Journal of Engineering and Technology Management 77 (2025) 101900

Contents lists available at ScienceDirect

Journal of Engineering and Technology Management

journal homepage: www.elsevier.com/locate/jengtecman

Business ecosystem governance, digital capabilities, and enterprises' digital innovation performance -Empirical data from China

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ARTICLE INFO

Keywords:
Business ecosystem governance
Digital capability
Digital innovation performance
Technological dynamism

ABSTRACT

Business ecosystems serve as a critical platform for firms to accumulate innovation resources, co-create value with stakeholders, and achieve innovation outcomes. Strengthening ecosystem governance can mitigate issues like "free-riding" and optimize the overall functioning of the ecosystem. Enhancing digital innovation performance through effective ecosystem governance has become a key strategy for complementary firms seeking innovation and growth. This study investigates how complementary firms within business ecosystems adapt to governance mechanisms to boost digital innovation performance. A survey of 684 complementary firms within the business ecosystem was conducted, with multiple regression analysis applied to examine the impact of ecosystem governance on digital innovation performance from the complementary firms' perspective. The analysis also explores the mediating role of digital capabilities and the moderating effect of technological dynamism. The findings indicate that: (1) both contractual and relational governance positively and significantly influence digital innovation performance; (2) digital perceptual capabilities and digital resource coordination capabilities mediate the relationship between ecosystem governance and digital innovation performance of complementary firms; (3) technological dynamism negatively moderates the relationship between contractual governance and digital capabilities, but does not influence the relationship between relational governance and digital capabilities. This research advances the understanding of the relationship between ecosystem governance and digital innovation performance in the context of the digital economy, offering insights from the perspective of complementary firms and highlighting the complex mechanisms through which ecosystem governance affects their digital innovation outcomes. The conclusions provide practical implications for complementary firms aiming to enhance their digital innovation performance within the digital economy.

1. Introduction

In the digital economy, both domestic and international firms are increasingly constructing or joining business ecosystems to secure

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https://doi.org/10.1016/j.jengtecman.2025.101900
Received 20 August 2024; Received in revised form 25 June 2025; Accepted 7 July 2025
Available online 12 July 2025

sustainable competitive advantages. Business ecosystems, typically dominated by focal firms and involving complementary players, including SMEs, are emerging as the predominant organizational model for digital innovation and value creation (Cozzolino et al., 2021). Innovation by complementary firms, relying on the focal firms and their dominant business ecosystems, has become a key approach for SMEs to drive innovation (Cenamor, 2021; Hong et al., 2024). For example, Alibaba Group has established a comprehensive online transaction ecosystem by integrating e-commerce platforms, logistics, and payment systems, while Haier has built a business ecosystem to foster small-scale innovations and entrepreneurship, utilizing an industrial internet platform as a new engine. These pioneering firms engage in cross-boundary collaboration and value co-creation with external stakeholders, including users, suppliers, and investors (Shi et al., 2023; Zhang et al., 2024), driving digital innovation and significant success. Their achievements, in turn, inspire complementary enterprises to pursue digital innovation and commercial success. In the context of business ecosystems, complementary firms are defined as providers of complementary components (Adner and Kapoor, 2010), offering additional resources or capabilities to other participants through direct or indirect involvement in production networks (Cennamo and Santalo, 2013). These firms also develop complementary products to expand business markets (Borner et al., 2023). By developing and providing complementary products, they enhance the product diversity of the ecosystem (Carst and Hu, 2024), increase user engagement (Carst and Hu, 2024), and contribute to the value creation within the ecosystem (Hong et al., 2024). Complementary firms play a pivotal role as value co-creators, enabling the commercialization of ecosystem value propositions (Adner and Lieberman, 2021; Liang et al., 2022).

Complementary enterprises—such as component suppliers and technology providers—face a pressing need to synchronize and collaborate with dominant firms, which possess substantial innovation resources and hold leadership positions within the ecosystem. This synchronization is essential to avoid obsolescence in the face of industry convergence and evolving business models (Yoo et al., 2024). Furthermore, business ecosystems offer complementary enterprises opportunities to acquire valuable resources through collaboration, build stable value networks, restructure their innovation capabilities, transform traditional business models, and strengthen competitive advantages (Clarysse et al., 2014; Howard et al., 2019; Bohnsack et al., 2024). However, realizing these opportunities requires effective governance of the business ecosystem (Pomegbe et al., 2021) to foster deep collaboration among participants for value co-creation. Business ecosystem governance (BEG) encompasses the rules, norms, and shared values that emerge from long-term interactions and exchanges between ecosystem members. It plays a critical role in shaping innovative behaviors and outcomes, including digital innovation performance (Coskun-Setirek et al., 2024). Nevertheless, complementary enterprises, constrained by their limited innovative resources and adherence to traditional innovation models, may eventually face resource scarcity, jeopardizing their competitive edge and exposing them to the risk of market obsolescence. This raises two key questions:

Q1: How can focal enterprises effectively govern business ecosystems to attract stakeholders, facilitate resource sharing, and ensure the ecosystem's sustainable development?

