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Original article

Empirical research on sustainable business model innovation for industrial enterprises driven by digital capability in China

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Abstract

Introduction

In the era of Industry 4.0, the digital economic environment has high uncertainty and unpredictability. As an critical subject of the real economy, traditional industrial enterprises need to use digital technology and disruptive thinking to innovate their business models in order to help enterprises better and faster realize digital transformation and sustainable development if they want to survive and develop in such a complex and volatile market environment. In accordance with this, the **purpose** of the study is an empirical study of the relevant processes.

Materials and methods

Through literature review and analysis, the theoretical models of digital ability, sustainable business model innovation, digital opportunity discovery and digital opportunity creation are constructed. The measure scales of the above four variables are also designed. Through the empirical research on the questionnaire survey of well-known industrial enterprises in 31 provincial administrative regions in China, the descriptive statistical analysis, structural analysis, correlation analysis and regression analysis of variables of the questionnaire were carried out by using the data analysis software SPSS 22.0.

Results

The study showed, that the digital ability of industrial enterprises have a significant positive impact on sustainable business model innovation. Digital opportunity discovery and digital opportunity creation play a continuous intermediary role between them. The theoretical model and hypothesis have been verified.

Conclusions

The views and conclusions of this research can find practical implementation for industrial enterprises in the current digital environment. However, the establishment, application and promotion of enterprises' digital capabilities and the mechanism on how affect business model innovation are a complex, long-term and dynamic process. Whether enterprises in different industries or in different regions can obtain the same research conclusions in different development stages and different economic environments remains to be further studied.

Keywords: industrial enterprises, digital capability, sustainable business model innovation, Industry 4.0, China

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Эмпирическое исследование инноваций устойчивых бизнес-моделей промышленных предприятий Китая на основе цифровых возможностей

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Аннотация

Введение

В эпоху Индустрии 4.0 цифровая экономическая среда отличается повышенной неопределенностью и непредсказуемостью. Являясь важным субъектом реальной экономики, традиционные промышленные предприятия должны использовать цифровые технологии и инновационное мышление для обновления своих бизнес-моделей для обеспечения более быстрой и эффективной цифровой трансформации и устойчивого развития для выживания и развития хозяйствующих субъектов в сложной и нестабильной рыночной среде. В соответствии с этим **цель исследования** – эмпирическое изучение соответствующих процессов.

Материалы и методы

На основе обзора и анализа литературы были построены теоретические модели цифровых способностей, инноваций устойчивых бизнес-моделей, обнаружения цифровых возможностей и их создания. Также были разработаны шкалы измерения вышеуказанных четырех переменных. В ходе эмпирического исследования по анкетированию известных промышленных предприятий в 31 административной провинции Китая были проведены описательный статистический анализ, структурный анализ, корреляционный анализ и регрессионный анализ переменных анкеты с использованием программного обеспечения для анализа данных SPSS 22.0.

Результаты

Исследование показало, что цифровые возможности промышленных предприятий оказывают значительное положительное влияние на инновации устойчивых бизнес-моделей. Поиск и создание цифровых возможностей постоянно играют промежуточную роль между ними. Теоретическая модель и гипотеза были проверены.

Выводы

Все мнения и выводы, содержащиеся в этом исследовании, могут найти практическое применение в деятельности промышленных предприятий в современной цифровой среде. Однако создание, применение и продвижение цифровых возможностей предприятий и механизмов, влияющих на инновации бизнес-моделей, являются сложным, долгосрочным и динамичным процессом. Вопрос о том, могут ли предприятия в разных отраслях или в разных регионах получить одинаковые результаты исследований на разных этапах развития и в разных экономических условиях, требует дальнейшего изучения.

Ключевые слова: промышленные предприятия, цифровые технологии, инновационная устойчивая бизнес-модель, Индустрия 4.0, Китай

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Introduction

In the era of Industry 4.0, the widespread application and continuous innovation of digital technology have brought many new development opportunities to traditional enterprises, such as artificial intelligence, the Internet of Things, and big data, and have also caused significant changes in the entire economy and society [1]. In such a competitive environment, traditional industrial enterprises that have encountered bottlenecks in development have begun to think more systematically and deeply about how to adapt to new times and environment, and how to transform their operational and business models to meet the requirements of the times.

