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How to unleash frugal innovation through internet of things and artificial intelligence: Moderating role of entrepreneurial knowledge and future challenges

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ABSTRACT

Frugal innovation, also known as frugal engineering or innovation, is an approach to product development and problem-solving that focuses on creating simple, affordable, and effective solutions. The research on frugal innovation is evolving which is mainly rooted in the challenges faced by people living in developing countries, where resource constraints and limited access to technology, infrastructure, and capital make it difficult to adopt traditional expensive and complex solutions. This study attempts to explore the impact of the Internet of Things (IoT) and artificial intelligence (AI) tools on frugal innovation from the perspective of China, a developing nation. Moreover, how entrepreneurial knowledge can play a moderating role among the nexus of frugal innovation, IoT, and AI is a key question of this study. This study spotlights the proposed inquiry based on seven hundred and seventy-nine responses as analyzed using SEM approach by SmartPLS. This study affirmed that IoT and AI both are valid predictors of frugal innovation therefore management should incorporate both capabilities to achieve frugal innovation and to win over competitors in today's technological-oriented era. This study highlights that acceptance of technology is imperative where entrepreneurial skills can play a significant role in incorporating innovative technologies like IoT and AI models into practices. This study also enlists several managerial implications along with limitations and future research possibilities for worldly scholars.

1. Introduction

The concept of frugal innovation is defined as an approach to problem-solving that focuses on creating simple, affordable, and resource-efficient solutions (Hossain, 2018; Hossain et al., 2023). Frugal innovation addresses challenges faced by people in resource-constrained circumstances that enable them to perform better within insufficient resources. It is stated that frugal innovation empowers the businesses to unleash the potential of innovative ideas and technologies by adopting simplicity, cost-effectiveness, and creativity (Sarkar and Mateus, 2022; Weyrauch and Herstatt, 2017). This concept has acquired global recognition that eventually not only benefits developing economies but inspires sustainable and inclusive solutions for developed markets. Frugal innovation nurtures impactful outcomes by exposing opportunities for progress and positive social transformation (Bhatti, 2012). Over the past decades, research on the theme of frugal innovation has evolved from the need to express challenges in resource-constrained conditions, specifically in developing countries. However, the role of artificial intelligence (AI) and the Internet of Things (IoT) in terms of frugal innovation is noteworthy that offers numerous opportunities to augment the impact and effectiveness of frugal solutions in various perspectives (Govindan, 2022; Park et al., 2022; Thakare et al., 2022).

IoT and AI can perform an imperative role for frugal innovation by permitting affordable automation, personalized solutions, data analytics, and clearer services. Such technologies aid in numerous ways, i.e., healthcare diagnostics, educational tools, predictive maintenance, energy efficiency, as well as making innovations viable and worthwhile. AI-based communication connects remote areas for the sake of essential services whereby the language translation increases the global reach of frugal solutions (Wu, 2021). AI permits frugal innovators to perform well by managing fewer resources, by addressing challenges within the developing economies in order to provide impactful and scalable solutions. Nonetheless, IoT is another notable factor that performs a central role in frugal innovation by connecting reasonable devices by enabling

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data-driven solutions for the organizations (Thakare et al., 2022).

IoT enhances efficiency in various perspectives of human life which includes agriculture, healthcare, and infrastructure, optimizing resource usage and reducing costs (Park et al., 2018; Pauget and Dammak, 2019). It facilitates remote monitoring and control of equipment that eventually supports predictive maintenance and extended lifespans. In healthcare, IoT empowers telemedicine and remote patient monitoring, bringing healthcare services to underserved areas (Azzawi et al., 2016). Additionally, by integrating IoT into frugal innovation, cost-effective, and impactful solutions can be scaled, benefiting marginalized communities, and addressing global challenges in resource-constrained environments. It indicated the importance of both factors such as IoT and AI concerning frugal innovation where entrepreneurial knowledge also supports deciding on the Internet of Things and artificial intelligence.

Entrepreneurial knowledge (EK) is closely linked with frugal innovation as it empowers individuals to identify opportunities, leverage limited resources, and develop affordable and scalable solutions (Karyaningsih, 2020; Roxas, 2014). Entrepreneurs with a deep understanding of market needs can apply their creativity, adaptability, and risk-taking abilities to address challenges in resource-constrained environments (Karyaningsih, 2020). Organizations can embrace frugal principles such as cost-effectiveness and simplicity to create innovative products and services for underserved markets (AlMulhim, 2021). Entrepreneurial knowledge drives the responsive development of frugal innovations by facilitating rapid iteration, positive societal, and market adoption impact. An entrepreneurs' mindset along with frugal innovation often promotes sustainable solutions to meet various global challenges. Frugal innovation can sense gaps from the existing solutions which eventually can provide solutions by enriching entrepreneurial knowledge to fulfil the needs of low-income population. Similarly, the organizations can carry out productive collaboration to additionally strengthen frugal innovation.

