INDUSTRY 4.0 AND DIGITAL GREEN INNOVATION WITH THE MEDIATING ROLE OF DIGITAL GREEN KNOWLEDGE CREATION: AN EVIDENCE FROM VIETNAM

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Abstract

Digital and green innovations are Industry 4.0's sustainable development trends. Eco-friendly innovation must include digital technologies to boost its performance and firm competitiveness. This study uses 171 Vietnamese manufacturing staff survey data to examine a new conceptual framework. The structural model is analyzed using PLS-SEM. The study illustrates a positive association between Industry 4.0 (I4.0), digital business intensity (DBI), and digital green innovation performance (DGIP) through mediating role of digital green knowledge creation (DGKC). The findings enrich the body of the current literature on high-technical factors impacting DGIP and the role of DGKC with DGIP in the technology eco-friendly integration context. It also provides several practical implications to help businesses improve their competitiveness, survival, and development.

Keywords: Industry 4.0, Digital Business Intensity, Digital Green Innovation Performance, Digital Innovation, Green Innovation, Digital Green Knowledge Creation, Knowledge Management

JEL Classification: I6

1. Introduction

Industry 4.0 is widely applied worldwide, making companies and organizations more concerned about the environment. It requires the design of pollution prevention and mitigation measures for business activities. In addition, governments and corporations also emphasize green innovation as a solution to environmental and economic challenges (Tang et al., 2020). The term "green innovation" includes techniques, products, services, businesses, and management strategies to reduce environmental risks and pollution through the rational use of resources and applying alternative solutions. Companies have used more environmentally friendly materials and less damaging processes (Ma et al., 2018). This has been so widespread that many predict that industrial companies will improve the environment and quality of life by encouraging companies to create environmentally friendly technologies and promote their long-term viability (Mubarak et al., 2021).

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Most research on green innovation focuses on technology or processes, and it is crucial to understand how green products and digital innovation will be integrated (Cheng et al., 2021). Wicki & Hansen (2019) has found the link between human knowledge and green technology and its consequences. According to Meirun et al. (2021), companies must choose between economic development and environmental protection in a sustainable economy. Despite many investigations of innovation in green technology, very few studies have examined green innovation and digital technology (Yin & Yu, 2022). The authors also suggested that future research in digital green innovation could use the PLS-SEM model to get more reliable research results and increase the variety and breadth of sample sources. Therefore, they suggested including them in future research to gain a deeper understanding of the issue.

The research provides several academic contributions:

(1) It studies the impact of DGKC on DGIP in the context of the Vietnamese manufacturing sector.

(2) It examines why high-tech investments and practices are necessary for increasing DGIP.

(3) It proves the influence of I40 and DBI on DGIP with DGKC-mediated support. Besides, the article also helps businesses overview how high-tech practices and investments such as I4.0 and DBI have affected DGKC and DGIP.

2. Literature review

2.1 Concept definition

2.1.1 Industry 4.0

I4.0 is the next generation of business breakthroughs that transcends earlier ones, such as electricity and automation, in which people, machines, and computer systems share real-time data (Maganga & Taifa, 2022). It provides businesses with more efficient ways to manage their supply chains and operations by digitizing nearly all of their manufacturing processes and allowing them to offer new products and services to their electronic customers. In addition, this technology can assist leaders by making management more collaborative and enabling firms to produce outstanding results (Bai et al., 2020). The assembly of manufacturing components enhances the company's processes, operational efficiency, quality, responsiveness, and overall performance. Ghobakhloo (2020) says that I4.0 improves processes, makes them more efficient, fixes quality problems, and gives real-world ways to reduce rework and waste (Liu et al., 2022).

