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Configuration research on innovation performance of digital enterprises: Based on an open innovation and knowledge perspective

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This paper takes 36 unicorn enterprises in China as a sample case. Based on the perspective of open innovation and knowledge, combined with the background of the transformation and development of China's digital economy, the antecedent conditions such as the three dimensions of knowledge integration ability, the two dimensions of open innovation and knowledge sharing are integrated by using configuration thinking and fuzzy set qualitative comparative analysis (fsQCA) method. The multiple concurrent factors and causal complex mechanisms affecting innovation performance are discussed. The results show that: 1) The different dimensions of knowledge integration capability, open innovation, and knowledge sharing have six configurations to achieve high-level firm performance; 2) Different knowledge integration capabilities can all promote innovation performance; 3) knowledge sharing improves the management and utilization of knowledge, which is an important guarantee for improving innovation performance. The conclusion expands the innovation perspective of the matching of knowledge and open innovation, helps to understand the mechanism of innovation performance, and provides theoretical reference and beneficial enlightenment for enterprises to effectively improve innovation performance.

KEYWORDS

open innovation, innovation performance, knowledge integration capability, knowledge sharing, fsQCA

Introduction

Along with the rapid development of information and communication technologies such as big data, cloud computing, the Internet of Things, artificial intelligence, blockchain, and 5G, the world economy has entered a new era of the digital economy (Autio et al., 2018). By 2020, China's digital economy will account for 38.6% of GDP and is expected to surpass the US as the world's largest digital economy in the future (Jiang, 2020). The digital economy contains two parts: digital industrialization and industrial digitization, corresponding to the digital economic benefits of digital enterprises such as communication technology, and the innovation efficiency of traditional primary, secondary and tertiary industries based on digital technology enhancement (Papadopoulos et al., 2020). Therefore, whether it is digital industrialization or the industrial digitization of digital enterprises and traditional enterprises, the development of the digital economy has become an inevitable trend in the market economy (Teece, 2018). In this process, the vigorous development of the digital economy has formed a new engine of economic development and new momentum, but also to the traditional economy and traditional industrial development has brought the "pain" of fission and the urgent hope of transformation needs, to promote open innovation based on the digital economy driven by the inevitable choice for the future development of enterprises (Cennamo et al., 2020). Compared with the traditional industrial economy environment, the digital economy environment has digital scenarios and new features such as openness, borderlessness, strong interactivity, and uncertainty (Yuan et al., 2021). Open innovation of enterprises in the digital economy environment requires more open knowledge sharing and inclusive knowledge creation mechanism, through which knowledge resources needed for open innovation can be obtained, and through the effective utilization and integration of knowledge, thus promoting the improvement of enterprise innovation capability and innovation performance (Lee et al., 2010; Eftekhari and Bogers, 2015; Sun et al., 2020; Scaliza et al., 2022).

Compared with closed innovation within the enterprise, open innovation breaks through the closed organizational boundaries of the traditional economy. By strategically using inside-out and outside-in paths to acquire knowledge and resources from outside the organization and combine them with the enterprise's original core competencies and organizational strategies, the enterprise can enhance its internal innovation capabilities and spread the innovation results to the external market, to further enhance its dynamic adaptive capabilities and innovation performance (Ahn et al., 2013; Sisodiya et al., 2013; Shu et al., 2016). Although open innovation may profoundly affect innovation performance (Audretsch and Belitski, 2022), existing studies have not clarified the mechanism of the effect of open innovation on innovation performance, so there is a need to further study and explore the relationship between the two (Tang et al., 2021).

Although scholars have studied the relationship between open innovation and innovation performance (Ebersberger et al., 2021; Naseer et al., 2021; Ovuakporie et al., 2021), most of these studies have focused on the independent effect of open innovation on innovation performance, while ignoring that the performance of the role of open innovation can be influenced by other organizational factors (Cheah and Ho, 2021). According to the knowledge base theory, knowledge, as the core element of open innovation, is the foundation of open innovation (Rauter et al., 2019). In the process of promoting the development of open innovation diffusion, knowledge not only needs to be shared but also needs to be integrated efficiently to enhance the degree of knowledge interaction and increase the width and thickness of knowledge, to further enhance the open innovation performance how enterprises carry out specific activities under open innovation (Gkypali et al., 2018). Therefore, knowledge, as an important part of enterprise resources, is bound to influence the role of open innovation in innovation performance (Scaliza et al., 2022). Therefore, this study argues that it is necessary to investigate the preconditions and paths of innovation performance from the perspective of knowledge management, with open innovation-knowledge management as the mainline, to supplement the "new perspective" of innovation performance research (Cuevas-Vargas et al., 2022). In practice, the premise of open innovation is the knowledge sharing among innovation subjects inside and outside the enterprises, and each innovation subject uses knowledge sharing to acquire complementary knowledge and form a knowledge integration mechanism, which eventually becomes innovation performance through systematic evolution and output.

