (2018), Oliveira *et al.* (2014), Wang *et al.* (2010)
	Technology competence (0, +)	Chatterjee *et al.* (2021), Hsu *et al.* (2014), Oliveira *et al.* (2014), Oliveira *et al.* (2019), Wang *et al.* (2010)
	Technology infrastructure (+)	Pacchini *et al.* (2019), Wei *et al.* (2015)
	Process smartness	Monshizadeh *et al.* (2023), Santos and Martinho (2020)
	Employee competence and skills (+)	Horváth and Szabó (2019), Raj *et al.* (2020), Tay *et al.* (2021)
	Financial resources (+)	Horváth and Szabó (2019), Veile *et al.* (2020)
	Firm size (+)	Bosman *et al.* (2020), Oliveira *et al.* (2014)
Environmental	Government support (0, +)	Hsu *et al.* (2014), Lin *et al.* (2018), Oliveira *et al.* (2014)
	Competitive pressure (0, +)	Arnold *et al.* (2018), Ghobakhloo and Ching (2019), Horváth and Szabó (2019), Wang *et al.* (2010)
	Labor shortage (+)	Horváth and Szabó (2019), Khin and Kee (2022)

Note(s): 0 (not related to adoption); + (positively related to adoption); − (negatively related to adoption)
Source(s): Authors work

Table 2. Key affecting factors in the literature

Organizational factors include top management support (Arnold *et al.*, 2018; Oliveira *et al.*, 2014), technology competence (Hsu *et al.*, 2014; Oliveira *et al.*, 2019), technology infrastructure (Pacchini *et al.*, 2019; Wei *et al.*, 2015), process smartness (e.g. the degree of digitization, automation, and intelligence of production management, quality management, supply chain management, energy consumption management, etc. (Monshizadeh *et al.*, 2023; Ramanathan and Samaranayake, 2022; Santos and Martinho, 2020). Process smartness is a manifestation of a firm's technological and managerial capabilities, which can contribute to the adoption of Industry 4.0 technologies.), employee competence and skills (Horváth and Szabó, 2019; Raj *et al.*, 2020; Tay *et al.*, 2021), financial resources (Horváth and Szabó, 2019; Veile *et al.*, 2020), firm size (Bosman *et al.*, 2020; Oliveira *et al.*, 2014), etc. Technology competence encompasses technology infrastructure and employee knowledge and skills (Oliveira *et al.*, 2019; Zhu *et al.*, 2006). It is one of the most important factors that get a firm ready for Industry 4.0 (Hizam-Hanafiah *et al.*, 2020). Thus, technology competence is included in this study. Firm size is used as a control variable.

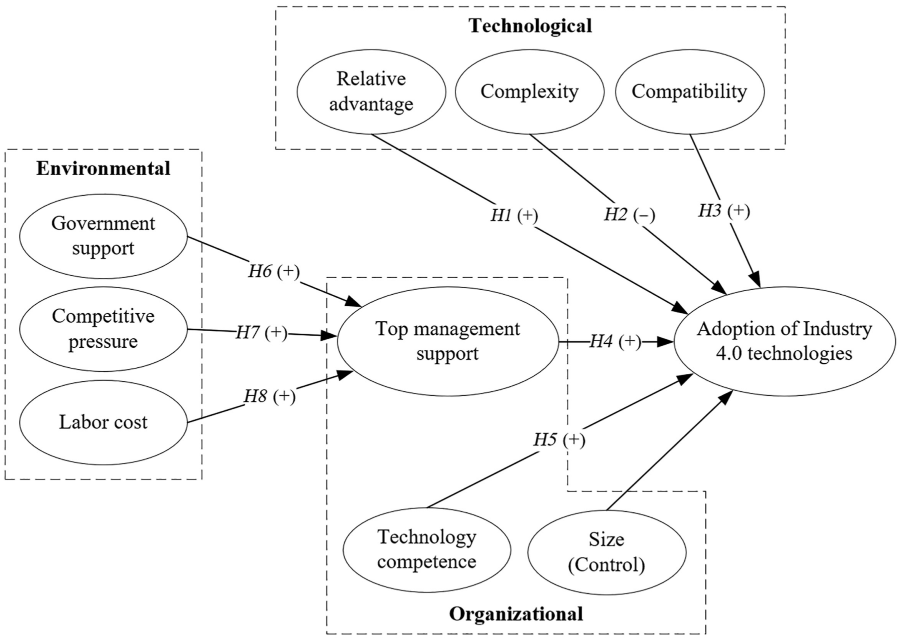
Environmental factors include government support (Hsu *et al.*, 2014; Lin *et al.*, 2018), competitive pressure (Arnold *et al.*, 2018; Ghobakhloo and Ching, 2019; Horváth and Szabó, 2019), labor shortage/cost (Horváth and Szabó, 2019), etc. The study by Oliveira *et al.* (2014) on the adoption of cloud computing (an Industry 4.0 technology) in Portugal showed that government support has no impact on the adoption decision. Consistent with that, the study by Hsu *et al.* (2014) in Taiwan found that pressures from regulations and government policies do not affect firms' intention to adopt cloud computing. However, an exploratory study on the Chinese automotive industry's response to Industry 4.0 revealed that government policy support positively affects the intention to use advanced production technologies (Lin *et al.*, 2018). The effects of competitive pressure also seem to be different in developed and developing economies. The study by Arnold *et al.* (2018) in Germany showed that competition is positively related to Industry 4.0 adoption, but Ghobakhloo and Ching (2019) found that competitive pressure is not related to the adoption of smart manufacturing information and digital technologies among SMEs in Malaysia and Iran.