2.1.2 DBI

According to Nwankpa et al. (2022), DBI represents the strategic growth of a company's technology through investments in analytics, cloud infrastructure, social networking sites, mobile platforms, and big data. DBI is founded on strategic investment decisions for future commercial, transactional, and functional differentiation, distinct from the theoretical underpinnings of information technology (IT) capabilities, consisting of existing systems, processes, channels, and people. In contrast to IT's concentration on optimizing present assets, DBI research focuses primarily on identifying prospective future investment prospects; when a company invests in cutting-edge, emerging technology, this is known as disruptive business innovation (or DBI). Businesses utilize DBI to adapt IT resources to a changing business environment and enhance performance. It is crucial for a company's success that organizations with a high DBI integrate cutting-edge digital technology into their processes, hence boosting performance (Nwankpa & Datta, 2017).

2.1.3 DGKC

The past economies will be replaced by new, superior economic growth fueled by digitization, cloud computing, artificial intelligence, and the Internet. This change is primarily attributable to the continuous discovery and development of new information (Yin & Yu, 2022). As information-based innovation activities gain prominence, the generation of new knowledge has become a crucial aspect of the development and survival of businesses. During the age of digitalization, the capacity to gather enormous amounts of cyberspace data using AI technology and other technical advances is essential for strengthening innovation capabilities. Thus, industrial firms can achieve sustainable growth by renewing digital technology and creating eco-friendly knowledge (Chen et al., 2019). Prior research has focused chiefly on sustainable knowledge creation in sustainability practices, whereas information resource generation in digitalization has received relatively less focus (Magnier-Watanabe & Benton, 2017). From a knowledge-based perspective, Yin & Yu (2022) state that knowledge capital is a crucial factor that impacts corporate strategy selection and resource allocation, as well as a significant source of competitive advantage for the business.

2.1.4 Knowledge-based view

Since digital innovation includes knowledge discovery, application, and transformation, the knowledge-based view (KBV) acts as the conceptual framework basis for this research (Saldanha et al., 2020). According to the KBV, knowledge is the most critical strategic asset for value development and competitiveness (Alavi & Leidner, 2001; Grant, 1996). Previous research indicates that innovations are the consequence of a company's quest for new opportunities and its willingness to experiment with relevant information to expand current progress into novel sectors of the economy (Saldanha et al., 2020). Innovative learning and problem-solving skills are associated with knowledge management techniques. Companies with superior knowledge management, especially knowledge creation, may stimulate innovation (Plessis, 2007). I4.0 and DBI highlight an organization's proactive information-collecting and synthesis activities. KBV adapted its operations to the digital economy by concentrating on DBI and I4.0 procedures. Knowledge is an essential asset for generating value as well as accumulating economic rents. The emphasis has switched from gathering information as a resource towards integrating explicit and tacit knowledge to providing non-replicable, unique, and enduring value (Nwankpa et al., 2022).

2.2 Hypotheses development and research model

2.2.1 The impact of DGKC on DGIP

Resources, the environment, and digital and physical transformations limit green digital innovation; exploitative knowledge development helps businesses decrease variability and duplication of information (Nair & Munusami, 2019). Businesses cannot randomly embrace environmental and technological transformation, but only expertise that has been successfully accepted and shown helpful in other organizations will be used. Modest competencies in DGIP enable firms to enhance digital green products or access current markets, which helps firms dominate the market for digital green goods (Shen et al., 2020). The previous studies have shown that information use enhances company creativity (Jiang et al., 2020). The discussion provides the following hypothesis:

H1: DGKC has a positive impact on the DGIP.

2.2.2 The impact of I4.0 on DGIP performance

I4.0 approaches to maximize the utilization of energy, assets, and people (Lasi et al., 2014). It also encourages using big data, blockchain technology, and the Internet of Things to make manufacturing more autonomous (Mubarak et al., 2021). According to (Machado et al., 2020), environmental performance could be improved by synchronizing the deployment of I4.0 technologies with desired environmental outcomes that assure maximum sustainable output. Song & Wang (2016) say that making industrial processes more eco-friendly is possible by looking at I4.0 developments and data from several IoT devices. Productivity is boosted by using quality management and digital technology. Economic, social, and administrative potential are all enhanced by I4.0 sociotechnical developments (Beier et al., 2020). I4.0 may aid green technological advancements. Environmental measures taken during the whole life cycle of a product lead to sustainable and ethical business practices (Gurtu & Johny, 2019). According to Piyathanavong et al. (2019), I4.0 skills and investment are required to enhance DGIP performance. Presented in this argument is the following hypothesis:

H2. I4.0 has a positive impact on the DGIP.