Q2: How can complementary enterprises engage in governance, explore the full potential of business ecosystems, transform opportunities into reality, and rebuild their capability frameworks to achieve digital innovation?

In addition to complementarity, the concept of complementors has become central in business ecosystem research, particularly in the fields of innovation and platform ecosystems (Tsujimoto et al., 2018; Toh and Agarwal, 2023; Miehé et al., 2023; Hong et al., 2024). However, existing literature continues to emphasize the dominant role of focal firms in business ecosystems (Rong et al., 2013; Adner, 2017; Huo et al., 2022; Liu et al., 2024). The sustainability of an innovative and technologically advanced business ecosystem is undermined when the products or services of member firms are incompatible with those of the focal firm. This requires the focal firm to selectively collaborate with complementary firms (Yoo et al., 2024), thus necessitating proactive governance behaviors from the focal firm to ensure the ecosystem's success.

BEG plays a critical role in fostering an efficient and synergistic network of relationships among complementary firms, thereby reducing effort and cost (Pomegbe et al., 2021). This network allows firms to share innovation expenses (Adner, 2017), diversify innovation risks (Gueler and Schneider, 2021), and enhance their innovation capabilities (Ciasullo et al., 2020). Jacobides et al. (2018) observed that effective governance mitigates transaction costs and limits opportunistic behavior in innovation processes. Adner (2017) further suggested that such governance cultivates a shared understanding and collective identity among ecosystem members, enhancing resource integration and collaboration in innovation initiatives. Iansiti and Levien (2004) posited that focal firms act both as architects and participants in the ecosystem; while enhancing their own capabilities, they also contribute resources to other firms, facilitating value co-creation. Clearly, the focal firm plays a central role in ecosystem governance (Iansiti and Levien, 2004), and its ability to balance stakeholder tensions within the ecosystem is essential for successful governance (Wareham et al., 2014; Ansari et al., 2016). These findings underscore the increasing evidence that governance within business ecosystems affects innovation performance, although significant gaps remain.

Most existing research primarily discusses the theoretical significance of BEG, with limited empirical analysis on its impact on digital innovation performance and insufficient exploration of the mechanisms through which governance influences innovation outcomes. Within business ecosystems, focal enterprises employ both formal and informal institutional frameworks to optimize resource allocation, coordinate stakeholder roles and responsibilities, and promote symbiosis among participants. This approach fosters mutual value creation, win-win outcomes, and sustainable development (Snihur and Bocken, 2022; Coskun-Setirek et al., 2024). Senyo et al. (2019) assert that governance is a key factor influencing innovation behaviors and outcomes in ecosystems, advocating for further research to clarify how governance affects innovation drivers, capabilities, and results. Moreover, Hoffmann et al. (2018) and Massa et al. (2017) call for empirical investigations into the effectiveness of governance mechanisms across diverse contexts.

Existing research has predominantly focused on the roles of cornerstone and dominant enterprises in BEG, with limited attention given to how governance mechanisms affect the digital innovation performance of complementary enterprises (Coskun-Setirek et al., 2024). Complementary enterprises are integral to the business ecosystem, targeting niche markets to drive growth, thereby enhancing

the complementarity, productivity, and creativity within the ecosystem (Iansiti and Levien, 2004). These firms engage in competitive ecosystems (Chen et al., 2023) and leverage platform resources offered by focal enterprises to overcome their own resource constraints. This access enables them to better identify and capitalize on opportunities (Suuronen et al., 2022), ultimately driving their own growth. Given the substantial number and importance of complementary enterprises within the business ecosystem, it is crucial to investigate how governance mechanisms influence their digital innovation performance.

Furthermore, while existing studies recognize the impact of BEG on firms' innovation outcomes, they do not clarify how this governance's effectiveness varies across different technological environments. Digital innovation inherently occurs within a dynamic, high-tech landscape characterized by uncertainty and complexity. Firms that rely solely on internal technologies to enhance capabilities, increasing flexibility and diversity, are better positioned to achieve digital innovation performance (Tang et al., 2023). Thus, further investigation is needed into how firms can select suitable governance mechanisms and digital capabilities (DCs) in response to changes in technological dynamics.