Environmental factors affect the behaviors of an organization through the role of human agents, exerting pressures on the top management, which in turn affects the adoption decision (Gholami *et al.*, 2013; Hsia *et al.*, 2019; Liang *et al.*, 2007). However, the mediating role of top management support between environmental factors and the adoption has been overlooked in research on Industry 4.0. In studies on information systems and management practices, the mediating role of top management support has been observed (Dubey *et al.*, 2018; Gholami *et al.*, 2013; Hsia *et al.*, 2019; Liang *et al.*, 2007; Ye *et al.*, 2013; Zhang *et al.*, 2018).

In summary, there are two main gaps in the current literature. First, the effects of technology advantage, competitive pressure, and government support on the adoption of Industry 4.0 technologies vary across studies conducted in developing and developed economies, but no study has dealt with these factors simultaneously to investigate whether the adoption of Industry 4.0 technologies is technology-pushed, market-pulled, or government-driven, especially among manufacturing firms in developing economies. Second, the mediating role of top management support between environmental factors and the adoption decision has been overlooked in the current literature on Industry 4.0. This study aims to fill the gaps.

3. Research model and hypothesis development

Based on the literature review and the TOE framework strengthened by institutional theory, we propose the research model consisting of technological, organizational, and environmental factors. Moreover, top management support is proposed as a mediator between environmental factors and the adoption of Industry 4.0 technologies. The research model is shown in Figure 1.



Source(s): Authors work

Figure 1.
Research model

3.1 Technological factors

3.1.1 Relative advantage. Relative advantage is "the degree to which an innovation is perceived as being better than the idea it supersedes" (Rogers, 2003). Relative advantage of a new technology provides adopting firms with the opportunity to improve their competitive advantage. As stated before, empirical research showed that Industry 4.0 technologies contribute to the improvement of organizational performance for manufacturing firms, such as product and innovation performance (e.g. improvement of product customization, reduction of product launch time) (Cugno *et al.*, 2021; Dalenogare *et al.*, 2018; Sarbu, 2022), operational performance (e.g. increased productivity, reduction of operational cost) (Calış Duman and Akdemir, 2021; Cugno *et al.*, 2021; Dalenogare *et al.*, 2018; Tortorella *et al.*, 2020), sustainability (Bag *et al.*, 2021), and profitability (Calış Duman and Akdemir, 2021). With all these claimed advantages, Industry 4.0 technologies draw the attention of manufacturing firms. Firms that perceive higher relative advantage will be more likely to adopt Industry 4.0 technologies. Hence, we hypothesize,

H1. Relative advantage of Industry 4.0 technologies positively influences the adoption of Industry 4.0 technologies.

3.1.2 Complexity. Complexity is "the degree to which an innovation is perceived as relatively difficult to understand and use" (Rogers, 2003). Although a technology may be perceived as useful, the firms might find it complex (Premkumar and Potter, 1995). The perceived complexity can undermine the adopters' confidence, which in turn will hinder the adoption of new technologies (Tornatzky and Klein, 1982). In the context of Industry 4.0, most of the technologies are new to employees so it may not be easy for them to deploy and use the technologies. It can be even more difficult for them to integrate these technologies with legacy technologies to fully realize the synthesis effects. If the technologies are too complex for employees to understand or use, and require more skills, the company's intention to adopt the technologies will be undermined (Meyer and Goes, 1988), especially in firms that lack technological expertise and IT specialists (Oliveira *et al.*, 2014; Sun *et al.*, 2016). The lack of qualified personnel is one of the main challenges that manufacturing firms are facing when trying to introduce Industry 4.0 technologies (Karadayi-Usta, 2020). Therefore, we hypothesize,

H2. Complexity negatively influences the adoption of Industry 4.0 technologies.