2.2.3 The impact of I4.0 on DGKC

I4.0 was created to enhance global competitiveness and adapt production to fluctuating market demands (Capestro & Kinkel, 2020). Due to these needs, modern production methods like unsupervised robots, efficient production technologies, additive manufacturing, and simulation have become much more productive and efficient (Rojko, 2017). Nevertheless, I4.0 is a comprehensive solution connecting all value chain actors with production and commercial operations. Therefore, information and past knowledge are vital for expanding corporate operations (Agrawal et al., 2018). Coordination and information are vital to digital transformation's economic and industrial benefits (Müller, 2019). Ardito et al. (2019) state new technologies for collecting, storing, and making data make integration easier for the supply chain. In a broader sense, the digital revolution generates new data that enhances selection, altering the company's business operations and architecture (Jerman et al., 2019). The authors, based on the argument, present the following hypothesis:

H3. I4.0 has a positive impact on the DGKC.

H4. I4.0 has a positive impact on the DGIP through DGKC.

2.2.4 The impact of DBI on DGIP

According to KBV's view, research into the past indicates that DBI will affect digital innovation. Through connectedness, adaptability, and reengineering, digital resources may stimulate creativity. In a digitally pervasive society, anecdotal evidence suggests that digital tools stimulate creativity. Technological developments provide digital features that allow firms to produce information, facilitate various operations, and efficiently utilize internal resources (Yoo et al., 2012). Trantopoulos et al. (2017) demonstrated that investing in digital technology allows businesses to develop new ideas, reposition and incubate, leading to technology transformation and achievements. Digital technology helps organizations to collect and promote external digital innovation. Combining the digital and physical economies improves innovation output, efficiency, and costs, making it an essential starting point for addressing environmental issues (Wei et al., 2022). Consequently, The DGIP efforts of industrial enterprises and the influence of digital technology on green innovation should be investigated. Therefore, the following hypothesis based on the above justifications has been proposed:

H5. DBI has a positive impact on the DGIP.

2.2.5 The impact of DBI on DGKC

As a result of the insights gleaned by big data, firms may utilize the additional time and money to expand in different ways. Data analytics consumption patterns and information strengthen knowledge management operations and strategies. In fact, Sumbal et al. (2017) have demonstrated that using big data in the fossil fuel industries may enhance knowledge management and result in better-informed choices. In addition to being crucial to knowledge management, data, information, and knowledge sharing are extensively distributed through digital platforms and technology (Razmerita et al., 2009). Khan & Vorley (2017) digital service platforms are essential to accumulating and exchanging enormous quantities of explicit knowledge, which is essential for information management. Additionally, innovative technologies enable individuals in many locations to produce new information and disseminate already-created information (Von Krogh et al., 2012). Companies are enhancing their DBI by integrating digital technologies into their operations. DBI creates vast quantities of data, information, and knowledge by combining connectivity with big data (Bharadwaj et al., 2013). This trend is expected to continue as these tools facilitate the development of novel methods for creating, sharing, and collaborating on information. The authors thus expect this association to hold the following:

H6. DBI has a positive impact on the DGKC.

H7. DBI has a positive impact on the DGIP through DGKC.