Based on this, this paper integrates the antecedent conditions of open innovation, knowledge integration capability, and knowledge sharing, constructs a model of the driving mechanism of innovation performance of digital enterprises, and mines the role of different groups of antecedent conditions on innovation performance through the fuzzy set qualitative comparative analysis (fsQCA) method. The innovations and theoretical contributions of this paper are 1) Integrating three types of elements, namely, open innovation, knowledge integration capability, and knowledge sharing, into a holistic analysis model and analyzing the influence of the configuration of these elements on innovation performance by applying the fsQCA method, which provides a new research perspective for understanding and explaining the complex causal relationships of the factors influencing innovation performance of digital enterprises. 2) It provides new ideas to explain the contradictions in innovation performance research. Previous studies have argued the relationship between different antecedent conditions and innovation performance, but there is still disagreement on the research findings. In contrast, this paper provides a new explanation for the research disagreement from a histological perspective: innovation performance is the result of matching and linking different antecedent conditions, and the effects of these different antecedent conditions have different characteristics, and exploring the net effect of a single antecedent condition in isolation may lead to contradictory research results.

Theoretical background and hypothesis development

Innovation performance plays a crucial role in the survival and long-term development of digital firms, and understanding and explaining the driving mechanisms of innovation performance has thus become a focal issue for scholars (Yao and Huang, 2022; Li et al., 2022). This paper explores the impact of three types of factors, namely open innovation, knowledge integration capability, and knowledge sharing, on the innovation performance of digital enterprises from the perspectives of open innovation and knowledge management, and constructs a framework for analyzing the driving mechanisms of innovation performance.

Knowledge sharing and innovation performance

The open, borderless, digital resource flow and value co-creation features presented by the digital economy itself contain the basic elements of knowledge flow, exchange, and sharing. Under the digital economy, in the open innovation process promoted by enterprises, knowledge sharing occurs in the innovation activities such as R&D cooperation and co-creation alliance between team members within the organization, between departments, and between the organization and the outside of the organization. This enables the organization's management system to form an inter-temporal and inter-level knowledge-sharing network that spans from consumers to supply chain members/cooperative units and then to the enterprise itself. In practice, the scenarios of knowledge sharing may go far beyond the scope of work in a narrow sense (Swap et al., 2001). These knowledge-sharing scenarios take the knowledge-sharing subject as a knowledge node, while the realization of knowledge-sharing is accomplished by the network transmission between nodes (Tsai, 2001). Tanriverdi (2005) believes that the stronger the absorptive capacity based on knowledge sharing, the more an enterprise can broaden the breadth and depth of knowledge, and the more effectively it can respond to changes in the environment. It is also more capable of screening out knowledge that is valuable for corporate innovation, thus enhancing the innovation performance of the organization (Tanriverdi, 2005). Knowledge sharing will make the sources of enterprise knowledge more diversified, and the higher the degree of diversification of knowledge sources and the higher the frequency of knowledge sharing and exchange, the faster the operation of technology development and other innovation activities of enterprises, thus shortening the product launch cycle. At the same time, when enterprises have better knowledge exchange and sharing mechanisms, they also have a stronger ability to manage new knowledge from other organizations. Successful commercialization of new products can facilitate innovation activities and improve organizational innovation performance. Zahra and George's (2002) empirical study on knowledge sharing, knowledge absorptive capacity, and innovation performance show that knowledge sharing can have an intrinsic effect on innovation performance through the mediating effect of knowledge absorptive capacity, in addition to its direct positive effect on innovation performance (Zahra and George, 2002). Thus, a synergistic evolutionary path of knowledge sharing, knowledge absorption capacity, and innovation performance is formed. Based on this evolutionary path, enterprises continuously increase knowledge stock and enhance knowledge absorption capacity through knowledge sharing, and then internalize each other's knowledge and innovation knowledge system to achieve innovation performance improvement and competitive advantage construction. Tripsas's (1997) empirical study on external knowledge sharing in organizations shows that knowledge is externally shared in the process of cooperation and communication between enterprises (Tripsas, 1997). In turn, this external sharing of knowledge achieves innovation in technology development, production processes, and business models through the creative stimulation of both parties, which in turn has a significant positive impact on innovation performance (Chesbrough and Schwartz, 2007).

Open innovation and innovation performance

Open innovation is based on the strategic goal of innovation development, breaking the traditional organization's closed boundaries, and using the inflow and outflow of knowledge from inside and outside the organization to promote innovation work such as new product development and business model reconstruction (Jin et al., 2022). Roh et al. (2022) believe that open innovation is not only a means but also a strategic business model (Roh et al., 2022). Through inside-out and outside-in open innovation, enterprises benefit from the introduction of new innovative knowledge and technology, and also profit from the export of patented technologies that are not used by enterprises. Baki and Peker (2022) reduce the risk of investment in R&D and enhance innovation performance by supporting new R&D technologies outside the organization through mutual flow or sharing of resources with consumers, suppliers, academic and research institutions, competitors, community teams, and non-profit organizations (Yildirim et al., 2022). The organization and these institutions then form an open-ended value co-creation mechanism, and this value co-creation mechanism can "divide" innovation and ultimately contribute significantly to enhancing the effectiveness of the firm's new product development.