Along with the rapid development of the economy, the economic, social, and ecological issues faced by humanity are increasing day by day, making sustainable development a critical topic and theme in current economic and social development. Industrial enterprises are an important component of the national economy, playing a leading role in various economic activities, and should shoulder the responsibility of promoting sustainable social development. Besides, the increasing awareness of environmental protection among consumers and various government policies also require industrial enterprises characterized by high energy consumption and heavy pollution to pay more attention to sustainable and green development. In response to the demand for sustainable development in society, enterprises can integrate the concept of sustainable development into their business model innovation activities. On the basis of maintaining the economic benefits of the enterprises, sustainable business model innovation can meet the green development needs of multiple parties, thereby promoting the sustainable development of society and the environment [2].

Despite the importance of digital solutions, relying only on digital capabilities is not enough to ensure the long-term survival and development for industrial enterprises. To achieve sustainable development in the highly uncertain digital economy environment, enterprises need to build a resource community with stakeholders, improve the efficiency and effectiveness of matching opportunities and resources, timely discover digital opportunities and obtain information and data to better understand customers' needs and resist market risks, eventually driving sustainable business model innovation [3]. Therefore, digital opportunity discovery may play a very important role in the relationship between digital capabilities and business model innovation.

Therefore, exploring the innovation of sustainable business models in industrial enterprises under the background of digital transformation, analyzing the internal mechanism of digital capabilities driving sustainable transformation and upgrading, and exploring the role of digital opportunity discovery and creation in the path between digital capabilities and sustainable business model innovation are of great theoretical and practical significance for enterprises to understand digital capabilities, fully utilize their own resource capabilities, and enhance their sustainable business model innovation capabilities through digital capabilities.

Literature review

The dynamic capabilities theory suggests that in a constantly changing market environment, companies can drive sustained product and business model innovation through specific dynamic capabilities [4]. Digital capcapabilities, as a specific dynamic capabilities of enterprises in the digital environment, can help them quickly develop intelligent products and services with digital characteristics, achieve connectivity between internal and external environments, change the entire product lifecycle including design, development, manufacturing, and service processes, strengthen communication and collaboration with stakeholders, and bring new impetus and resources to enterprise business model innovation [5].

Nambisan pointed out that the successful development of digital products and innovative business models by enterprises highly depends on their own digital capabilities. Digital capabilities are a key factor for enterprises to survive and compete in the digital environment, and also the micro foundation for business model innovation [6]. From this, it can be seen that industrial enterprises need to enhance their strategic flexibility based on digital capabilities, improve their capabilities to discover and seize

digital opportunities, adjust their resource combinations, and achieve sustainable innovation in business models.

Schaltegger and Hansen proposed that sustainable business models mainly include how companies acquire, create, and deliver sustainable value propositions for all stakeholders, and how companies need to obtain economic profits while maintaining and creating environmental and social benefits [7]. Bocken et al. emphasized that sustainable business models should meet the needs of more partners and bring economic, social, and environmental benefits to more stakeholders. Based on practical research, they constructed a classification of sustainable business model prototypes and ultimately summarized eight sustainable business model prototypes, including maximizing resource utilization efficiency, creating value from waste, using renewable energy, and transferring functionality rather than ownership [8].

Haynie found that how companies apply digital capabilities to achieve complex interactions between digital opportunities and resources profoundly affects the relationship between digital capabilities and business model innovation [9]. Ray relies on the entrepreneurial opportunity theory to point out that the lack of precise discovery and control of digital machine opportunities in enterprises can affect the effective integration and utilization of resources, and the inertia of resource dependence often restricts the sustainable innovation and innovation of business models [10]. Chen Hui also suggests that business model innovation requires the recombination of entrepreneurial elements to obtain new value attributes [11]. Managers in the digital age are more focused on continuously discovering and creating digital opportunities, creating more distinctive new business models through the interaction between digital opportunities and resources across organizational boundaries [12].