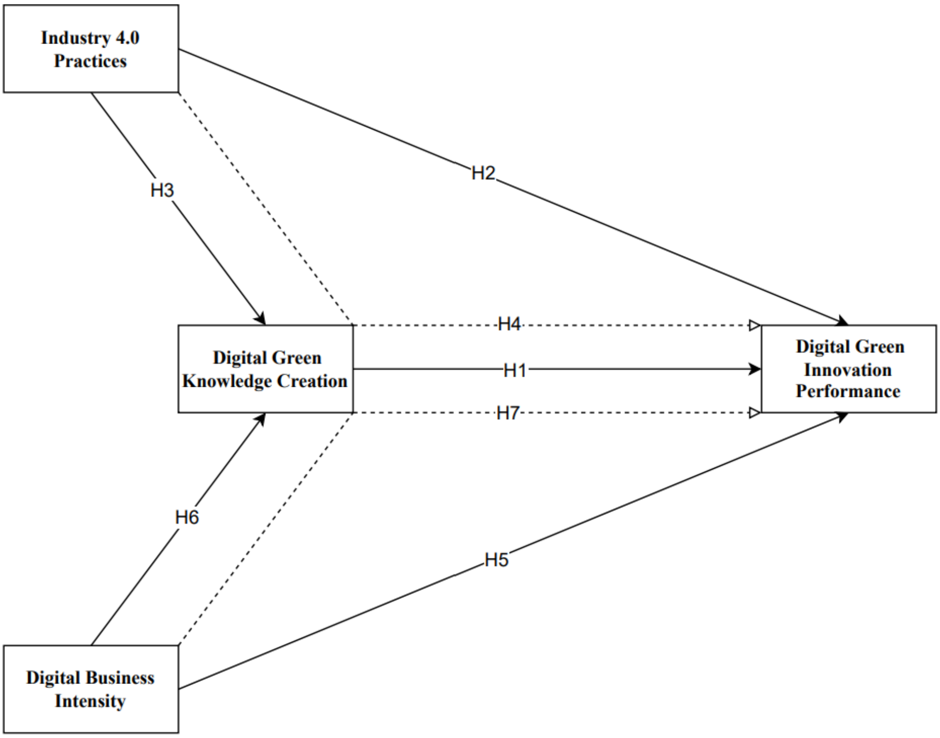

Figure 1. Research model

3. Research design

3.1 Measures

Measurements of numerous factors were derived from several prior research investigations. Items for I4.0 were derived from Saha et al. (2022). Digital business intensity measurement items were adapted from Nwankpa et al. (2022). DGKC and innovation performance indicators were adapted from Yin & Yu (2022).

3.2 Sampling Design

The data was acquired using convenience approaches from Vietnam's manufacturing operators working for various companies. Due to the Covid epidemic, only electronic communications were used to get the necessary data. The data was collected using email and Google forms and gathered in October 2022 in Vietnam by distributing a link to electronic questionnaires to manufacturing staff. Respondents were asked to rate their degree of agreement with statements on a scale ranging from one to five, with one denoting severe strong disagreement and five representing strong agreement. The questionnaire was completed by 171 respondents, and legible replies were chosen for further analysis; thus, the collected responses may be efficiently utilized to assess the hypothesis of this study. The characteristics of the sample are illustrated in Table 1 below.

Characteristics	Distribution	Frequency	%
GENDER	Male	122	71.35%
	Female	49	28.65%
AGE	20-30	96	56.14%
	30-40	48	28.07%
	40-50	16	9.36%
	>50	11	6.43%
EDUCATION	Bachelor	167	97.66%
	Master	4	2.34%

Table 1. Sample characteristics[4]

3.3 Data Analysis

The SPSS 26 and SmartPLS 3.3 software are used to analyze data. Smart partial least squares, a structural equation modelling (SEM) method based on variance, was used to analyze the data (Smart-PLS). Path analysis was created for hypothesis testing, and smart-PLS was used to implement structural equation modelling (Le, 2022).

4. Finding

4.1 Measurement model analysis

The measuring model was evaluated to determine the reliability and validity of the items used to evaluate I4.0, DBI, DGKC, and DGIP. The key metrics to examine the reported reliability and validity are shown in Table 2 below. Cronbach's Alpha indexes for all variables and all composite reliability among the defined factors are more than 0.70, confirming the validity of all measures in this research (Hair et al., 2017). Regarding the reliability test, the findings indicate that specific factor loadings and average variance extracts (AVE) for all items are more prominent than 0.7 and 0.5, which is acceptable compared to the acceptance standards (Hair et al., 2017). Convergent validity was thus supported. According to Hair et al. (2014), discriminant validity is demonstrated if one structure is sufficiently distinguishable from the others. According to Fornell & Larcker (1981), discriminant validity is demonstrated once the square root of each construct's AVE is larger than the correlations between the constructs. Table 3 displays the values that satisfy the requirements specified by Fornell & Larcker (1981).