In the digital economy driven by big data, cloud computing and artificial intelligence, open innovation based on internal and

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external cooperation, intra-enterprise innovation and entrepreneurship and open innovation with the help of public knowledge have become important means for enterprises to adapt to the development of digital transformation and build dynamic competitive advantages (Benitez et al., 2022; Chaithanapat et al., 2022; Kitsios and Kamariotou, 2022). The crowdsourcing model and C2B innovation model around which open innovation is formed constitute important support for the digital development of enterprises. Yang et al. (2022) classify open innovation strategies into two dimensions: "wide external search strategy" and "deep external search strategy" to facilitate the development of new products and improve innovation performance (Yang et al., 2022). At the same time, the external search target of open innovation is divided into two dimensions: "competitors" and "non-competitors". Based on the moderating effect of environmental competitiveness, an empirical study is conducted to investigate the relationship between open innovation strategy and new product innovation performance (Najafi-Tavani et al., 2022; Sanni and Verdolini, 2022; Santos-Vijande et al., 2022). When the external search target is an external organization other than a competitor, the competitive market environment positively moderates the relationship between "depth and width of external search strategy" and "new product innovation performance". When the external search target is a competitor, the competitive market environment negatively adjusts the relationship between "deep external search strategy" and "new product innovation performance".

Knowledge integration capability and innovation performance

Knowledge integration is the connection of formal or informal knowledge between individuals and business organizations that leads to new knowledge sharing and communication and can provide a basis for transforming individual knowledge into organizational knowledge. When an individual's or organization's knowledge is connected with another team's knowledge and discussed, communicated, and exchanged by the individual or organization, it may further develop and integrate up-ward into the organization's knowledge (Inkpen, 1996). Based on knowledge foundation theory and organizational learning theory, when the internal knowledge accumulation of an organization is not enough to support the development of an enterprise, seeking knowledge from outside becomes one of the important channels for the innovation and development of an enterprise. In the era of a knowledge-driven digital economy, cross-organizational cooperation enables enterprises to acquire more knowledge. However, how can the new knowledge acquired be effectively converted into useful value for the organization and make the organization more innovation-driven? Only by integrating relevant knowledge and resources more rapidly and flexibly, and coordinating the allocation of internal and external knowledge of the organization, can such effective conversion of new knowledge be successful in the open digital competitive environment.

McDonough et al. (2001) believe that enterprises create new knowledge through knowledge integration, and apply it to the business activities of the enterprise. Therefore, by the knowledge integration ability, the knowledge advantage created by the knowledge exchange and combination will be reflected in the related activities of the organization's value creation, thus contributing to the organization's innovation performance. Ritala et al. (2017) believe that knowledge integration is the integration of professional knowledge among members to meet the organization's adaptation to a specific business environment. Because integrated knowledge enables organizations to efficiently plan products and markets in uncertain environments, promote new product innovation and evolution, and lay the foundation for business operations to achieve expected execution results. Therefore, the stronger the knowledge integration capability of the organization, the more knowledge will be available. The more solidly these organizations can establish their core competencies, the higher their innovation performance.

Zobel et al. (2017) empirical research based on organizational learning theory shows that if an enterprise can acquire new knowledge and integrate existing knowledge in the organization in different ways, the enterprise will have a good performance in innovation matters such as products and processes. Therefore, the stronger the organizational knowledge integration capability, the higher the level of enterprise innovation. Based on the perspective of dynamic capability theory and the empirical data of 261 enterprises participating in the Standard Alliance, Zhang et al. (2022) conducts an empirical study on the relationship between knowledge integration capabilities, partnership quality, and alliance innovation performance. The knowledge integration ability of the enterprise has a positive effect on improving the performance of the technical standards alliance, and the improvement of the quality of the partnership in the technical standards alliance will also help the knowledge integration ability and the alliance management ability to jointly play a positive role in the performance of the technical standards alliance (Qin et al., 2021; Sousa-Ginel et al., 2021; Junaid et al., 2022; Sultana et al., 2022).

The linkage of knowledge integration capability, open innovation, and knowledge sharing

Open innovation guides the direction and behavioral choices of digital enterprises and has a supportive role in their innovation performance. To achieve the goal of open innovation-oriented innovation performance, enterprises must have sufficient