As the analysis showed, existing research has provided ideas and references for the promotion of sustainable business model innovation in industrial enterprises through digital capabilities. However, from the overall perspective of existing research literature, current research perspective focuses more on theoretical and conceptual exploration, with scattered content and a lack of in-depth exploration of the mechanism of digital capabilities and sustainable business model innovation in industrial enterprises, as well as empirical research on the relationship between them. Therefore, it is crucial to thoroughly analyze the impact mechanism of digital capabilities on sustainable business model innovation.

Model Construction and Data Explanation

Model building and research hypotheses

Based on existing literature about digital capabilities, digital opportunity discovery, and sustainable business model innovation, this research gradually analyzes the logical relationships and impact mechanisms among them and proposes the theoretical model and hypotheses.

1. The impact of digital capabilities on business model innovation.

Renko believed that business model innovation is triggered by technological direction. The development of digital technology provides new sources of creativity for business models, and digital capabilities are the foundation and driving force for sustainable business model innovation [13]. Tauscher and Laudien pointed out that the digitization of infrastructure and modules brought about by the application of digital technology can provide new avenues for value creation, transmission, and acquisition, thereby driving innovation in business models [14]. The research results of Patrick also indicate that selectively using digital technology can help businesses build digital ecosystem platforms, improve convenience and efficiency, while reducing costs in a more sustainable way, ultimately providing a more balanced value proposition [15]. Therefore, this research proposes the following hypothesis.

H1: The digital capabilities has a positive impact on sustainable business model innovation .

2. The mediating role of digital opportunity discovery between digital capabilities and sustainable business model innovation

Li et al. found that industrial enterprises with digital capabilities can focus more on the application and development of digital technology, better discover digital opportunities in the market, tap into the inherent value of existing opportunities, and promote business model innovation . That is to say, digital capabilities can discover sustainable business model innovations that impact businesses through digital opportunities[16]. Firstly, digital capabilities can enhance the information perception level of enterprise managers. Secondly, business model innovation is an organizational design activity undertaken by enterprises to seize opportunities. Finally, digital capabilities enable enterprises to guide the restructuring and optimization of resources based on discovered digital opportunities. Therefore, this research proposes the following hypothesis [17].

H2: Digital ability has a positive impact on digital opportunity discovery.

H3: Digital opportunity discovery has a positive impact on sustainable business model innovation.

H4: Digital opportunity discovery plays a mediating role between digital capabilities and sustainable business model innovation.

Based on the above discussion, this study presents hypotheses about the relationships between the variables involved, forming the empirical model as shown in Fig 1.

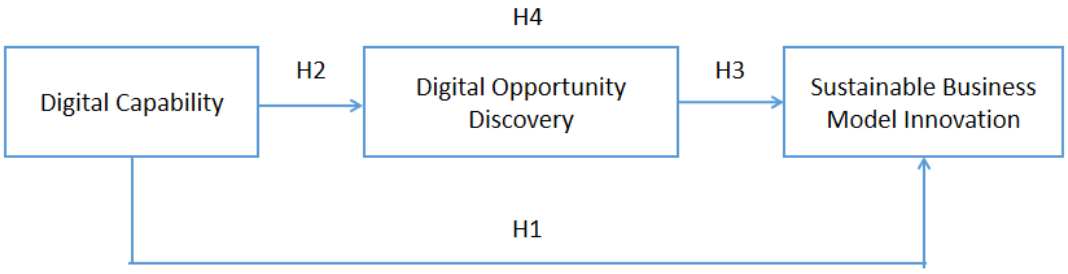

Fig. 1 Theoretical models and research hypotheses

Variable measurement scale

This study referred to Khin and Ho's [5] measurement scale for digital competence, González's (2017) [18] scale for digital opportunity discovery and creation, as well as Boons [19] and Nancy Bocken's [20] research on sustainable business model innovation. The measurement scale for each variable are shown in Table 1. In order to avoid possible interference from other variables on the research results, it is necessary for enterprises to consider the influencing factors at the enterprise level and improve the accuracy and practicality of the research results. Therefore, this study selected enterprise age, size, and proportion of digital investment as control variables. The age of the enterprise is measured by the length of its establishment, while other variables are evaluated using Likert's 5-point scale, and are uniformly set as dummy variables.