To address these gaps, this study explores how BEG influences the digital innovation performance of complementary enterprises. Specifically, it first adopts a holistic view of BEG, categorizing it into contractual and relational governance, and examines the impact of these two governance approaches on the digital innovation performance of complementary enterprises. Then, it recognizes the dependence of complementary enterprises on ecosystem resources and the pivotal role of DCs in enabling integration into the ecosystem and accessing these resources. Additionally, it introduces DCs as a mediating variable to explore how governance mechanisms influence digital innovation performance. Finally, this study investigates the moderating effect of technological dynamics on the relationship between governance and DCs.

2. Literature review

2.1. Digital innovation performance

The growing prevalence of digital technologies has a profound impact on various aspects of firms' products, services, and operations. These innovations have the potential to radically transform product and service development, giving rise to digital innovation (Yoo et al., 2012; Felicetti et al., 2024). Digital innovation performance refers to the application of digital technologies by firms to improve existing products, services, and processes, thereby achieving desirable outcomes such as enhanced organizational performance, competitive advantage, and improved product or service results (Arias-Pérez and Vélez-Jaramillo, 2022). It is characterized by the advantages that digital solutions, whether developed internally or launched externally, offer in terms of quantity, quality, differentiation, and novelty (Satı, 2024). When firms take a proactive and leading role in ecosystem governance—establishing connections with ecosystem partners and contributing to the creation of formal rules—they expand their access to external resources and enhance the efficiency of resource utilization. This approach also reduces the risks of competitive lock-in (Rong et al., 2024), thereby boosting the output of digital innovations, including digital patents and digital transformations.

Existing research on the drivers of digital innovation performance has examined a range of external factors, such as distributed innovation (Tang et al., 2023), digital orientation (Arias-Pérez and Vélez-Jaramillo, 2022), digital transformation (Li et al., 2023), and governance mechanisms (Li et al., 2024a), as well as internal factors like digital leadership (Fatima and Masood, 2024), digital platform capabilities (Jiang et al., 2023), digital technology applications (Shen et al., 2022), and decision-making logic (Zhang et al., 2023). Among these, governance mechanisms have drawn significant attention for their impact on digital innovation performance (Yin and Li, 2022). Li et al. (2024b) argue that governance mechanisms can alleviate conflicts and reduce opportunistic behavior during enterprise participation, promote proactive resource sharing, and ultimately improve innovation efficiency.

As digital technologies such as big data advance, the boundaries of enterprise innovation activities are increasingly becoming more fluid (Gawer, 2021). This shift facilitates a move from a bilateral cooperative value creation model between enterprises and customers to a multilateral, networked collaborative model within the business ecosystem (Agarwal and Kapoor, 2023). Consequently, ecosystem members—including suppliers, customers, and competitors—are exerting a growing influence on the direction, implementation, and effectiveness of digital innovation within enterprises (Fernández-Portillo et al., 2024). In the current digital economy, enterprises leverage digital technologies to integrate key resources, restructure innovation processes, and transform their products, services, business processes, and business models, thereby optimizing value creation and enhancing digital innovation performance (Liu et al., 2023). Given the involvement of numerous stakeholders in digital innovation, it is crucial to consider the role of external actors. Thus, a higher-order perspective is necessary to examine the contextual factors affecting enterprise digital innovation performance, such as the business ecosystem (Senyo et al., 2019; Lee and Roh, 2023).

2.2. Business ecosystem governance

A business ecosystem refers to a collaborative alliance formed among various stakeholders that influence enterprises, including customers, suppliers, producers, funding providers, industry associations, and other risk bearers (Kapoor and Lee, 2013). The primary goal of such ecosystems is to meet market demands and create value (Agarwal and Kapoor, 2023). Business ecosystems significantly blur industry boundaries, offering enterprises unprecedented opportunities to transcend traditional industry divisions, dismantle conventional labor division models, and integrate new resources for digital innovation (Chen et al., 2023; Winkler et al., 2024). These ecosystems not only enhance competitive advantages but also reduce transaction costs, facilitate knowledge complementarity and sharing, and reshape capability structures, thereby fostering a favorable external environment for performance achievement (Lee and Roh, 2023). A business ecosystem is an open and complex system (Iansiti and Levien, 2004) that encompasses a diverse array of

interdependent firms or organizations engaged in complementary exchanges of resources and capabilities. Within this framework, members sustain the ecosystem by creating and enhancing shared value (Teece, 2018; Jacobides et al., 2018). Moreover, the regulations, standards, and value systems developed through sustained interactions and transactions among ecosystem members establish the "rules of the game" that govern the ecosystem, known as BEG. This governance influences member activities and their outcomes (Wareham et al., 2014; Coskun-Setirek et al., 2024).