This study enlists certain motivations to presently serve empirical research on the theme of frugal innovation along with AI and IoT technologies. For instance, it strengthens how AI together with IoT might be incorporated into frugal innovations to discover multiple ways by maximizing the efficiency of resource usage in inexpensive and viable ways. According to the past researchers, investigating the potentials of both AI and IoT in frugal innovation may lead to more fruitful, dynamic, and data-driven solutions in order to address critical societal challenges (Azzawi et al., 2016; Park et al., 2018; Thakare et al., 2022; Wu, 2021). The research on the theme of frugal innovation allows practical measures to direct potential issues by ensuring the responsible deployment of technology. In addition, by conducting additional research on frugal innovation with consideration of AI and IoT, we can harness the transformative power of these evolving technologies to create sustainable and affordable solutions. To perform more research on frugal innovation with a focus on AI and IoT permits the organizations for continuous expansion and refinement of technological integration. The research with consideration of AI and IoT was mainly conducted in the developed nation and developing nations were ignored over the past decade. It would be interesting and fruitful to provide more empirical evidence from developing nations like China for validation of the notion of AI and IoT. Hence, it is worth mentioning to reveal the nexus among frugal innovation, IoT, and AI along with moderation of EK from the perspective of Chinese SMEs.

SMEs in China contribute a significant role in the country's economy (Zhu et al., 2012). They contribute to job creation, technological innovation, and exports (Huang and Mirza, 2023). With government support and market reforms, Chinese SMEs have seen steady growth, becoming vital drivers of economic development and global trade (Huang and Mirza, 2023). China is the world's most populous country and the second-largest economy in the world (Liu et al., 2023). It boasts a rich history, diverse culture, and remarkable technological advancements. China's rapid industrialization and urbanization have propelled it to the forefront of global influence, making it a key player in international affairs. Therefore, considering the Chinese market and SMEs in China for this study will offer a unique and interesting outcome by meeting certain objectives, as follows.

First, the study investigates the impact of IoT on frugal innovation based on resource-based view (RBV) theory & practices. Second, the study attempts to uncover the influence of AI on frugal innovation. Third, the aim is to unveil the moderating connection of entrepreneurial knowledge between IoT and frugal innovation. Finally, the target is to reveal the moderating connection of entrepreneurial knowledge between AI and frugal innovation, respectively. This study is organized based on the following outlines. First, this study discusses the theoretical framework as well as hypotheses about frugal innovation, IoT, AI, and entrepreneurial knowledge along with the study model. Subsequently, the author discussed the methods of the study, including sampling procedures, collection procedures, and analysis procedures. Part of the discussion along with implications (i.e., managerial, and theoretical) are reported accordingly. The final part consists of limitations and future opportunities for the scholars of the world to validate the findings by taking different perspectives, domains, and themes.

2. Literature review

Resource-Based View (RBV) theory is a management framework that highlights the strategic significance of a firm's internal resources and capabilities in achieving sustainable competitive advantage using different techniques and methods (Kruesi and Bazelmans, 2023; Wernerfelt, 1984). RBV is developed by scholars Jay Barney and Birger Wernerfelt in the 1980s which mainly emphasizes that firms' heterogeneity in resource endowment allows them to achieve superior performance over rivals (Wernerfelt, 1984). The theory posits that resources should be valuable, rare, inimitable, and non-substitutable to be sources of competitive advantage (Wernerfelt, 1984). RBV guides managers in identifying and leveraging their unique resources to create distinct value propositions, adapt to changing environments, and secure long-term success in highly competitive markets (Kraaijenbrink et al., 2010).

This theory implies a fruitful model to carry out further research on the theme of AI and IoT by studying frugal innovation (Gupta et al., 2018; Stroumpoulis et al., 2022). This theory also assists the investigators to connect the critical resources along with capabilities that include IoTs and AI technologies to offer interesting outcomes from multiple nations (Gupta et al., 2018). Furthermore, RBV theory supports the researchers to recognise the unique assets that can drive thriving and successful frugal innovations (Soni and T. Krishnan, 2014). RBV's focus on achieving sustainable competitive advantage guides researchers in exploring how frugal innovators can create long-term value and scale their solutions effectively (Madhani, 2010). RBV aids in analyzing the link between entrepreneurial knowledge, resource heterogeneity, and the ability to adapt to dynamic frugal environments, shedding light on the factors that enable successful outcomes in these innovative settings (Madhani, 2010; Rodríguez-Espíndola et al., 2022). Hence, it might be a worsening to empirically investigate the nexus of IoT, AI, and entrepreneurial knowledge toward frugal innovation from the perspective of Chinese SMEs. To this end, the author proposed certain hypotheses and explained them below and highlighted in Fig. 1.

2.1. Internet of things (IoT) and frugal innovation

The relationship between the IoT and FI is expected to be symbiotic with each concept reinforcing and complementing the other (Azzawi et al., 2016; Park et al., 2018; Park et al., 2022). For instance, FI discusses developing affordable, cost-effective solutions to address the needs of resource-constrained populations like developing nations (Bhatti, 2012). IoT can perform a crucial role in in managing resource usage, reducing waste, and streamlining processes which thereby may productively contribute more cost-efficient products and services

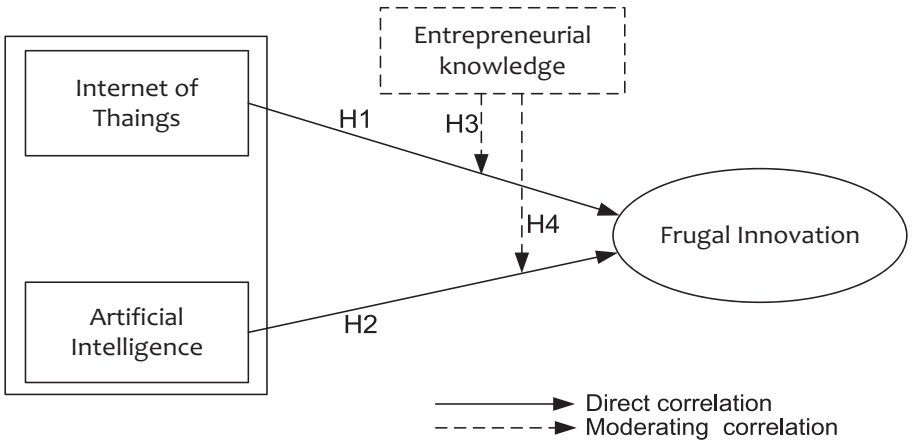

Fig. 1. Research framework.