Empirical Test

1. Data collection

This research chooses stratified random sampling method and conducted random sampling from May 2023 to the end of 2024, targeting 32 provincial-level administrative regions in China according to the classification of industrial enterprises (excluding Hong Kong and Macao Special Administrative Regions), in order to achieve the goal of using stratified samples to represent the overall sample.

The distribution and collection of survey questionnaires are mainly carried out through e-mail, WeChat, QQ and other methods. The main targets of contact are government enterprise management departments, business associations, chambers of commerce, alumni associations of outstanding entrepreneurs. Through their assistance, suitable research enterprises are selected and contacts are quickly established. Finally, a total of 700 questionnaires were distributed for the formal survey, and 412 questionnaires were collected. After excluding questionnaires with incomplete data and inconsistent information, a total of 384 valid samples were obtained, with a total effective response rate of 54.86%.

Table 1 – Measurement scales

Dimensions	Identifier	Items
Digital Capability	DC1	Enterprises can accurately assess their digital level and develop appropriate digital transformation schemes for themselves
	DC2	Enterprises can use digital means to optimize business processes or resource allocation
	DC3	Enterprises can break industry boundaries and promote cross enterprise cooperation and cross industry integration
	DC4	Enterprises and partners can form benign coupling interaction and diversified cooperation
	DC5	Enterprises can conduct real-time dynamic analysis and flexible adjustment of products, services and resources
	DC6	Enterprises improve the efficiency of business intelligence decision-making through digital tools and components
Digital Opportunity Discovery	DOD1	Enterprises can quickly discover and grasp the information of various digital opportunities
	DOD2	Enterprises can quickly discover the possible market changes brought by digital opportunities
	DOD3	Enterprises are more sensitive or alert to capture digital opportunities
	DOD4	Enterprises can successfully use new digital products, digital technologies or digital services to improve enterprise efficiency
Sustainable Business Model Innovation	SBMI1	Enterprises often develop or adopt new products with low energy consumption
	SBMI2	Enterprises often improve production processes to reduce environmental pollution
	SBMI3	Enterprises provide healthy and comfortable working environment for employees
	SBMI4	Enterprises prefer to choose environmentally friendly partners
	SBMI5	Enterprise optimized the cost structure, innovated the source of income, and significantly increased profit
	SBMI6	The products and services meet the needs of customers in environment protection or sustainable development aspects

2. Sample description

Descriptive statistical analysis of sample data mainly includes personal level information such as gender, age, and position of respondents, as well as statistical descriptions of enterprise level data such as age, size, and industry classification. The descriptive statistical results of the 384 valid sample data collected are shown in Table 2.

Table 2 – Descriptive statistics of sample data

Item	Option	Frequency	Percent (%)
Gender	Female	121	31.51
	Male	263	68.49
Educational Level	Bachelor	292	76.04
	College and below	22	5.73
	Doctor	24	6.25
	Master	46	11.98
Management position	Middle	269	70.05
	Primary	66	17.19
	Senior	49	12.76
Industry classification	Manufacturing	274	71.35
	Mining	60	15.63
	Power, heat, gas and water production and supply	50	13.02
Number of employees	20-300 persons	165	42.97
	300-1000 persons	65	16.93
	< 20 persons	78	20.31
	>1000 persons	76	19.79
Years of establishment	3-5 years	129	33.59
	6-10 years	106	27.60
	<3 years	73	19.01
	>10 years	76	19.79
Proportion of digital investment	10%-15%	65	16.93
	3%-6%	142	36.98
	6%-10%	58	15.10
	<3%	78	20.31
	>15%	41	10.68
Geographical area	Central China	85	22.14
	North China	64	16.67
	South China	52	13.54
	East China	46	11.98
	Northeast China	67	17.45
	Southwest China	39	10.16
	Northwest China	31	8.07

3. Reliability analysis

The reliability of a questionnaire is usually tested using the Cronbach's Alpha coefficient. It is generally agreed that when the Cronbach's Alpha value is above0.7, the reliability of the scale is acceptable. The results of the questionnaire reliability test are shown in Table 3.