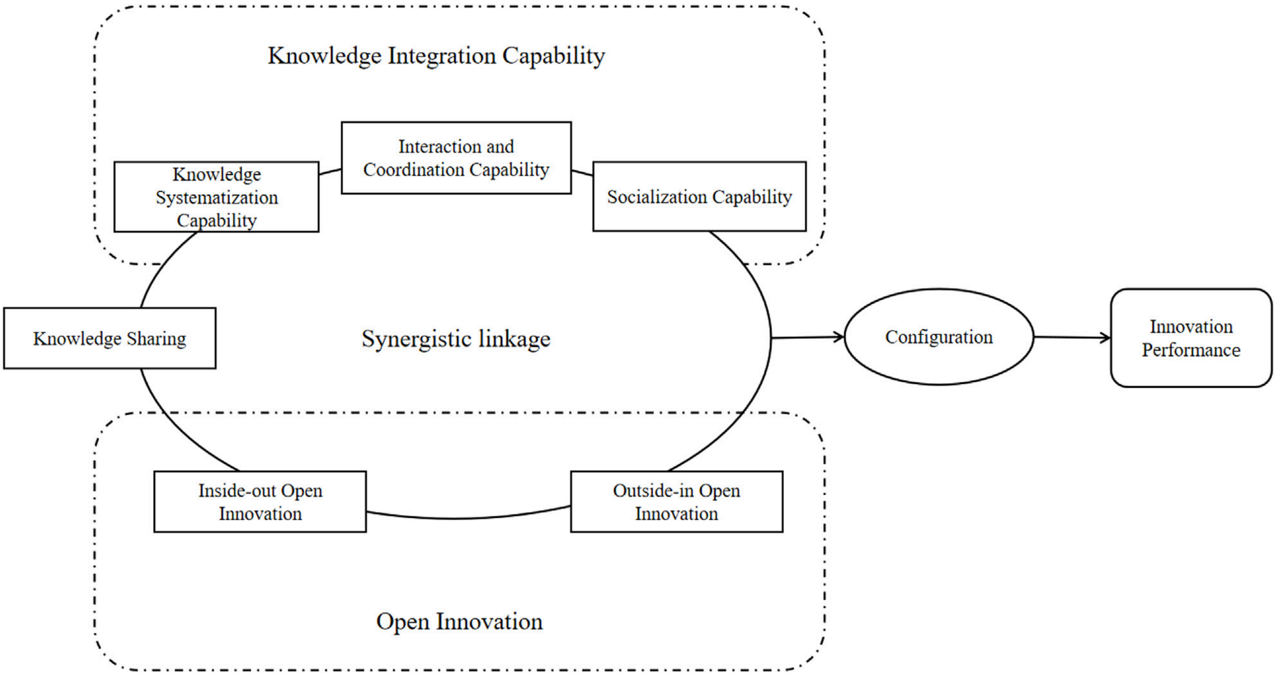

FIGURE 1
Research model.

organizational resources to promote innovation actions (Acharya et al., 2022). For enterprises, the knowledge integration capability accumulated in the long-term production and operation process becomes a valuable capability. Knowledge integration capability can provide support for the realization of enterprise innovation performance (Ahlfänger et al., 2022). When the knowledge integration ability is difficult to be directly utilized, the enterprise will realize the improvement of its innovation performance by sharing knowledge with other enterprises and complementing them through knowledge sharing (Bao and Wang, 2022). Compared with enterprises with strong knowledge integration ability, enterprises with weak knowledge integration ability need to play the role of knowledge sharing more and fully release knowledge value through knowledge-sharing processes such as constructing a knowledge portfolio, improving knowledge management ability, and using knowledge to leverage opportunities (Kong et al., 2021). Meanwhile, knowledge sharing improves the open innovation environment of enterprises through optimal knowledge management, which is conducive to better innovation performance (Sheng and Hartmann, 2019; Qin et al., 2021). Therefore, the innovation performance of digital enterprises may be influenced by the linkage and complementarity of open innovation, knowledge integration capability, and knowledge sharing, which include six factors: inside-out open innovation, outside-in open innovation, knowledge systematization capability, interaction and coordination capability, socialization capability and knowledge sharing. The research framework of this paper is shown in Figure 1.

Research design

Method

The main reasons for adopting fsQCA in this paper are as follows: 1) Traditional statistical analysis methods, such as regression analysis, can only analyze the "net effect" of individual conditions on innovation performance, which cannot solve the problem of causal complexity in innovation performance research (Ragin, 2014; Xie and Wang, 2020). The QCA method can reveal the impact of complex relationships among multiple antecedent conditions on the results based on the pooling theory (Fiss, 2011). 2) Although the group states relationships among the antecedents of innovation performance can be tested by typical correlation analysis and discriminant analysis. However, these methods are difficult to identify the interdependence and asymmetric causality among the antecedent conditions (Ragin, 2006). 3) The causal conditions in this paper are mostly continuous variables, and fsQCA can ensure the accuracy of the data after variable processing, which

TABLE 1 Basic information of sample enterprises.

Number	Enterprise	Industry segment	Number	Enterprise	Industry segment
N1	ZGSH	Manufacturing	N19	CBC	Finance and insurance
N2	BGJT	Manufacturing	N20	CMSB	Finance and insurance
N3	HFJ	Manufacturing	N21	CIB	Finance and insurance
N4	DFQC	Manufacturing	N22	HW	Technology
N5	SAJT	Manufacturing	N23	XM	Technology
N6	SHBL	Wholesale/retail	N24	JD	Consumer business/goods
N7	DLSC	Wholesale/retail	N25	TB	Consumer business/goods
N8	BJHL	Wholesale/retail	N26	SXDJ	Industrials (construction and industrial goods)
N9	GMDQ	Wholesale/retail	N27	SXJZ	Industrials (construction and industrial goods)
N10	JLF	Wholesale/retail	N28	AMM	Agriculture
N11	SNPC	Energy and utilities	N29	APB	Agriculture
N12	CNPC	Energy and utilities	N30	PBB	Health care
N13	CPCS	Energy and utilities	N31	HCR	Health care
N14	CT	Telecommunications	N32	XJT	Consulting services
N15	CM	Telecommunication	N33	ZLZP	Consulting services
N16	CU	Telecommunication	N34	YYQ	Oil and gas
N17	PBC	Finance and insurance	N35	SM	Oil and gas
N18	BOB	Finance and insurance	N36	BJZY	Pharmaceutical

can fully reflect the subtle effects produced by changes in different degrees or levels of innovation performance influencing factors.