(Sullivan et al., 2023). IoT technologies permit devices to be connected to share data and communicate with each other (Sullivan et al., 2023). Such connectivity may improve the accessibility of frugal innovation by making organizations more user-friendly and adjustable to various contexts (Park et al., 2018). Frugal innovation is recognized as an endless process of development where innovations are refined over time (Hossain, 2018). On the other hand, IoTs might be accumulated valuable data from numerous users' interactions and patterns through enabling innovators in shaping data-driven decisions to restate frugal solutions more realistically way (Park et al., 2018; Park et al., 2022). According to specialists, IoT can qualify frugal innovation to be personalized for satisfying individuals' needs and preferences (Furini et al., 2020). An adaptability of IoT may allow frugal innovation to be improved in a more effectively by moving toward a broader audience along with affecting more lives across several regions across the globe (Tiwari, 2021). Additionally, frugal innovation is extremely concerned about optimization of the use of resources which includes energy, materials, and water (Soni and T. Krishnan, 2014). IoT grants a real-time data on utilization of resources which can be employed to identify ineffectiveness to reserve resources in a successfully way (Furini et al., 2020; Park et al., 2018). It is advocated that IoTs might be employed to establish a smart infrastructure for frugal innovations (Furini et al., 2020).

On the other side, there are multiple studies that show concern related to frugal innovation and IoT from numerous perspectives and themes of the world by indicating distinct encouraging outcomes, worldwide (Azzawi et al., 2016; Park et al., 2018; Thakare et al., 2022). Most of the past researchers have recommended carrying out additional research on this area for guaranteeing outcomes in numerous ways. Similarly, RBV delivers a theoretical framework to assess frugal innovation and IoT by accentuating the significance of valuable resources and capabilities (Kruesi and Bazelmans, 2023; Madhani, 2010). It is suggested that by using RBV, investigators can detect critical resources, assess complementarity, and can examine how it contributes toward the sustained competitive advantage (Madhani, 2010; Wernerfelt, 1984). RBV theory allows a deeper identification on how organizations can leverage resources to foster the cost-effective and socially responsible IoT-based frugal solutions (Wernerfelt, 1984). Using RBV principles, researchers can conduct more comprehensive studies to uncover essential success factors and foster the development of sustainable and innovative frugal practices in the realm of IoT (Gupta et al., 2018; Madhani, 2010). Hence, IoT and FI have the potential to bring about significant positive change, particularly in addressing social and economic challenges in resource-limited settings. The author currently propositioned the following assumption to empirically validate the outcomes from the perspective of Chinese SMEs based on the above connections and supporting arguments of RBV and researchers' recommendations.

H1. Internet of Things (IoT) is positively correlated with Frugal Innovation.

2.2. *Artificial intelligence (AI) and frugal innovation*

The relationships between Artificial Intelligence (AI) and Frugal Innovation are likely to be mutually reinforcing as AI can complement and enhance the principles and practices of frugal innovation (Govindan, 2022; Jabeur et al., 2022). It is explained in the literature, AI can optimize processes and automate tasks in FI that increase efficiency and reduce costs (Thakare et al., 2022). Using AI-driven automation, frugal solutions can be produced, distributed, and maintained more efficiently which transforms the organizations more accessible to resource-constrained populations (Govindan, 2022; Masanja and Mkumbo, 2020). FI relies on data to design context-specific, cost-effective solutions (Masanja and Mkumbo, 2020). AI can analyze large datasets, identify patterns, and extract valuable insights to inform the development of FI (Alliance, 2020). AI can assist FI to be additionally personalized and tailored to individual needs (Alliance, 2020; Govindan, 2022). AI can help optimize the use of scarce resources in FI (Govindan, 2022). Therefore, using advanced analytics and smart algorithms, AI can identify opportunities for resource efficiency, leading to reduced waste and lower resource consumption (Alliance, 2020). AI can enable the development of affordable smart technologies that align with the principles of FI (De Waal et al., 2019).

However, various studies have shown findings on the theme of AI and FI from numerous perspectives and themes of the world showing distinct outcomes (Alliance, 2020; De Waal et al., 2019; Stroumpoulis et al., 2022; Thakare et al., 2022; Wu, 2021). Most researchers suggested carrying out more research on this domain for ensuring the outcomes in different ways (Alliance, 2020; Stroumpoulis et al., 2022; Thakare et al., 2022). For example, RBV emphasizes the importance of identifying and understanding the unique resources and capabilities that organizations possess (Bakar and Ahmad, 2010). In the context of FI and AI, researchers can explore which specific resources (i.e., AI expertise, data, access to technology) and capabilities (i.e., AI development, integration with frugal solutions) are critical in driving successful projects. RBV theory identifies that organizations acquire different combinations of resources which indeed lead to improve organizational performance (Bakar and Ahmad, 2010). By utilizing RBV, investigators can probe how various organizations improve AI in their frugal innovation initiatives and how these strategies influence organizational competitive advantage as well as success (Gupta et al., 2018; Madhani, 2010; Wernerfelt, 1984). Therefore, the incorporation of AI with frugal innovation has the potential to improve the adoption of cost-effective, socially beneficial, and sustainable solutions. AI's capabilities in data analytics, automation, and optimization align well with the objectives of frugal

innovation which indeed support the creation of innovative solutions (De Waal et al., 2019). The author currently propositioned the following hypothesis to empirically authenticate the outcomes from the perspective of Chinese SMEs based on the above connections and supporting arguments of RBV.