The result shows that the reliability coefficients of the scales for digital capability, sustainable business model innovation and digital opportunity discovery are all greater than 0.7. The total reliability coefficient is 0.912, indicating good consistency, stability, and reliability of the scale.

4. Validity analysis

Before conducting exploratory factor analysis, it is necessary to conduct Bartlett's sphere test results. If the KMO value reaches 0.7 or above and the Bartlett sphericity test result is significant, it indicates that the factor analysis result is acceptable. The test results are shown in Table 4.

Table 3 – Reliability analysis

Dimensions	Items Number	Cronbach's Alpha	Cronbach's Alpha
Digital Capability	6	0.794	0.912
Sustainable Business Model Innovation	6	0.790	
Digital Opportunity Discovery	4	0.749	

Table 4 – KMO and Bartlett's test

Dimensions	KMO Value	*p* Value
Digital Capability	0.827	0.000
Sustainable Business Model Innovation	0.815	0.000
Digital Opportunity Discovery	0.769	0.000

According to the KMO and Bartlett test results, the KMO detection values of each variable are greater than 0.7. The significance levels of each factor are less than 0.001. The test results prove that this scale is suitable for factor analysis.

5. Factor analysis

As shown in Table 5, the factor analysis ultimately extracted 3 factors with eigenvalues greater than 1. The explanatory variances (after rotation) are 31.990%, 27.075%, 14.086%, respectively. The cumulative explanatory variance (after rotation) is 73.151%.

Table 5 – Explained variance

Factor	Eigenvalue			Rotated		
	Eigenvalue	Explained Variance (%)	Cumulative (%)	Eigenvalue	Explained Variance (%)	Cumulative (%)
1	**7.593**	57.965	57.965	**4.398**	31.990	31.990
2	**1.730**	8.648	66.613	**3.415**	27.075	59.065
3	**1.308**	6.538	73.151	**2.817**	14.086	73.151
4	0.922	4.608	75.759	-	-	-
5	0.878	4.390	79.149	-	-	-
6	0.806	4.031	81.180	-	-	-
7	0.781	3.907	83.088	-	-	-
8	0.723	3.614	84.702	-	-	-
9	0.686	3.428	86.130	-	-	-
10	0.628	3.139	88.270	-	-	-
11	0.600	3.002	90.272	-	-	-
12	0.528	2.639	92.911	-	-	-
13	0.471	2.355	95.266	-	-	-
14	0.457	2.283	97.549	-	-	-
15	0.422	2.111	99.660	-	-	-
16	0.193	0.967	100.000	-	-	-

The specific factor loadings and total explanatory power results are shown in Table 6.

Table 6 – Factor Loading (Rotated)

Item	Loading			Communality (Common Variance)
	Factor 1	Factor 2	Factor 3	
DC1	0.173	0.035	**0.735**	0.571
DC2	0.113	0.311	**0.712**	0.616
DC3	0.168	0.166	**0.732**	0.592
DC4	0.251	0.322	**0.618**	0.549
DC5	0.226	0.323	**0.660**	0.591
DC6	0.251	0.346	**0.576**	0.514
SBMI1	0.072	**0.796**	-0.013	0.639
SBMI2	0.225	**0.764**	0.219	0.682
SBMI3	0.205	**0.729**	0.185	0.608
SBMI4	0.220	**0.652**	0.341	0.590
SBMI5	0.316	**0.615**	0.197	0.517
SBMI6	0.230	**0.599**	0.379	0.555
DOD1	**0.724**	0.265	0.133	0.612
DOD2	**0.640**	0.212	0.274	0.530
DOD3	**0.623**	0.305	0.223	0.531
DOD4	**0.733**	0.228	0.097	0.599
Note: Bold font represents absolute loadings greater than 0.5.				
Rotation Method: Varimax Rotation Method.				

The results of factor analysis are consistent with the model and variables proposed in this research. There is also a high discriminant validity among the various measurement scales.