Furthermore, for a model to be well-structured, the Heterotrait-Monotrait Ratio (HTMT) must be less than 1.0. However, Henseler et al. (2015) argue that a discriminant value is formed between the selected pair of constructs if HTMT is less than 0.9. Table 4 illustrates that all values within the table are respectively less than 0.9. This confirms the conclusion that all reliability and validity have been shown.

[4] Source(s): Author's work

Constructs	Items	Factor loading	Cronbach's Alpha	Composite reliability	AVE
DBI	DBI_1	0.837	0.872	0.913	0.723
	DBI_2	0.846			
	DBI_3	0.875			
	DBI_5	0.843			
DGIP	DGIP_1	0.866	0.894	0.922	0.703
	DGIP_2	0.813			
	DGIP_3	0.804			
	DGIP_4	0.837			
	DGIP_5	0.871			
DGKC	DGKC_1	0.826	0.888	0.918	0.691
	DGKC_2	0.813			
	DGKC_3	0.859			
	DGKC_4	0.813			
	DGKC_5	0.845			
I4.0	I40_1	0.848	0.887	0.917	0.688
	I40_2	0.819			
	I40_3	0.833			
	I40_4	0.806			
	I40_5	0.840			

Table 2. Result of reliability and convergent validity

	DBI	DGIP	DGKC	I4.0
DBI	**0.850**			
DGIP	0.756	**0.839**		
DGKC	0.788	0.786	**0.832**	
I4.0	0.725	0.738	0.790	**0.829**

Table 3. Fornell-Larcker Criterion

	DBI	DGIP	DGKC	I4.0
DBI				

DGIP	0.853		
DGKC	0.892	0.878	
I4.0	0.823	0.826	0.888

Table 4. Heterotrait-Monotrait Ratio

4.2 Indexes of Fit

The following model fit indexes have been evaluated: R^2 has values of 0.685 and 0.722 for DGKC, and DGIP. Besides, DGKC and DGIP have respective Q^2 values of 0.490 and 0.473, which are more than 0. The f^2 values of all variables were superior and more than 0.02. The SRMR value of 0.049 (<0.08) indicated that the model fits the data well (Hair et al., 2017). The findings demonstrate that the indices meet the standards suggested by the present research. Thus, the model has a high degree of predictive ability.

4.3 Hypothesis testing and discussion

The hypothesized hypothesis and path coefficients were tested using the bootstrapping method with a 5,000-sample loop once the validity and reliability of the measurement model and the overall model fit had been validated.The results of the SEM analysis are shown in Table 5.

Table 5 shows that DGKC positively and significantly influences DGIP (0.369; p<0.001). The discovery of a positive link between DGKC and DGIP is consistent with the research of Albort-Morant et al. (2018), which knowledge management found to enhance an organization's capacity to use natural resources effectively to become environmentally friendly. Knowledge creation promotes innovation, allowing businesses to generate high-quality goods and services at a reduced cost and with little natural resource use. The analytical results support Hsu and Sabherwal (2012), who found knowledge management a vital innovation precursor. This finding is also corroborated by Song et al. (2020). They found that green knowledge enhances a company's ability to use resources and expand sustainably efficiently. This indicates that the capacity of an organization to manage green knowledge is directly proportional to its capacity for green innovation; the greater it is capacity to manage green knowledge, the greater it is capacity for green innovation. This conclusion is inferentially significant because companies should not make digital expenditures in a vacuum; instead, their digital investment decisions should reflect their current knowledge and management skills.