H2. Artificial Intelligence (AI) is positively correlated with Frugal Innovation.

2.3. Moderation of entrepreneurial knowledge (EK) among AI, IoT, and FI

EK describes to the specialized understanding, skills, and expertise acquired by individuals engaged in entrepreneurial activities, i.e., the adoption of new and innovative technologies such as IoT and AI (Giuggioli and Pellegrini, 2023; Liu et al., 2020; Roxas, 2014). It encompasses a wide range of competencies, including business acumen, market insights, innovative thinking, risk management, and the ability to seize opportunities, crucial for successful entrepreneurship (Giuggioli and Pellegrini, 2023). EK as a moderator can play a role in the connection of AI, IoT, and FI in various ways (Vrontis et al., 2022). For example, EK in AI and IoT can aid entrepreneurs to extract valuable insights from data that indeed lead to the development of more informed and context-specific FI (Dost et al., 2019; Haffar et al., 2021). Entrepreneurs having expertise in frugal innovation and AI are likely to shape cutting-edge solutions for the organizations which may support in optimization of the resources, can improve affordability, and may better address societal needs (Haffar et al., 2021). It is claimed by the scholars that EK of AI can better drive frugal innovation by expanding scalability and by optimizing overall impact (Nassani et al., 2022). EK in AI-frugal innovation can develop IoT and AI adoption that can enable data-driven insights and risk management (Giuggioli and Pellegrini, 2023; Haffar et al., 2021).

It is noteworthy to report that entrepreneurs having strong knowledge about AI and IoT could better navigate risks which are associated with implementation in frugal innovation projects (Leliveld and Knorringa, 2018). EK among the domains of AI, IoT, and frugal innovation can aid collaborations to create AI-driven frugal solutions that eventually align specific needs and constraints (Altmann and Engberg, 2016; Fischer et al., 2021). EK supports the frugal innovation highlight productive insights into market to detect best options for product-market fit (Fischer et al., 2021). Entrepreneurs are equipped with understanding on how AI can advance automation to upgrade frugal innovations (Cetindamar et al., 2020). EK encourages the entrepreneurs to develop a team with multiple skills by integrating both capabilities such as AI and IoT to bring frugal innovation for the sake of problem-solving and productive solutions of the problems (Abushakra and Nikbin, 2019; Cetindamar et al., 2020). Hence, the correlation among EK, AI, IoT, and frugal innovation may enhance the design, accomplishment, and impact frugal solutions (Leliveld and Knorringa, 2018). Entrepreneurs having deep knowledge in both domains can harness IoT and AI's capacity to initiate sustainable, cost-effective, and socially responsible solutions (Fischer et al., 2021; Govindan, 2022; Vrontis et al., 2022). Hence, the author currently propositioned the following assumption to empirically validate the outcomes from the perspective of Chinese SMEs based on the above connections and supporting arguments of researchers' recommendation.

H3. Entrepreneurial knowledge (EK) moderates the relationships between the Internet of Things (IoT) and Frugal Innovation.

H4. Entrepreneurial knowledge (EK) moderates the relationships between Artificial Intelligence (AI) and Frugal Innovation.

3. Methodologies

In this research, one thousand questionnaires were carefully distributed to the concerned managers within the Chinese market. A few procedures were carried out during the data collection procedure, such as online circulation through WeChat and emails as well as personal visits were made with the help of Chinese colleagues. The author currently focused on the Chinese market to affirm additional empirical evidence from this market on how the incorporation of IoT and AI could play an essential role in frugal innovation within the Chinese market. The participants were separately invited for the surveys and 860 responses were successfully got back. Finally, a total of seven hundred and seventy-nine ($N = 779$) questionnaires were considered for the aim of data analysis after evaluating and scrutinizing improperly filled information along with other critical issues such as incomplete responses just to ensure the feedback authenticity. A seven-point Likert scale was majorly employed by inspiring previously published studies of scholars (Makkonen et al., 2016; Mehmood et al., 2019; Shahid et al., 2022; Younas et al., 2017). Furthermore, the main inquiry statements consisted of forty-nine questions while respondents' profiles were assessed using 5 characteristics as mentioned in Table 1 below.

3.1. Pilot analysis

Furthermore, it is important to work on pilot testing before surveying on a large scale to assess better and more fruitful results (Thabane et al., 2010). A total of forty-five ($n = 45$) questionnaires were treated for this purpose and results are evaluated based on the suggested criteria of the statisticians (Black and Babin, 2019; Hair, 2011). The present values are normal where IoT at 0.695, AI stood at 0.755, EK stood at 0.698, and FI stood at 0.744, respectively (Hair, 2011).