3.1.3 Compatibility. Compatibility is "the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters" (Rogers, 2003). If a technology is not compatible with the existing process or organization, more efforts will be needed to put into adjustment, a process of mutual adaptation that requires the "re-invention" of the technology and the adaptation of the process and organization (Leonard-Barton, 1988). Organizational and process changes are among the main barriers to Industry 4.0 adoption (Kamble *et al.*, 2018). The adaptation cost in terms of time, labor, and money can scare away potential adopters. For example, to deploy Industry 4.0 technologies such as AR and VR in the design or production process, many efforts have to be committed to the customization work. On the one hand, customized software development is needed to meet the task requirements. On the other hand, the employees need to get used to the new ways of working. The higher the task-technology compatibility is, the easier it can be integrated into the organization and the more willing the organization will be to adopt it (Cooper and Zmud, 1990). Thus, we hypothesize,

H3. Compatibility positively influences the adoption of Industry 4.0 technologies.

3.2 Organizational factors

3.2.1 Top management support. Industry 4.0 is of strategic importance to manufacturing firms (Büchi *et al.*, 2020; Ivanov *et al.*, 2021). Top managers are often involved in the decision to introduce Industry 4.0 technologies. Their aspiration can be an important driving force for the adoption of Industry 4.0 technologies (Horváth and Szabó, 2019). Once top managers develop beliefs about the new technologies, they are likely to turn their beliefs into actions (Liang *et al.*, 2007). Previous studies showed that top management support is a powerful enabler in the adoption of various strategically important technologies (Damanpour and Schneider, 2006; Oliveira *et al.*, 2014; Premkumar, 2003). Top management has the power to influence the attitudes of members of the organization and conquer organizational resistance to new technologies (Oliveira *et al.*, 2019; Thong, 2001; Thong *et al.*, 1996). If top managers hold the beliefs that new technologies provide strategic edges, it will send powerful signals to other members of the organization (Chatterjee *et al.*, 2002). More importantly, they can ensure the allocation of resources needed (money, people, time, etc.) and act as champions to make changes (Sila, 2013; Thong *et al.*, 1996). Therefore, we hypothesize,

H4. Top management support positively influences the adoption of Industry 4.0 technologies.

3.2.2 Technology competence. Technology competence consists of technology infrastructure and human resources (Oliveira *et al.*, 2019; Zhu *et al.*, 2006). Technology infrastructure refers to the established technologies that support and enable Industry 4.0 technologies. Human resources refer to employees who possess the knowledge and skills necessary for the implementation of Industry 4.0 technologies. Since Industry 4.0 technologies are burgeoning new technologies that demand a high level of technological understanding and relevant qualifications from the employee side (Ghobakhloo, 2020; Ivanov *et al.*, 2021), the availability of competent human resources and a well-established infrastructure can prepare an organization in a better position for the adoption of these technologies. Specifically, Industry 4.0 is built upon the integration of information and communication technologies (ICT) and industrial technologies (Alcácer and Cruz-Machado, 2019; Zhou *et al.*, 2015). ICT technology competence is a core dimension that gets a firm ready for Industry 4.0 (Hizam-Hanafiah *et al.*, 2020). However, manufacturing firms often fall short of ICT technology competence. The lack of technology competence will undermine their confidence in the deployment and use of Industry 4.0 technologies, which in turn undermines their intention to adopt the technologies. Hence,

H5. Technology competence positively influences the adoption of Industry 4.0 technologies.

3.3 Environmental factors

Environmental factors affect the behaviors of an organization through the role of human agents (Liang *et al.*, 2007). Top management is the focal human agent and serves as an interface between environmental forces and organizational actions (Chen *et al.*, 2015; Hsia *et al.*, 2019). Through the lens of institutional theory (DiMaggio and Powell, 1983), of which the core constructs are coercive pressures, normative pressures, and mimetic pressures, we elaborate on the effects of environmental factors on top management support for Industry 4.0 technologies.

3.3.1 Government support. Government policies and regulations can be sources of coercive pressures and normative pressures (Liang *et al.*, 2007; Teo *et al.*, 2003). In developing economies like China where the government has considerable impacts on businesses, these pressures are often felt by managers (Liang *et al.*, 2007). It is reasonable for managers to comply with government policies. They tend to build guanxi with government officials to develop a network, which makes it easier to get resources (Park and Luo, 2001). Governments of developing economies have initiated national programs to provide support to domestic enterprises to promote Industry 4.0 (Li, 2018; Majstorovic and Mitrovic, 2019). Subsidies and preferential tax benefits are provided by the governments (Li, 2018). These incentive instruments are a part of normative pressure and coercive pressure (Zhang *et al.*, 2018). Besides, by leveraging subsidies and tax cuts, firms can reduce the cost of adopting Industry 4.0 technologies. When studying the assimilation of Internet technologies and E-business, researchers found that the regulatory environment plays a more important role in developing countries than in developed countries (Chau *et al.*, 2008; Zhu *et al.*, 2006). Thus, we hypothesize,

H6. Government support positively influences top management support for Industry 4.0 technologies.