Sample selection and data collection

Regarding existing studies and the normative requirements of fsQCA methods (Fiss, 2011; Ragin, 2014). When there are 6 pre-elements in the configuration path model, more than 25 research samples are required to ensure the reliability and validity of the research results. This study combines industry planning and thinks tank research reports such as “the 2020 China Unicorn Enterprise Research Report” and “the 2020 Hurun List of China’s Top 500 Private Enterprises”. A total of 36 digital enterprises (including five provinces: Shaanxi, Henan, Jiangsu, Zhejiang, and Liaoning) provided by MBA students of Xi’an Jiaotong University are selected as research samples. The information of sample enterprises is shown in Table 1. The sample selection in this paper follows the theoretical sampling principle (Fiss, 2007), which satisfies the following three criteria: 1) the sample enterprises should be listed enterprises or industry-leading enterprises among digital enterprises to ensure the adequacy of the information. 2) The enterprises have experienced a complete innovation performance process to ensure the typicality of the sample. 3) The enterprises are involved in different industries to ensure the diversity of the sample. Meanwhile, according to the requirements of the QCA method on sample size, when the number of conditions is n, the number of samples should not be less than 2^{n-1}. Based on this, 36 digital enterprises are finally selected as samples in this paper, and the basic information of some sample enterprises is shown in Table 1.

The research data in this paper were mainly collected through secondary sources. The reasons are as follows: first, the relevant public information data are abundant and have high authenticity and reliability; second, to avoid subjective influence on the collection and analysis of information when researchers conduct interviews; third, the number of sample enterprises and their scattered locations make it more difficult to conduct field research and interviews. At the same time, to try to avoid the limitations of the research caused by secondary data, this paper selects high-quality information such as annual reports of enterprises, authoritative research reports, and well-known media reports when collecting data; when processing data, members of the research team conducted several data collations and discussions and conducted coding reliability tests to ensure the validity and reliability of secondary information. The sources of information in this paper include 1) official websites of enterprises, annual reports, internal speeches, and public interviews of senior leaders; 2) industry research reports and related books; and 3) information such as mainstream media reports and comments of self-publishers. In collecting and organizing the information, the main focus is on enterprises’ innovation performance experience, open innovation, knowledge integration capability, and corresponding knowledge-sharing activities, which eventually results in a sample database of more than 900,000 words.

TABLE 2 Questionnaire.

Variable	ID	Measurement item	Sources
Innovation performance	IP1	The speed of new product development.	Zobel et al. (2017)
	IP2	The number of new products introduced to the market.	
	IP3	The number of new products that are first-to-market	
	IP4	The variable share of incremental innovation	
	IP5	The number of new technologies that are first-to-market	
	IP6	The number of new technologies introduced to the market	
	IP7	With self-developed patents	
Inside-out open innovation	IOI1	Our enterprise often sells its technology to outside organizations	Chesbrough and Schwartz (2007)
	IOI2	Our enterprise often sells its patents to outside organizations	
	IOI3	Our enterprise often licenses its patents or technologies to outside organizations	
	IOI4	Our enterprise often promotes our industry presence by disclosing new knowledge and technologies	
Outside-in open innovation	OOI1	Our enterprise often collaborates with outside organizations to develop new technologies	Chesbrough and Schwartz (2007)
	OOI2	Our enterprise often receives knowledge support from external organizations	
	OOI3	Our enterprise often collaborates with external organizations to develop new technologies	
	OOI4	Our enterprise sells the intellectual property for commercial value	
Knowledge sharing	KS1	Our enterprise can acquire new knowledge quickly according to the market	Daniel Sherman et al. (2005)
	KS2	Our enterprise can quickly acquire new knowledge from universities or academic research	
	KS3	Our enterprise can quickly acquire new knowledge from other companies	
	KS4	Our companies can acquire new knowledge to implement new business models	
	KS5	Our enterprise can acquire new knowledge to generate new products	
	KS6	Our enterprises can acquire new knowledge to generate new technologies	
Knowledge systematization capability	KSC1	Priori procedures	De Boer et al. (1999)
	KSC2	formal language and codes	
	KSC3	Policies and working manuals	
	KSC4	information systems	
Interaction and coordination capability	ICC1	Our enterprise has a good cooperative relationship with other companies	De Boer et al. (1999)
	ICC2	Our enterprise has a good cooperative relationship with other companies	
	ICC3	Our enterprise has many professionals	
	ICC4	Our enterprise has a very good licensing environment.	
	ICC5	Our enterprise uses a flat management model	
Socialization capability	SC1	Our enterprise has a common ideology (culture)	De Boer et al. (1999)
	SC2	Our enterprise produces a distinct identity for its participants	
	SC3	Our employees have a strong sense of identity with the corporate values	
	SC4	Our enterprise has a very good and authoritative training system	

The coding basis for the QCA approach is derived from a holistic reflection of quantitative and qualitative data. This paper mainly draws on the concept of anchoring variables and looks for statements about open innovation, knowledge integration capability, knowledge sharing, and innovation performance from the case materials as the basis for the assignment. Referring to Fiss's (2011) approach (Fiss, 2011), this paper adopts a quadratic assignment method, which is based on four anchors of 0 (completely unaffiliated), 0.33 (biased unaffiliated), and 0.67 (biased affiliated), and 1 (completely affiliated). The specific coding assignment process includes three steps: constructing a coding table (see Table 2), coding the information, and testing the coding reliability. Taking the coding of knowledge-sharing factors of ZGSH as an example: this paper first draws on 's study to construct a coding table and determines six indicators in two dimensions of knowledge-sharing channels and knowledge-sharing degree as coding criteria (Daniel Sherman et al., 2005). Then two coders from the research team independently coded the sample enterprises based on the information collected from them. The coders assigned a value of 1 to the market orientation factor when they judged that the enterprise met 5 or more of the 6 indicators,

TABLE 3 Analysis of necessary conditions.