3.2. Measures

IoT and AI are used as the independent measures, entrepreneurial knowledge (EK) is used as moderating measure, frugal innovation is used as the dependent variable, and innovation management as the moderating variable. First, IoTs were accessed using 5-items as adopted from the past study (Umair et al., 2021). Second, AI was measured using 15-items as adopted from the past study (Schepman and Rodway, 2020). Third, EK was measured using 6-item adopted from past studies (Roxas, 2014). Finally, frugal innovation was measured using 9-items as adopted from past studies (Levänen et al., 2016). All the scales were assessed by past studies whereby some items were further deleted owing to lower reliability based on adopted analysis techniques, as follows.

3.3. Analysis tools and techniques

First, the author applied descriptive statistics to calculate the basic

Table 1
Descriptive findings (N = 779).

	Male		Female	
	Freq.	%	Freq.	%
Gender	415	53.27	364	46.73
Qualification				
Bachelor	084	20.24	039	10.71
Master	101	24.34	122	33.52
Ph.D.	120	28.92	101	27.75
Others	110	26.51	102	28.02
Age in years				
17–20	074	17.83	045	12.36
21–23	105	25.30	112	30.77
24–27	115	27.71	100	27.47
>28	121	29.16	107	29.40
Work Experience in years				
<3 years	051	12.29	047	12.91
4–8 years	128	30.84	110	30.22
9–13 years	120	28.92	105	28.85
>14 years	116	27.95	102	28.02

information about the participants' profiles. Subsequently, a correlation testing approach was applied to understand the interrelationships among variables of the study. Third, discriminant validity was calculated and examined based on two methods such as Fornell and Larcker along with Heterotrait-Monotrait (HTMT) methods (Ab Hamid et al., 2017; Fornell and Larcker, 1981a). Likewise, the convergent validity approach was carried out as per suggested methods such as AVEs, loadings, and by evaluation of reliability (Russell, 1978). SEM using SmartPLS software was eventually applied to affirm the directional relationships among the variables (Ramayah et al., 2018). It is critical to calculate the values of NIF and SRMR to confirm the authenticity of the model, SEM (Hu and Bentler, 1999). The advised criteria for each analysis and indices are reported as follows. For instance, values should be between −1 to +1 in Pearson testing (Cohen et al., 2009; Hair, 2011), loading and average variance extracted (AVEs) outcome values should be lower than 0.5 (Hu and Bentler, 1999), reliability values should be higher than 0.7 (Hair, 2011), values should <0.9 in HTMT (Henseler et al., 2015), the outcomes of Square roots of AVEs should be higher than the following interrelationships in discriminant validity (Henseler et al., 2015), values of NFI should be higher than 0.9 (Hu and Bentler, 1999), and finally the outcomes of SRMR should lower than 0.08 (Hair, 2011; Hu and Bentler, 1999).

4. Results

Table 2 below confirms the validity as well as reliability values along with other descriptions of means and standard deviations. As reported above, loadings and AVEs outcome values should be lower than 0.5 as well as reliability values should be higher than 0.7 (Hair et al., 2005).

4.1. Pearson's correlation

Table 3 below indicates the outcome values of correlation analysis to affirm the relationships among the proposed variables of this study. The values should be between −1 to +1 where negative values affirm a negative connection, lower values affirm a lower connection and higher values assure a higher connection (e.g., Fornell and Larcker, 1981a; Hair et al., 2019; Kline, 2005). The results are reported below.

4.2. Model of discriminant validity

Table 4 below shows the values for discriminant analysis being used for validation of the dataset. Researchers have suggested the criteria for this analysis. For example, the outcomes of square roots of AVEs should be higher than the following interrelationships in discriminant validity (Fornell and Larcker, 1981b). The bold values given in the first row of each column represent the square roots of AVEs, and non-bold values show interrelationships.

4.3. Heterotrait–monotrait (HTMT)

Other than Fornel and Lacker (2001) analysis, another technique is HTMT which affirms the validity of the data exploring the similarities. As per the recommendation by Henseler et al. (2015), values should be <0.9 in HTMT analysis as mentioned in Table 5. Therefore, the present results confirmed the HTMT validity in the data based on the following accuracy of the results.

4.4. Path relationships using SEM

Table 6 below shows the directions of major paths that were evaluated based on beta values through a model of SEM. It is recommended that CFI and SRMR should be observed to discover and analyze the authenticity of the SEM model. For example, the values of NFI should be higher than 0.9 and SRMR should be lower than 0.08 (Hu and Bentler, 1999). The present values are best fit as per recommendations where

Table 2
Validity and reliability of the constructs.[a]