6. Correlation analysis

Before conducting linear regression analysis, it is necessary to first test the variables using Pearson correlation analysis to preliminarily determine the degree of correlation between variables and eliminate the possibility of multicollinearity between variables. If the correlation coefficient between variables is less than 0.7, it indicates that the analysis results will not be affected by multicollinearity. The results of the correlation analysis are shown in Table 7. According to the correlation analysis results in Table 7, there is a significant correlation between digital capabilities, sustainable business model innovation, and digital opportunity discovery at the significance level of $p<0.001$ (bilateral). The correlation between the scale, age, and proportion of digital investment of enterprises and the research is not significant. Next, linear regression analysis can be conducted.

7.Regression analysis and hypothesis testing

By using the linear regression analysis function of SPSS 22.0, the relationships and hypotheses between variables of digital capability, sustainable business model innovation and digital opportunity discovery were tested (shown in Table 8).

Table 7 – Pearson Coefficient (Standard Format)

Variables	Mean	S.D.	Number of employees	Years of establish-ment	Proportion of digital investment	Digital capability	Sustainable business model innovation	Digital opportunity discovery
Number of employees	2.169	1.183	1					
Years of establishment	2.250	1.122	0.104	1				
Proportion of digital investment	2.708	1.263	0.290	0.057	1			
Digital capability	3.857	0.930	0.089	-0.018	0.082	1		
Sustainable business model innovation	3.919	0.843	0.037	-0.095	0.093	0.614***	1	
Digital opportunity discovery	3.935	0.875	0.046	-0.114	0.042	0.694***	0.707***	1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 8 – Multiple regression analysis results

Variables	Sustainable business model innovation			Digital opportunity discovery	
	model 1	model 2	model 3	model 4	model 5
Number of employees	0.021	-0.024	-0.023	0.048	-0.003
Years of establishment	-0.102	-0.084	-0.030	-0.121	-0.100
Proportion of digital investment	0.093	0.055	0.059	0.035	-0.009
Digital Capability		0.611***	0.238***		0.693***
Digital opportunity discovery			0.537***		
R-squared	0.019	0.387	0.534	0.017	0.492
Adjust R-squared	0.011	0.381	0.528	0.010	0.487
F Test	2.459	59.879***	86.522***	2.243	91.937***
*p < 0.05, ** p < 0.01, *** p < 0.001					

Model 1 is a regression analysis of controlling variables for sustainable business model innovation. On this basis, digital capabilities are introduced into Model 1 to establish Model 2. The results showed a significant positive correlation between digital capability and sustainable business model innovation (β=0.611, p<0.001). Hypothesis H1 is valid.

Model 4 is the relationship between control variables and digital opportunity discovery. On this basis, digital capabilities are introduced into Model 4 to establish Model 5. The results showed a significant positive correlation between digital ability and digital opportunity discovery (β=0.693, p<0.001). Hypothesis H2 is valid.

Model 3 is established to test the relationship between digital opportunity discovery and sustainable business model innovation by adding digital opportunity discovery to Model 2. The results showed a significant positive correlation between digital opportunity discovery and sustainable business model innovation (β=0.537, p<0.001). Hypothesis H3 is valid.

After adding the variable of digital opportunity discovery, the regression coefficient of the impact of digital ability on sustainable business model innovation changed from β=0.611 (model 2: p<0.001) to β=0.238 (model 3: p<0.001), and the regression coefficient significantly decreased, indicating that digital opportunity discovery plays a significant mediating role between digital ability and sustainable business model innovation. Hypothesis H4 is valid.

Conclusion and discussion

On the basis of reviewing existing research results, this research constructed a theoretical model of "digital capability – digital opportunity discovery – sustainable business model innovation", and conducted empirical tests through questionnaire surveys to uncover the inherent mechanisms between digital technology, digital opportunity discovery and sustainable business model innovation, which enrich the relevant research in relevant fields.

Through the empirical research result, in the current digital economy environment, sustainable business model innovation of traditional industrial enterprises has become an important way to break through development difficulties for traditional industrial enterprises. Digital capability can provide information support for the entire process of industrial enterprises, strengthen information sharing, enable enterprises to allocate internal and external resources reasonably, support the development of value propositions that integrate economic, social, and environmental values, and make substantial contributions to achieving high-quality development goals for enterprises.

This research takes industrial enterprises as the main object, and further research is needed to determine whether consistency conclusions can be drawn for enterprises in different industry, in different development stage as well as in different economic environment.

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