3.3.2 Competitive pressure. Many Industry 4.0 projects are started in response to the growing competitive pressure (Schuh *et al.*, 2020). The extent of technology adoption by competitors and the perceived success by competitors form mimetic pressures (Teo *et al.*, 2003). The competitive condition further forms coercive pressures (Liang *et al.*, 2007). The pressures can come from the aspiration of the firm to look progressive, or the belief that if a technology is gaining popularity it must be of value (Fichman, 2000). Liang *et al.* (2007) found that higher levels of mimetic pressures lead to stronger top management beliefs about IT technology and higher levels of coercive pressures lead to stronger top management participation. These pressures derived from competition make the top management support new technologies (Gangwar *et al.*, 2015; Wei *et al.*, 2015). On the one hand, potential adopters tend to adopt new technologies to avoid being perceived as technologically inferior to their competitors (Teo *et al.*, 2003). On the other hand, given the uncertainty of the outcomes of the new technologies, top managers are likely to imitate the successful competitors to avoid potential loss of opportunities and to secure the legitimacy of the adoption decision (Hsia *et al.*, 2019; Liang *et al.*, 2007). Hence, we hypothesize,

H7. Competitive pressure positively influences top management support for Industry 4.0 technologies.

3.3.3 Labor cost. The labor cost in developing economies has been rising for years, e.g. wages for workers in China began to rise sharply since 2000 because of the shortage of workers from the countryside (Zhang *et al.*, 2011). People expect that a modern manufacturing firm should be well equipped with advanced automated and intelligent technologies. The social expectation can be a source of normative pressures, especially against the backdrop of rising labor cost. Once a new technology becomes available, normative pressures arise (Yigitbasioglu, 2015). Industry 4.0 promotes the idea of unmanned factories, also known as "dark factories" or "lights out factories" (Oztemel and Gursev, 2020), which can be an appealing picture to the top management. Firms need new technologies and inventions to reduce labor cost (Li *et al.*, 2020). Along with the temptation to reduce labor cost, top management feels the normative pressures from customers, suppliers, and consultants that a factory should use less direct labor and be highly automated and intelligent in the Industry 4.0 era. Therefore, we hypothesize,

H8. Labor cost positively influences top management support for Industry 4.0 technologies.

4. Methodology

An empirical approach was followed to conduct this study. Development of the questionnaire, collection of the data, and method for analysis are presented in this section.

4.1 Questionnaire development

To collect data for the study, a questionnaire was prepared. An expert panel of three scholars was formed to improve the clarity and validity of the questionnaire. Based on their suggestions, we rewrote some of the items. We further solicited suggestions from six top managers (C-suit members) from six manufacturing firms. Suggestions from the first four managers helped arrive at the final questionnaire. We stopped the process with the last two managers giving no suggestions.

A total of 14 Industry 4.0 technologies presented in Section 2.1 were used to measure the extent of adoption of Industry 4.0 technologies. As Hsu *et al.* (2014) did, each technology was measured on a three-point scale (0: no plan to adopt; 1: plan to adopt in one year; 2: already adopted). If a firm has adopted all the 14 technologies, it would get 28 points.

All other constructs were measured by five-point Likert scales ranging from 1 (strongly disagree) to 5 (strongly agree). Each construct has three or four items, which were adapted from existing research. Firm size, used as a control variable, was measured by the number of employees of the firm. To reduce data variation in the analysis, the firm size variable was log-transformed (Zhu *et al.*, 2006).