	Items[a]	Mean value	SD	Loadings	AVE	Reliability
Internet of things (IoT)					0.751	0.801
	IoT-F1	5.104	1.356	0.655		
	IoT-F2	4.985	1.022	0.674		
	IoT-F3	5.982	1.351	0.633		
	IoT-F4	5.130	1.021	0.635		
	IoT-F5	5.104	1.540	0.580		
Artificial intelligence (AI)					0.741	0.804
	AI-F1	5.130	1.354	0.555		
	AI-F2	5.104	1.041	0.674		
	AI-F3	4.985	1.355	0.633		
	AI-F4	5.982	1.021	0.635		
	AI-F6	5.130	1.540	0.550		
	AI-F7	5.104	1.351	0.634		
	AI-F8	5.130	1.021	0.554		
	AI-F10	5.104	1.354	0.674		
	AI-F11	5.130	1.356	0.633		
	AI-F12	5.104	1.026	0.635		
	AI-F13	4.985	1.451	0.750		
	AI-F14	5.982	1.021	0.634		
	AI-F15	5.130	1.540	0.507		
Entrepreneurial knowledge (EK)					0.744	0.800
	EK-F1	5.134	1.351	0.505		
	EK-F2	5.982	1.026	0.674		
	EK-F3	5.130	1.351	0.633		
	EK-F4	5.104	1.021	0.635		
	EK-F5	4.985	1.540	0.550		
	EK-F6	5.134	1.354	0.434		
Frugal innovation					0.689	0.842
	FI-F1	5.982	1.356	0.557		
	FI-F2	5.130	1.024	0.674		
	FI-F3	5.104	1.351	0.620		
	FI-F4	4.985	1.026	0.635		
	FI-F5	5.982	1.540	0.550		
	FI-F6	5.130	1.351	0.634		
	FI-F7	5.104	1.025	0.548		
	FI-F8	4.985	1.354	0.674		
	FI-F9	5.982	1.025	0.622		

[a] Items removed having < 0.5 AVEs and loadings.

Table 3
Pearson correlation.

	IoT	AI	EK	FI
IoT	1.00			
AI	0.24	1.00		
EK	0.32	0.28	1.00	
FI	0.15	0.34	0.35	1.00

Note. IoT = internet of things; AI = artificial intelligence; EK = entrepreneurial knowledge; FI = frugal innovation.
Values should be between − 1 to + 1 in Pearson testing.

Table 4
Model of discriminant validity.

	IoT	AI	EK	FI
IoT	**0.866**			
AI	0.140	**0.8**59		
EK	0.285	0.328	**0.8**62	
FI	0.358	0.228	0.235	**0.8**30

Note. Bold are square roots of AVEs, and rest are interrelationships.

Table 5
HTMT.

	IoT	AI	EK	FI
IoT				
AI	0.251			
EK	0.358	0.268		
FI	0.145	0.248	0.358	

Note. Values should be < 0.09.

Table 6
SEM model results.

Directions	Direct	Moderating	Sig.	S. E	Decision
H1: IoT → FI	0.158***	__	0.000	0.017	Supported
H2: AI→FI	0.248***	__	0.000	0.025	Supported
H3: IoT * EK → FI	__	0.254***	0.002	0.007	Supported
H4: AI * EK → FI	__	0.178***	0.001	0.024	Supported
	Model fitness				
	NFI		0.925		
	SRMR		0.914		
Age[a]	-		-	-	-
Size[a]	-		-	-	-

ES = expected signs; S.E = standard errors; NFI must be > 0.9; SRMR must < 0.08.
*** sig at 0.05.
[a] Control variables; control variables.

NFI stood at 0.911 and SRMR at 0.0321.

5. Discussion and implications

A total of four hypotheses were proposed to explore the nexus of the Internet of Things (IoT), artificial intelligence (AI), entrepreneurial knowledge (EK), and frugal innovation. First, it was assumed in H1 that IoT is positively linked with FI. The results after SEM implementation have shown a positive connection between IoT and FI at (β = 0.158; 0.000). Based on such calculations and findings, H1 (IoT → FI) is accepted. In addition, the outcomes are supporting past studies in which experts suggested a positive connection between IoT and FI from numerous perspectives, worldwide (Azzawi et al., 2016; Bhatti, 2012; Furini et al., 2020; Hossain, 2018; Park et al., 2018; Park et al., 2022; Sullivan et al., 2023; Tiwari, 2021). Second, it was assumed in H2 that AI is positively linked with FI. The results after SEM implementation have shown a positive connection between AI and FI at (β = 0.248; 0.000). Based on such calculations and findings, H2 (AI→FI) is accepted. Besides, the outcomes are supporting past studies in which experts suggested a positive connection between AI and FI from numerous perspectives, worldwide (Alliance, 2020; Bakar and Ahmad, 2010; De Waal et al., 2019; Govindan, 2022; Masanja and Mkumbo, 2020; Thakare et al., 2022; Wu, 2021).

Third, it was assumed in H3 that EK moderates the connections between IoT and FI. The results after SEM implementation have shown a positive moderation of EK between IoT and FI at (β = 0.254; 0.002). Based on such calculations and findings, H2 (EK*IoT → FI) is accepted. Finally, it was assumed in H4 that AI is positively linked with FI. The results after SEM implementation have shown a positive connection between AI and FI at (β = 0.178; 0.001). Based on such calculations and findings, H4 (AI→FI) is accepted. In addition, the outcomes are supporting past studies in which experts suggested a positive connection between AI and FI from numerous perspectives, worldwide (AlMulhim, 2021; Cetindamar et al., 2020; Fischer et al., 2021; Giuggioli and Pellegrini, 2023; Haffar et al., 2021; Nassani et al., 2022; Roxas, 2014; Vrontis et al., 2022). In addition, the author found no connection of any moderation that was discussed in the earlier section (Fig. 2).