Conditional variable	Consistency	Coverage
IOI	0.811	0.829
~IOI	0.189	0.850
OOI	0.622	0.812
~OOI	0.378	0.872
KSC	0.834	0.824
~KSC	0.166	0.882
ICC	0.556	0.833
~ICC	0.444	0.833
SC	0.590	0.828
~SC	0.410	0.841
KS	0.856	0.846
~KS	0.144	0.765

Notes: IOI, interaction and coordination capability; OOI, outside-in open innovation; KSC, knowledge systematization capability; ICC, interaction and coordination capability; SC, socialization capability; KS, knowledge sharing; "~", the negation of the condition.

and a value of 0.67 if it met 3–4 of the 6 indicators, 0.33 if it met 1–2 of the 6 indicators, and 0 if it met less than 1. Finally, the coding reliability test was conducted based on the aggregated results of the coders to ensure the reliability of the coding results.

Coding reliability test

Coding reliability refers to the degree of consistency in the coders' assignment of factors. The higher the degree of consistency, the higher the coding reliability. Drawing on the studies of Bhatt et al. (2010) and Greckhamer et al. (2018) (Bhatt et al., 2010), this paper uses the average mutual agreement reliability index to measure coding reliability. This paper contains 252-factor coding assignments (36 enterprises, 7-factor coding assignments per enterprise), and a total of 43-factor coding assignments were initially inconsistent between the two coders in the coding process, so the value of the mutual agreement index (MAI) obtained using the Holsti formula is 82.94%, which is calculated as follows:

$$MAI = \frac{2M}{N_1 + N_2} = \frac{2 \times (252 - 43)}{252 + 252} \times 100\% = 82.94\% \quad (1)$$

where M is the number of factors assigned identically by both coders, N_1 is the number of factors assigned by the first coder, and N_2 is the number of factors assigned by the second coder.

Since this paper is assigned by two coders, the mutual agreement is the average mutual agreement, and the reliability coefficient is calculated as follows:

$$\text{reliability} = \frac{n \times MAI}{1 + (n-1) \times MAI} = \frac{2 \times 0.8294}{1 + (2-1) \times 0.8294} \times 100\% = 90.67\% \quad (2)$$

From the above calculation results, it can be seen that this paper has good coding confidence. In addition, for the different results appearing in the process of coding assignment, the members of the group discuss together and finalize the corresponding assignment results.

Data analysis and results

Analysis of the necessity of individual conditions

The necessity of the antecedent conditions was first analyzed to test whether any single antecedent condition constitutes a necessary condition for innovation performance. fsQCA3.0 test results are shown in Table 3. It can be seen that the consistency values of the influence of each antecedent condition on innovation performance are below 0.9, indicating that there is no single antecedent condition that has a dominant influence on innovation performance, and a configuration analysis of each antecedent condition is required.

Analysis of sufficient conditions

The adequacy of conditional configuration is measured using conformance, but its calculation method and minimum acceptance criteria differ from necessity analysis. According to Schneider and Wagemann, the frequency threshold should be set according to the size of the research sample, and the frequency threshold for small and medium-sized studies is usually set to 1 (Schneider et al., 2010). Since the number of samples in this paper is 36, the frequency threshold is set to 1 in the adequacy analysis. Meanwhile, according to the suggestion of Ragin and Fiss, this paper sets the original consistency threshold to 0.8 and the PRI consistency threshold to 0.75. In subsequent normalization operations, complex, parsimonious, and intermediate solutions are obtained. Following the existing research practice, this paper selects the intermediate solution as the main reference for the explanatory sufficiency analysis and distinguishes the core and auxiliary elements of the group state based on the parsimonious solution and the intermediate solution. If the antecedent condition appears in both the parsimonious solution and the intermediate solution, the condition is the core condition; if the antecedent condition appears only in the intermediate solution, the condition is the auxiliary condition, and the results are shown in Table 4.

TABLE 4 Sufficiency analysis of conditional configuration.

Conditional configuration	Path					
	A balanced drive model of "knowledge integration capability-open innovation-knowledge sharing"		A dual drive model of "knowledge integration capability-open innovation"		A dual drive model of "knowledge integration capability-knowledge sharing"	
	Configuration 1	Configuration 2	Configuration 3	Configuration 4	Configuration 5	Configuration 6
KSC	●	●		●	●	●
ICC		●	●	⊗	●	⊗
SC			●	⊗		●
IOI	●		●	●	●	
OOI		●	⊗	⊗	●	⊗
KS	●	●	●			●
Raw coverage	0.589	0.366	0.222	0.199	0.321	0.177
Unique coverage	0.178	0.090	0.023	0.022	0.045	0.011
Consistency	0.841	0.846	0.869	0.900	0.879	0.941
Solution coverage	0.780					
Solution consistency	0.844					

Notes: IOI, interaction and coordination capability; OOI, outside-in open innovation; KSC, knowledge systematization capability; ICC, interaction and coordination capability; SC, socialization capability; KS, knowledge sharing; ●, core casual condition (present); ● = peripheral casual condition (present); ⊗, core casual condition (absent); ⊗, peripheral casual condition (absent). Blank spaces indicate "do not care."