Further, the statistical results confirm the existence of positive and significant relationships between the remaining variables, particularly between I4.0 and DGIP (0.230; p<=0.001) and DGKC (0.460; p<0.001); between DBI and DGIP (0.298; p<=0.001) and DGKC (0.454; p<0.001). The analytical result also demonstrates a correlation between DBI and I4.0 on DGIP and provides empirical support for previously anecdotal findings about the influence of DBI and I4.0 on innovation (Trantopoulos et al., 2017). Our findings underscore the enabling function of technology investments and applications and contribute to the expanding body of research that tries to comprehend the processes through which businesses may exploit digital investments to foster innovation and current strengths.

Moreover, a well-aligned DBI and I4.0 may foster knowledge creation, thus boosting innovation performance. However, a misaligned DBI and I4.0 might bring disruptive developments that may inhibit an organization's ability to exploit its knowledge management skills. Consequently, managers must grasp that technology investments and applications are fundamentally strategic.

Besides, the analysis results indicate p-values less than 0.001 for the relationships I4.0→DGKC→DGIP and DBI→DGKC→DGIP. The link between I4.0 and DGIP, as well as DBI and DGIP, is thus mediated by DGKC. In other words, in this circumstance, I4.0 and DBI influence DGIP through DGKC. Therefore, it may be concluded that all study hypotheses were supported.

Hypothesis	Relationship	Paths Coefficients	t-statistics	p-values	Conclusions
H1	DGKC → DGIP	0.369	4.860	0.000	Supported
H2	I4.0 → DGIP	0.230	3.296	0.001	Supported
H3	I4.0 → DGKC	0.460	6.756	0.000	Supported
H4	I4.0 → DGKC → DGIP	0.170	3.805	0.000	Supported
H5	DBI → DGIP	0.298	3.267	0.001	Supported
H6	DBI → DGKC	0.454	6.524	0.000	Supported
H7	DBI → DGKC → DGIP	0.168	3.952	0.000	Supported

Table 5. Path analysis and hypothesis testing

5. Implications

This study's findings are significant for the digital green knowledge creation processes of manufacturing businesses in Vietnam's implementation of digital transformation to accomplish sustainable objectives. During the adoption phase of digital green knowledge production, businesses must prioritize investments in high-tech and digital technological practices, such as big data, AI, Blockchain, and IoT. The data indicate that DGKC has the most significant influence on promoting DGIP. I4.0 and DBI have a significant boosting impact on DGKC. Some theoretical and standardized information is complex for firms to use immediately. However, such information may assist businesses in gaining a deeper understanding of the fundamental causes of innovation issues and exploring digital green knowledge production schemes based on their organizational context. Managers should devote sufficient resources and time to the process of creating digital solutions for the development of environmentally friendly knowledge. In this way, not only can employees get a comprehensive and accurate understanding of digital green knowledge development, but they can also make practical implementation. Businesses should also consider the amount of digital green knowledge creation. Companies should not rely excessively on previous achievements. Businesses must be more patient when exploring digital green knowledge production.

6. Conclusions, limitations, and future research

In conclusion, our research demonstrates that DBI and I4.0 are necessary and effective catalysts for following digital green innovations in a world where digital technologies and innovation are prevalent. In analyzing the downstream consequences of DBI and I4.0 practices, we reveal how knowledge management, particularly DGKC, functions as a catalyst and mediator for DGIP. Organizations must use their DBI and implement I4.0 to achieve a knowledge management state. Attempting to exploit a current DBI while examining for unforeseen situations might result in an overload of information and hinder a company's ability to embrace new performance. This study provided a more complex depiction of innovation success by emphasizing the intersections and interactions of downstream responsibilities and expectations for investments and digital technologies utilization.

The study, like several other studies, has several drawbacks. First, the study focused on Vietnamese circumstances, although differences in contextual variables may impact the relevance of research results and implications for practice in other contexts. Consequently, future research may compare outcomes with more regionally unique characteristics in various situations. The current study focuses on the manufacturing sector. To broaden the perspectives, future research might concentrate on additional domains. Third, although this study mainly relied on quantitative approaches, future research may choose a blended multi-methods strategy to bring additional views.

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