6. Implications

6.1. Theoretical implications

Theoretically, this study adds to the body of literature on the Internet of Things (IoT), artificial intelligence (AI), entrepreneurial knowledge (EK), and frugal innovation showing empirical evidence from SMEs in China. IoTs and Ais are crucial in today's dynamic business environment which supports achieving frugal innovation. This study adds to the existing literature showing a positive connection between IoT and frugal innovation. Second, the study contributes by spotlighting positive relationships between AI and frugal innovation. Third, this study additionally contributes to the literature by highlighting the significance of EK as a moderator between IoT and frugal innovation. Finally, the results also add to the literature by showing the significant importance and connection of EK as a moderator between AI and frugal innovation, respectively. Besides, this study has several implications for the management that how organizational management can get benefits from evolving tools such as IoT and AI along with entrepreneurial skills like EK to obtain frugal innovation in the present era of competition in technology.

6.2. Managerial implications

From a managerial perspective, IoT and AI tools in the context of frugal innovation can have significant impacts on businesses and organizations. Managers have suggested that both AI and IoT tools could be cost-effective. For example, IoT and AI can enable frugal innovation by automating processes, reducing manual interventions, and optimizing resource utilization. Managers should focus on leveraging these technologies to achieve cost-efficiency in operations and product development. IoT devices can collect valuable data about various stakeholders and their preferences. AI algorithms can analyze this data to understand market trends and provide insights for product customization. Managers should use this information to tailor their offerings to meet the specific needs and requirements of their target audience within frugal markets. FI targets large populations with limited access to sophisticated technologies.

Furthermore, the concerned management can explore collaboration with stakeholders of the organizations using AI and IOT technologies. It is advised that by optimizing expertise organizations and improve the adoption of IoT and AI technologies into practices to better facilitate productive and innovative solutions to frugal markets. Frugal innovation should be environmentally responsible which can better reduce energy consumption consequently managers should focus on this capability to minimize carbon footprint to win over the market. AI and IoT technologies in terms of frugal innovation may unlock multiple opportunities for the organizations to provide impactful, customer-centric, and cost-effective solutions. It is stated that a successful implementation needs strategic level planning and collaboration to have a strong emphasis on fulfilling the needs of frugal customers of the organizations. However, managerial implications of entrepreneurial knowledge (EK) as a moderator between IoT and AI in the context of frugal innovation can be crucial for successfully leveraging these technologies to create impactful solutions. Entrepreneurs are suggested to possess an insightful understanding about frugal innovation and to meet frugal market challenges in a more productive way. EK will support the entrepreneurs

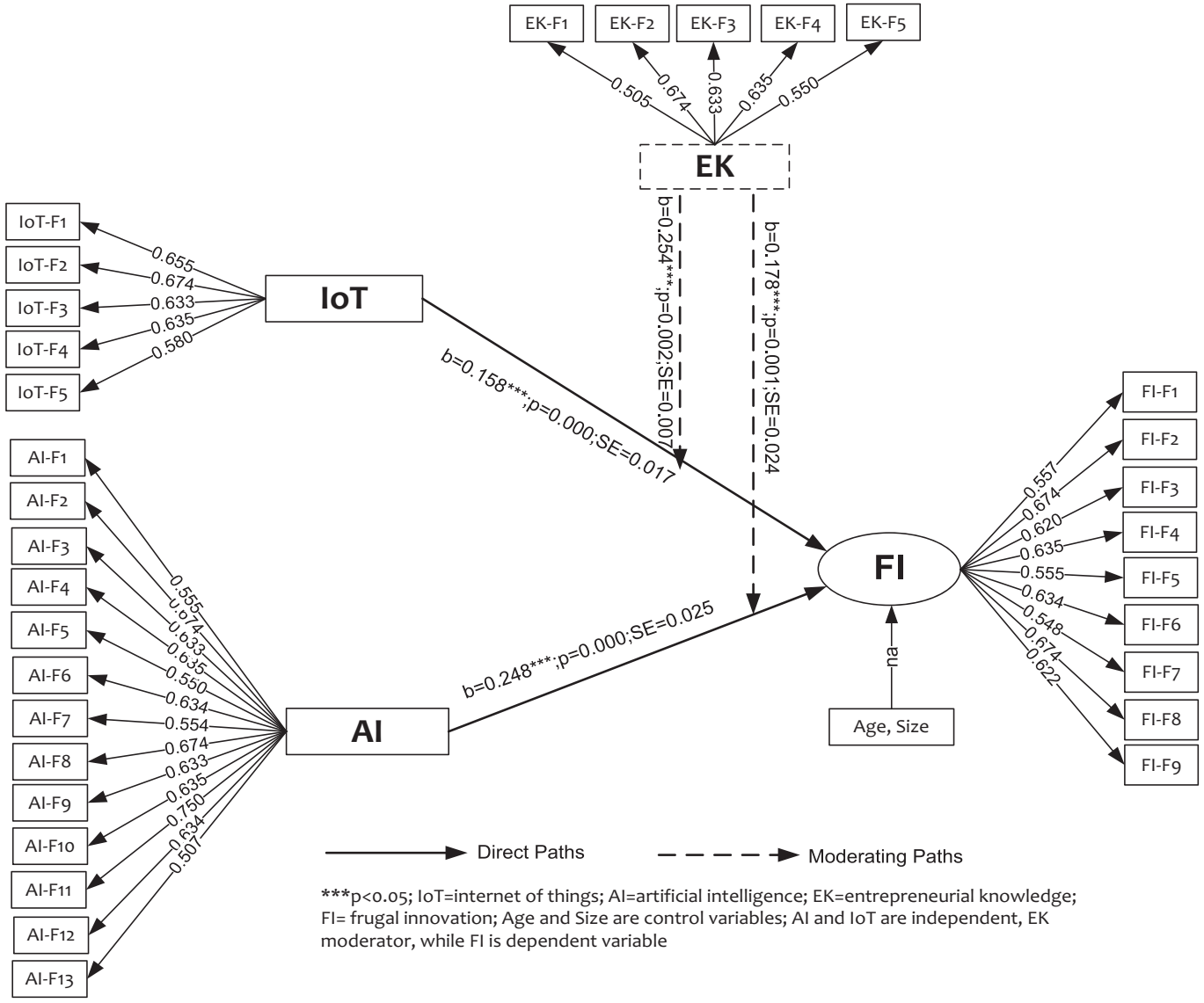

Fig. 2. Structural model of paths.