As can be seen from Table 4, the consistency level of both individual solutions (configuration) and the overall solution is above the minimum acceptable standard of 0.75, where the consistency of the overall solution is 0.844 and the coverage of the overall solution is 0.780. The six configurations in Table 4 can be considered a sufficient combination of conditions for digital firms to achieve innovative performance.

Configuration 1 (KSC*IOI*KS→IP): This configuration is a sufficient condition for innovation performance consisting of high knowledge systematization capability, high inside-out open innovation, and high knowledge sharing capability. When the knowledge systematization capability is strong, to meet market demand, achieve competitive advantage in the market and achieve high innovation performance, enterprises need knowledge sharing and knowledge systematization capability to break organizational boundaries. At the same time, enterprises can further improve the effectiveness of knowledge utilization through knowledge sharing, creatively integrate and allocate knowledge to market innovation activities, and improve the ability of enterprises to launch new products and develop new technologies, thus promoting innovation performance.

Configuration 2 (KSC*ICC*OOI*KS→IP): This configuration is a sufficient condition for innovation performance consisting of high knowledge systematization capability, high interaction and coordination capability, high outside-in open innovation, and high knowledge sharing capability. Unlike configuration 5, although the knowledge systematization capability and interaction and coordination capability are high in configuration 2, it only has high outward-inward open innovation. In this case, knowledge sharing becomes a key factor to ensure the successful development and use of new products and technologies.

Configuration 3 (ICC*SC*IOI*~OOI*KS→IP): This configuration is a sufficient condition configuration for innovation performance consisting of high interactive co-ordination capability, high socialization capability, high inside-out open innovation, low outside-in open innovation, and high knowledge sharing capability. The results of this configuration show that firms with high interaction and coordination capabilities and high socialization capabilities are willing to invest in knowledge acquisition actions inside and outside the organization and influence innovation performance by exploring new technologies, products, and business markets. In contrast, more inside-out open innovation and strong knowledge-sharing capabilities provide firms with the knowledge and capabilities to undertake technological innovation and new product development, which in turn leads to innovation performance.

Configuration 1, Configuration 2, and Configuration 3 are all manifested by the combined effect of open innovation, knowledge integration capability, and knowledge sharing, so this paper names them as the balanced driving model of "knowledge integration capability-open innovation-knowledge sharing".

Configuration 4 (KSC*~ICC*~SC*IOI*~OOI→IP): This configuration is a sufficient condition for innovation performance consisting of high knowledge systematization capability, low interaction, and coordination capability, low socialization capability, high inside-out open innovation, low outside-in open innovation. In configuration 2, the firm has high knowledge systematization capability as the main knowledge integration capability, and high inward-looking open innovation provides a suitable environment for the firm's innovation and innovation performance. At the same time, the low external-inward open innovation environment reduces the external coordination pressure on innovation and allows firms to focus on improving their innovation performance in technology innovation and new product development due to the low number of collaborators and the difficulty of transforming existing knowledge and technology into market-compatible value innovation.

Configuration 5 (KSC*ICC*IOI*OOI→IP): This configuration is composed of high knowledge systemization ability, high interaction, and coordination ability, high in-side-out open innovation, and high outside-in open innovation configuration of sufficient conditions for innovation performance. Enterprises with dual capabilities of high knowledge systemization ability and high interaction and coordination ability need to improve their innovation performance in the case of a highly open innovation environment. Because enterprises need an open innovation environment, to achieve breakthroughs in both market development and technological innovation. The inside-out open innovation guarantees the internal environment that enterprises need to carry out risk-taking activities and free innovation, while the outside-in open innovation promotes enterprises to improve their innovation performance based on external knowledge.

Both Configuration 4 and Configuration 5 show that the innovation performance of digital enterprises is driven by knowledge integration capability and open innovation, so this paper names them as a dual drive model of "knowledge integration capability-open innovation".

Configuration 6 (KSC*~ICC*SC*~OOI*KS→IP): This configuration is a sufficient condition for innovation performance consisting of high knowledge systematization capability, low interaction and coordination capability, and high socialization capability, low outside-in open innovation, and high knowledge sharing. This configuration reflects the tendency of enterprises to develop the knowledge integration capability of internalizing knowledge systematization and turning knowledge into value. Under this knowledge integration capability, enterprises are good at seizing opportunities and being brave in innovation, and continuously integrating and developing existing knowledge, which can significantly affect innovation performance. However, due to the limited innovation environment within the enterprise, it is necessary to promote the cultivation of open innovation culture through knowledge sharing, reduce the cost of market development and innovation actions, and then ensure that corporate activities can be supported by innovation culture.

Configuration 6 shows the linkage effect of knowledge integration capability and knowledge sharing on innovation performance, so this paper names it a dual drive model of "knowledge integration capability-knowledge sharing".