4.2 Data collection

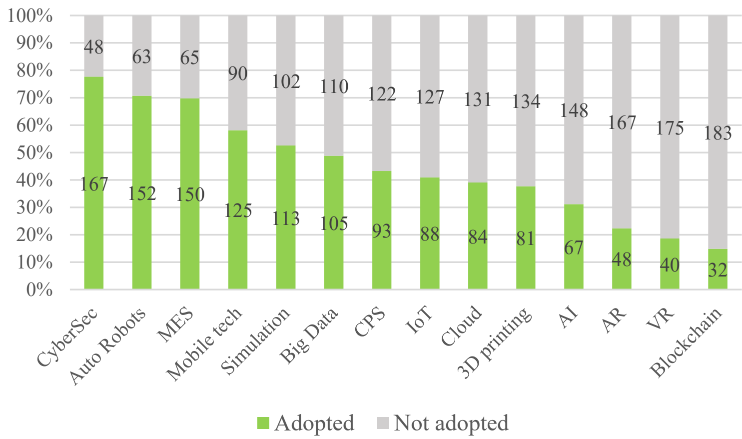
An online questionnaire was designed. The questionnaire link was distributed in WeChat (an instant messaging app in China) groups, whose members were top or middle managers in manufacturing firms. One of the authors had access to these groups due to his involvement in the manufacturing industry for many years. Filter questions included the informant's title and the number of years he/she had been in the firm. To control common method bias *ex ante*, respondents were assured that the information they provided would only be used for academic purposes and remain anonymous. At the end of eight weeks (from December 2021 to January 2022), a total of 215 useable responses were obtained. The adoption of Industry 4.0 technologies is shown in Figure 2. The demographic information is shown in Table 3.

4.3 Analysis method

SEM implemented in Mplus 8.3 was the main method used to analyze the data. First, the measurement model was evaluated using CFA to confirm the reliability and validity. Second, the structural model was assessed to test the hypotheses. Additionally, a post-hoc analysis was performed using cluster analysis and ANOVA.

5. Analysis and results

Before the SEM analysis, the possible common method bias was checked by conducting Harman's one-factor test (Podsakoff *et al.*, 2003). The first extracted factor accounts for 23.28% of the variance. Common method bias is not significant since none of the factors individually explain the majority of the variance.



Source(s): Authors work

Figure 2. Adoption of Industry 4.0 technologies among the firms (N = 215)

Industry	Number	Percentage	Respondent's title	Number	Percentage
Machinery	78	36.3%	CEO/Deputy CEO	41	19.1%
Automobile	37	17.2%	Digitalization/Smart manufacturing manager	29	13.5%
Electronics	32	14.9%	Production manager	22	10.2%
Aviation	29	13.5%	Head of production-related department	21	9.8%
Others	39	18.1%	Technology manager	15	7.0%
			Industrial Engineering manager	14	6.5%
Years the respondent in the firm			Other middle managers	73	34.0%
<2	10	4.7%	*Firm size (number of employees)*		
2–5	36	16.7%	<500	63	29.3%
5–10	51	23.7%	500–1999	58	27.0%
≥10	118	54.9%	≥2000	94	43.7%

Source(s): Authors work

Table 3. Demographic information (n = 215)

5.1 Measurement model

Reliability and validity were evaluated in the measurement model analysis. The results are shown in Table 4 and Table 5. Confirmatory Factor Analysis (CFA) shows that the item loading for each item is above 0.6, showing satisfactory indicator reliability (Chin, 1998). We further calculated the composite reliability and Cronbach's alpha values. Composite reliability and Cronbach's alpha values are above the recommended level of 0.7 for all the constructs, showing good reliability (Fornell and Larcker, 1981; Hair *et al.*, 2014). Convergent validity was tested using average variance extracted (AVE). The AVE values are higher than 0.5 for all the constructs, indicating that convergent validity is established (Fornell and Larcker, 1981; Hair *et al.*, 2014). Discriminant validity was established by showing that the square root AVE of each construct is greater than its correlation coefficients with other constructs (Fornell and Larcker, 1981; Zhu *et al.*, 2006). The square root AVE values and the correlation matrix are shown in Table 5.

5.2 Structural model

We used the bootstrap approach (with 1000 resamples) to test the structural model (Preacher and Hayes, 2008). The model fit indices conform to the recommended thresholds, as shown in Table 6. Figure 3 presents the results. Technological characteristics: relative advantage ($\beta = -0.078, p > 0.05$), complexity ($\beta = -0.073, p > 0.05$), and compatibility ($\beta = 0.138, p > 0.05$) are not significantly related to adoption. Therefore, H1, H2 and H3 are rejected. Top

Table 4.
Validity and reliability indicators of the constructs

Construct	Items	Loading	CR	AVE	Cronbach's alpha
Relative advantage	RelaAdv1	0.780	0.812	0.521	0.804
	RelaAdv2	0.796			
	RelaAdv3	0.643			
	RelaAdv4	0.656			
Complexity	Cplx1	0.836	0.813	0.593	0.810
	Cplx2	0.792			
	Cplx3	0.673			
Compatibility	Compty1	0.778	0.799	0.575	0.792
	Compty2	0.853			
	Compty3	0.625			
Top management support	TMS1	0.867	0.884	0.717	0.881
	TMS2	0.873			
	TMS3	0.799			
Technology competence	TechComp1	0.854	0.892	0.673	0.890
	TechComp2	0.876			
	TechComp3	0.782			
	TechComp4	0.765			
Government support	GovS1	0.786	0.866	0.621	0.856
	GovS2	0.942			
	GovS3	0.750			
	GovS4	0.646			
Competitive pressure	ComP1	0.627	0.823	0.539	0.831
	ComP2	0.759			
	ComP3	0.823			
	ComP4	0.715			
Labor cost	LaborC1	0.631	0.771	0.532	0.739
	LaborC2	0.723			
	LaborC3	0.822			