to identify the most relevant IoT and AI applications that can refer to the specific needs of target spectators. Entrepreneurs frequently possess an ability for classifying opportunities therefore managers of organizations with entrepreneurial knowledge can efficiently look for IoT and AI technologies that align with the values of frugal innovation. EK can develop an innovative and unique culture within an organization therefore managers are advised to promote such an environment where they can encourage employees to experiment, take risks, and provide out-of-the-box solutions for using IoT and AI technologies in terms of frugal innovation. Finally, frugal innovation is a capability that needs a quick decision-making where entrepreneurs are encouraged to make agile decisions for accepting AI and IoT-based technologies for the organizations. Therefore, knowledge of the entrepreneurs regarding technology and acceptability of technologies like AI and IoT could play a productive role for betterment of the organization. Ultimately, the concerned management is strongly suggested to focus on IoT, EK, and AI technologies to productively perform in the perspective of frugal innovation to effectively compete in today's business environment.

6.3. Future challenges

It is worthwhile to consider distinct future challenges that could be encountered by the organizations while embedding technologies such as IoT and AI into business operations. For instance, infrastructure is one of the major limitations that could be considered as a key hindrance in developing nations to incorporate IoT and AI-based technologies. Data privacy and concerns related to security may create trouble using of these technologies into distinct business operations. Likewise, a high cost of AI and IoT technologies along with a need for skilled professionals for managing these systems could lead toward a financial barrier, especially for the developing nations. Furthermore, certain cultural along with regulatory factors could influence the acceptance of AI and IoT solutions in certain geographical regions of the world. Because of addressing such challenges will require collaborative efforts such as from governments, organizations, as well as from tech communities to ensure reasonable access to transformative technologies for frugal innovation. Therefore, entrepreneurs that are pursuing AI and IoT technologies for frugal innovation may encounter numerous challenges such as initial capital investment which is mainly required to implement AI and IoT technologies. Another challenge is skilled and talented professionals to maintain IoT and AI-based technologies and systems. Finally, navigating through the complex procedures and adopting cultural barriers can be time-consuming and challenging. Therefore, to overwhelm these challenges, entrepreneurs need access to inexpensive

technology solutions, particular training programs, and helpful ecosystems that foster collaboration which enable them to pull certain growing technologies more effectively for sustainable frugal innovation.

7. Conclusion

It is concluded that the integration of IoT and AI tools into practices extends an immense significance for frugal innovation, especially within developing nations. It is concluded, by leveraging transformative technologies such as IoT and AI-based technologies within developing nations can establish cost-effective solutions. IoT aids interconnected devices which improve resource utilization and improve efficiency, while AI permits data-driven decision-making to advance better services. IoT and AI enable frugal innovation by nurturing sustainable development, advancing healthcare, education, and overall infrastructure. It is additionally concluded that by embracing such technologies such as IoT and AI can help progress of the organization and permit developing nations to advance to a more affluent and inclusive future. Likewise, it is concluded that EK plays a pivotal role in driving frugal innovation in developing nations since having limited resources, entrepreneurs in these regions possess the ability to identify cost-effective solutions that address pressing challenges creatively. It is concluded that developing nations can unlock the potential of their local talents to create impactful and sustainable ventures by adopting a culture of innovation and providing access to entrepreneurial education. Moreover, this study reached these conclusions because it confirmed a positive connection between IoT and FI along with AI and FI. The study also confirmed a significant moderating connection of EK among the relationships of AI, IoT, and FI, respectively. Besides, there are several drawbacks of this study as listed below along with future directions both for academic scholars and practitioners of the world.

7.1. Limitations and future research avenues

There are certain limitations of the study that future researchers can consider understanding insights into the Internet of Things, artificial intelligence, entrepreneurial knowledge, and frugal innovation. First, the sample size was small which restricts its generalization. Second, only one developing country was focused on China. Third, the study ignored considering any mediating variable among the connections of the Internet of Things, artificial intelligence, entrepreneurial knowledge, and frugal innovation. This study focused only on three major provinces of China during data collection such as Beijing, Shenzhen, and Shanghai therefore other regions could be considered in the future along with the following recommendations. First, the longitudinal studies may consider using a higher sample size within the Chinese context and the rest of the economies across the world. Future studies could be expanded with consideration of certain mediating factors to affirm the depth of the relationships between the Internet of Things, artificial intelligence, entrepreneurial knowledge, and frugal innovation. This study used both IoT and AI as a cumulative variable to determine the effectiveness of frugal innovation therefore each sub-dimension of each variable may provide additional evidence to the literature in the future.

CRediT authorship contribution statement

Weiwei Qin: Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing.

Declaration of competing interest

None.

Data availability

No data was used for the research described in the article.

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