Robustness test

We used standard methods to conduct a robust analysis of QCA results. The commonly used methods are: Adjusting the calibration threshold, changing the consistency threshold, adding or deleting the shell, changing the frequency threshold, and adding other conditions. This paper draws on Greckhamer's practice and increases the PRI consistency threshold from 0.75 to 0.80 to carry out an adequacy analysis (Greckhamer et al., 2018), and finds that the test results are almost completely consistent with the original research results (see Table 4). In addition, in this paper, the original consistency threshold is increased from 0.80 to 0.85, the robustness test is performed again, and the obtained results are consistent with the original consistency threshold of 0.80.

Discussion and implications

Research implication

From the perspective of configuration matching, this paper uses fuzzy set qualitative comparative analysis (fsQCA) to explore the configuration effects of antecedent conditions, such as knowledge systematization ability, interaction coordination ability, socialization ability, open innovation from inside out, open innovation from outside in and knowledge sharing, on innovation performance of digital firms. Three models to improve innovation performance are summarized: the balanced driving mode of "knowledge integration ability-open innovation-knowledge sharing", the dual driving mode of "knowledge integration ability-open innovation" and the dual driving mode of "knowledge integration ability-knowledge sharing".

Firstly, innovation performance has the characteristics of "multiple concurrent" and "all paths lead to the same destination". The innovation performance of digital enterprises is the result of the interaction of multiple antecedents, that is, multiple concurrencies. In addition, the interaction between antecedent conditions will form different configurations, that is, all paths lead to the same destination. The results show that there are six different configurations of innovation performance, and each configuration is composed of multiple antecedent conditions. In this paper, the fsOCA method is adopted to reveal the matching effect of the above antecedent conditions on innovation performance, explain the influencing mechanism of innovation performance from a holistic perspective, and enrich and supplement the previous research on innovation performance based on the contingency perspective.

Secondly, knowledge integration ability is an important foundation for digital enterprises to improve innovation performance. It can be seen from the configuration results that among the six configurations to improve innovation performance, any configuration has the condition of knowledge integration ability, that is, innovation performance can be improved under the guidance of knowledge systematization ability, interaction coordination ability, or socialization ability. Under different knowledge integration capabilities, enterprises will present different choices for their organizational knowledge management and utilization methods. No matter what kind of knowledge integration capability is based on, enterprises' innovation actions are formulated and implemented according to the internal and external conditions of enterprises (Sun et al., 2022). Therefore, different knowledge integration capabilities can promote innovation performance to a certain extent.

Thirdly, knowledge sharing is important for enterprises to improve innovation performance. According to the configuration results of innovation performance, knowledge sharing plays a core role in multiple configurations. This indicates that no matter whether there is a good open innovation environment or not (Fan et al., 2021), enterprises need to integrate and utilize knowledge effectively. When the enterprise has a good open innovation environment, only by using an effective knowledge-sharing strategy can the open innovation environment be converted into real performance gains. In the conservative open innovation environment, enterprises can fully cultivate the open innovation environment by using knowledge sharing, excavating the innovation value of the environment, and avoiding the low innovation performance caused by the environment.

Management implications

This paper provides the following management implications for digital enterprise innovation performance.

Firstly, the environment in which digital enterprises are located is characterized by uncertainty, interactivity, and borderlessness. It is increasingly difficult for enterprises to improve innovation performance in the actual development process. Therefore, enterprises should pay attention to the guiding role of knowledge integration ability in innovation performance (Hu et al., 2020). Based on selecting knowledge integration ability suitable for their development, enterprises should make corresponding adjustments to innovation activities according to knowledge integration ability, and promote the formation of technology or product innovation matching knowledge integration ability.

Open innovation can improve the risk tolerance of enterprises in pursuing innovation performance and provide them with necessary environmental support. This internal policy for the enterprise offers a new way to improve innovation performance: according to the needs of innovation performance, enterprises in the process of production and management necessary to have a good open innovation environment, namely through the analysis of the unfavorable situation of innovation may face and the deep understanding of the effect on different types of open innovation. Enterprises can achieve a dynamic balance between innovation performance and knowledge sharing to avoid hindering high innovation performance due to too high or too low open innovation levels.

The findings of this paper can inspire digital firms to consider and improve innovation performance from a knowledge-sharing perspective. The purpose of knowledge sharing is to manage the knowledge owned by an enterprise and to generate "new knowledge or capabilities". The improvement of innovation performance depends, to a certain extent, on acquiring and using knowledge. Therefore, enterprises should explore and create new uses for their existing knowledge through knowledge sharing, try to construct new knowledge combinations, and apply the new combinations to innovation performance practices.

Limitations and further research

This paper has the following shortcomings, and also provides a direction for future research: Firstly, this paper only considers antecedent conditions such as knowledge integration ability, open innovation, and knowledge sharing, but many factors affect innovation performance. Future research can include factors such as strategic orientation, resources, and senior management team, to study the influencing factors of innovation performance more comprehensively and improve the explanatory power of research results. Secondly, 36 enterprises were selected as the analysis samples in this paper. Limited by the number of samples, the results of qualitative comparative analysis are limited in the universality of application. In the future, more data on industries and enterprises can be collected for further analysis.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

JG made significant contributions to the conception or design of the work, and made major adjustments to the theoretical framework in the process of repair. TC and RM critically drafted or modified important knowledge contents, and made major adjustments and modifications to research hypotheses in the revision stage to sort out the structure of the full text.

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Conflict of interest

HD, TC ,and RM were employed by Shaanxi Provincial Land Engineering Construction Group Co., Ltd.

The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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