Source(s): Authors work

Table 5. Mean, standard deviation, correlations, and square root AVE of the constructs

	Mean	SD	1	2	3	4	5	6	7	8	9
1. Complexity	3.391	1.070	**0.770**								
2. Compatibility	3.681	0.822	−0.223	**0.758**							
3. Relative advantage	4.572	0.546	0.063	0.271	**0.722**						
4. TMS	4.340	0.740	−0.005	0.102	0.242	**0.847**					
5. Tech competence	3.720	0.912	−0.077	0.363	0.158	0.171	**0.820**				
6. Competitive pressure	4.174	0.735	−0.036	0.236	0.457	0.361	0.350	**0.734**			
7. Labor cost	4.301	0.763	0.360	0.019	0.363	0.125	0.011	0.309	**0.729**		
8. Government support	4.442	0.626	0.021	0.142	0.415	0.427	0.269	0.396	0.188	**0.788**	
9. Adoption	15.014	6.910	−0.190	0.263	0.036	0.249	0.354	0.206	−0.156	0.173	n.a

Note(s): Square root AVE values are on the diagonal
Source(s): Authors work

management support (β = 0.183, p <0.05) and technology competence (β = 0.238, p <0.001) are significantly associated with the adoption of Industry 4.0 technologies. Hence, H4 and H5 are supported. Government support (β = 0.337, p <0.05) and competitive pressure (β = 0.230, p <0.05) are significantly related to top management support so H6 and H7 are supported. However, labor cost (β = −0.009, p >0.05) is not significantly related to top management support so H8 is rejected. The control variable firm size (β = 0.396, p <0.001) is significantly related to adoption.

The mediating effect of government support on adoption via top management support is significant, with effect size = 0.062 and 95% CI = [0.006, 0.177] (zero is not included in the confidence interval). The mediating effect of competitive pressure on adoption via top management support is also significant (effect size = 0.042, CI = [0.001, 0.133]). However, the mediating role of labor cost is not significant. The effect size = −0.002 and CI = [−0.036, 0.028]). A summary of the results is shown in Table 7.

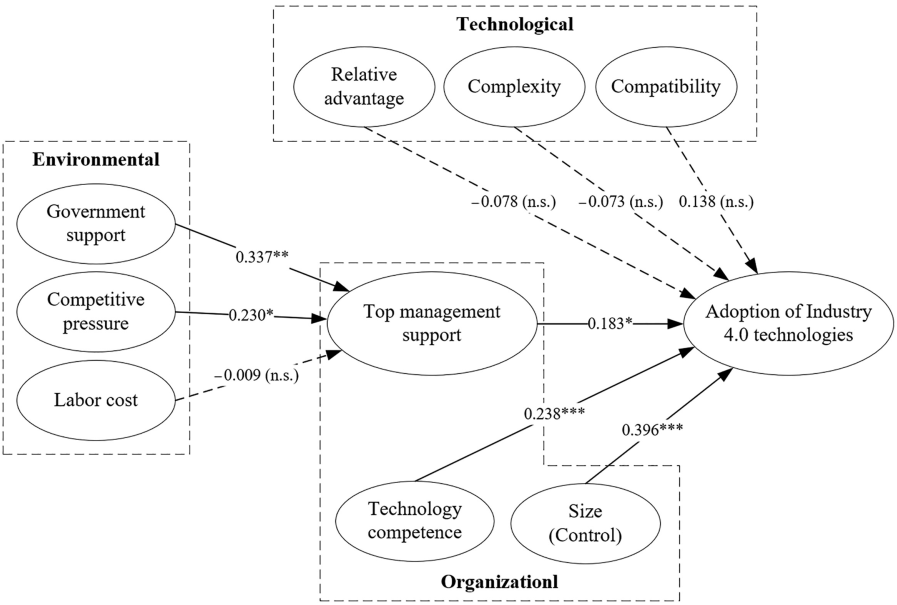
5.3 A post-hoc analysis

We performed a post-hoc analysis using cluster analysis and ANOVA. Cluster analysis was employed to explore the adoption patterns of Industry 4.0 technologies, and ANOVA was used to compare the differences between clusters.

Table 6.
Model fit indices

Indices	χ^2 / df	RMSEA	CFI	TLI	SRMR
Value	1.57	0.051	0.928	0.916	0.066
Threshold	≤ 3	≤ 0.08	≥ 0.9	≥ 0.9	≤ 0.08

Source(s): Authors work



Note(s): *p < 0.05; **p < 0.01; ***p < 0.001
Source(s): Authors work

Figure 3.
Results of the hypothesis testing

Before conducting cluster analysis, we made a categorization of Industry 4.0 technologies so that cluster analysis can better reveal the adoption patterns of different types of technologies. According to Culot *et al.* (2020), Industry 4.0 technologies can be categorized by the nature of technological elements (hardware/software) and network connectivity (limited in department/extended to supply chain). Accordingly, there are four types of Industry 4.0 technologies: physical-digital interface technologies (high share of hardware and extended connectivity), physical-digital process technologies (high share of hardware and low level of connectivity), network technologies (high share of software and extended connectivity), data-processing technologies (high share of software and low level of connectivity). Among the 14 Industry 4.0 technologies in this study, IoT, CPS, MES, AR, and VR belong to physical-digital interface technologies, while 3D printing and autonomous robots belong to physical-digital process technologies. Cloud computing, cyber security, mobile technology, and blockchain are classified as network technologies. Big data, simulation, and AI are data-processing technologies. We then calculated the adoption level of each technology type for each firm by summation.

We performed a two-step cluster analysis, as suggested by Tortorella and Fettermann (2018) and Frank *et al.* (2019). First, we conducted a hierarchical cluster analysis to determine the proper number of clusters, which we found to be either two or three. We chose to create three clusters for greater differentiation and performed K-means cluster analysis with $k = 3$ to refine the cluster memberships. The centers of the obtained three clusters are shown in Table 8, and we labeled the clusters as light adopters, moderate adopters, and heavy adopters respectively.

As shown in Table 8, regardless of technology type, heavy adopters tend to adopt more technologies than moderate and light adopters, and moderate adopters tend to adopt more than light adopters. Additionally, we observed that light adopters focus more on network technologies, moderate adopters focus more on physical-digital process technologies, and heavy adopters focus more on data-processing technologies.

We further conducted ANOVA to assess the differences in technological, organizational, and environmental factors among the three clusters of firms. The results in Table 9 indicate

Paths	Effect size	95% confidence interval	Results
Government support → TMS → Adoption	0.062	[0.006, 0.177]	Supported
Competitive pressure → TMS → Adoption	0.042	[0.001, 0.133]	Supported
Labor cost → TMS → Adoption	−0.002	[−0.036, 0.028]	Not supported

Source(s): Authors work

Table 7. Summary of the mediating effects

Technology type	Light adopters (N = 58)	Moderate adopters (N = 90)	Heavy adopters (N = 67)
1. Physical-digital interface technologies	0.16	0.31	0.70
2. Physical-digital process technologies	0.11	0.67	0.74
3. Network technologies	0.21	0.46	0.72
4. Data-processing technologies	0.16	0.31	0.87

Note(s): The clustering is based on normalized scores ranging from 0 to 1
Source(s): Authors work

Table 8. Cluster centers for low, moderate, and advanced adopters

Factor	Mean value Light adopters (N = 58)	Moderate adopters (N = 90)	Heavy adopters (N = 67)	F value
Relative advantage	4.57	4.54	4.61	0.29
Complexity	3.50	3.47	3.19	1.66
Compatibility	3.53	3.64	3.86	2.55
Top management support	4.14	4.34	4.52	4.19*
Technology competence	3.38	3.63	4.14	12.76***
Government support	4.34	4.39	4.59	2.99*
Competitive pressure	3.97	4.19	4.34	3.96*
Labor cost	4.24	4.43	4.18	2.44

Note(s): * Significant at 0.05; *** Significant at 0.001
Source(s): Authors work

Table 9.
The results of ANOVA

that there are significant differences between the three clusters for several factors, including government support, competitive pressure, top management support, and technology competence. The results are consistent with the findings of the SEM analysis, highlighting the important role of these factors in predicting the adoption of Industry 4.0 technologies.

6. Discussion

Overall, the results show that technology-push (represented by technology advantage) does not significantly affect the adoption of Industry 4.0 technologies. Market-pull and government-drive play important roles, with competitive pressure and government support significantly promoting top management support, which in turn contributes to the adoption decision. A detailed discussion of the results is presented below.

6.1 Technological factors

It seems that technology-push does not work in the adoption of Industry 4.0 technologies in China since technological characteristics, especially relative advantage, are found to have no significant influence on the adoption decision. This is a surprise to us. However, it is consistent with the study by Wei *et al.* (2015) on RFID in China, they showed that technological characteristics are not related to its adoption. The finding is also in line with the research by Sodhi *et al.* (2022). They found that "the characteristics of the technologies do not inform user expectations at the early stage of adoption". Managers' ranking of the characteristics of emerging technologies remained the same across different technologies and different organizations (in terms of industry, firm size, and levels of globalization) (Sodhi *et al.*, 2022). This makes it difficult to distinguish adopters from non-adopters by perceived technology characteristics. A possible explanation could be that the managers do not know much about these emerging technologies at the early stage.

6.2 Environmental and organizational factors

Market-pull and government-drive have played their roles. As environmental factors, both competitive pressure and government support significantly lead to top management support for Industry 4.0 technologies, which in turn influences the adoption decision. Developing economies like China have been undergoing an institutional transition from a network-centered to a market-centered transaction structure, but the transition cannot get rid of the former (Peng, 2003). Top managers tend to cooperate with the government to build political ties to acquire the necessary resources to deal with market competition (Shen *et al.*, 2023; Sheng *et al.*, 2011).

From the perspective of institutional theory, environmental factors (like government support and competitive pressure) are sources of coercive, mimetic, and normative pressures (Liang *et al.*, 2007; Teo *et al.*, 2003). These pressures drive top management to support the new technologies, whose beliefs and attitudes influence other members of the organization. More importantly, top managers can ensure the allocation of resources needed to introduce new technologies (Thong *et al.*, 1996). Earlier research on information systems and management practices also revealed that top management support serves as a mediator between institutional pressures and the adoption decisions in developing economies (Dubey *et al.*, 2018; Gholami *et al.*, 2013; Liang *et al.*, 2007; Ye *et al.*, 2013).

Labor cost, as an environmental factor, is not significantly related to top management support or adoption (tested in the structural model) in the context of Industry 4.0 technologies. There are two possible explanations. First, as Acemoglu (2010) showed, labor scarcity and high wages induce technological advances if the technology is labor-saving. However, advanced technology use is accompanied by the need for more skilled labor (Baldwin and Lin, 2002). Industry 4.0 technologies require more employees who have a higher level of skills and knowledge (Beier *et al.*, 2022; Ghobakhloo, 2018). A firm may not be able to reduce labor cost by substituting unskilled labor for skilled labor. Second, as Li *et al.* (2020) showed, the inducement effect of labor cost on innovation or technology adoption is reduced by government intervention in terms of employment and other social objectives. To comply with the government's employment and other social objectives, firms may put labor cost concerns at a lower priority. This study also confirms that technology competence is an important facilitator of the adoption of Industry 4.0 technologies. This is consistent with previous research (Chen *et al.*, 2015; Oliveira *et al.*, 2014).

7. Conclusions

This study aims to investigate whether the adoption of Industry 4.0 technologies among manufacturing firms in developing economies is technology-pushed, market-pulled, or government-driven. The TOE framework reinforced with institutional theory is employed to develop the research model. The results show that market-pull and government-drive have played important roles, with competitive pressure and government support significantly promoting top management support, which in turn contributes to the adoption decision. Technology-push has not shown its influence since technology advantage is not significantly related to the adoption.

The theoretical contribution is two-fold. First, this is the first study that tries to investigate whether the adoption of Industry 4.0 technologies is technology-pushed, market-pulled, or government-driven among manufacturing firms in developing economies. The results show that market-pull and government-drive have played their roles, while technology-push is not significant. Second, This study uncovers the previously overlooked mediating role of top management support between environmental factors and the adoption decision within the literature on Industry 4.0.

There are some implications for governments and managers. For governments that are promoting Industry 4.0 or smart manufacturing, it is effective to show their support for the emerging technologies. Preferential policies such as tax incentives, favorable loan rates, or financial subsidies are recommended. Moreover, top managers should be the target audience. In turn, managers should keep an eye on government policies and leverage government support to facilitate technology adoption. To prepare for Industry 4.0 technologies, firms should enhance their technology competence through infrastructure investment and the development of employee knowledge and skills. This is particularly important for firms that plan to be heavy adopters of Industry 4.0 technologies, as they tend to prioritize data-processing technologies such as AI and big data, which require high-order knowledge and skills from employees.

There are limitations in our study. First, the data were collected in China so care should be taken when generalizing the findings to other developing economies. A follow-up study to collect data from different economies and compare the results can be noteworthy. Second, this study did not link the adoption of specific technologies or technology types to the needs of manufacturing firms. While this study operationalized relative advantage as the technologies' ability to improve efficiency, cost, quality, and company image, it did not fully capture a company's specific needs and the alignment between those needs and specific technologies or technology types. Future researchers can do a fine-grained study by linking a company's needs to the adoption of specific technologies or technology types.

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