Business ecosystems, as critical platforms for complementary innovation resources, along with their governance mechanisms, play a pivotal role in driving digital innovation. BEG refers to an institutional framework (Hoetker and Mellewigt, 2009). Vos (2006) introduced the concept, defining BEG as the process of coordinating and motivating members to establish and pursue common goals through the design of normative mechanisms within the ecosystem. This process promotes resource sharing, facilitates complementarity among members, and strengthens the system's dynamic capabilities. Li et al. (2022a) defined BEG as a comprehensive set of formal and informal institutional arrangements designed to constrain opportunistic behavior, align the interests of member enterprises, optimize control rights and resource allocation, and ensure the ecosystem's healthy and orderly operation. Led by the focal firm, BEG involves the joint participation of diverse actors, coordinating behaviors through various strategies to minimize risks and misbehavior while maximizing the overall value creation capacity of the system. This, in turn, promotes the synergistic, standardized, and diversified development of the ecosystem (Ofe and Sandberg, 2023). Focal firms, as the central nodes in multilateral relationships and controllers of key production factors, are at the heart of BEG research, particularly concerning their governance logic (Yang et al., 2020). By effectively governing the ecosystem, focal enterprises can maximize the development of unique ecological advantages and mitigate the risk of uncommitted users or complementors shifting to emerging ecosystems (Bohnsack et al., 2024). Effective governance equips members with a clear vision and incentives, enabling them to leverage specialized mechanisms and freely pursue common goals, thereby enhancing dynamic capabilities.

Drawing from existing research (Vos, 2006; Hoetker and Mellewigt, 2009; Pomegbe et al., 2021; Hou et al., 2024), BEG is primarily realized through two mechanisms: contractual governance, which relies on specialized assets, and relational governance, which depends on social capital. Business ecosystem contractual governance (BECG) focuses on coordinating relationships among ecosystem members via formal, legally binding agreements or contracts (Pomegbe et al., 2021). These agreements define mutual rights and obligations, helping mitigate innovation risks (Inoue, 2021). It assumes that collaboration partners may have opportunistic tendencies and emphasizes the importance of initial contracts in driving innovation performance. By clearly outlining the rights, obligations, goals, policies, and strategies of the collaboration, contractual governance reduces opportunistic behavior among ecosystem members through legally enforceable commitments. The advantages of contractual governance stem from its ability to establish formal agreements among a limited number of complementors, enabling them to collectively define strategic decisions, such as setting shared goals and determining the evolutionary trajectory of the business ecosystem (Zhou et al., 2023). However, a key drawback of contractual governance is the potential for an unequal distribution of benefits among complementors. Business ecosystem relational governance (BERG), on the other hand, influences partner behavior through shared objectives, open communication, trust, and collaboration, thereby fostering self-management mechanisms and facilitating resource coordination for value creation (Bouncken et al., 2016; Pomegbe et al., 2021). Serving as an essential complement to contractual governance, relational governance promotes mutual trust, reciprocity, and mutual benefit, enhancing relationship coordination, reputation management, knowledge transfer, and collaborative innovation (Shamim et al., 2020). However, relational governance carries its own disadvantages, such as uncertainty regarding the future development of the business ecosystem and increased internal organizational costs (Li et al., 2024b). For instance, focal firms must consistently invest in maintaining relationships with partner firms, which inevitably drains internal resources and results in higher operational costs.

2.3. *Digital capabilities*

Digital capabilities (DCs) refer to an organization's ability to effectively leverage information technology and digital networks to integrate digital assets with other business resources, thereby driving innovation in products, services, and processes to enhance operational efficiency and value output (Grego et al., 2024). Some scholars, from a dynamic capability perspective, view DCs as a mechanism for restructuring resource bases in response to environmental changes (Warner and Wäger, 2019). Ferreira et al. (2024) argue that DCs enable firms to quickly adapt to dynamic environmental shifts, maintaining a sustainable competitive advantage by integrating digital and organizational resources across value networks to drive systemic transformation and digital value creation. Additionally, other researchers approach DCs from a technological standpoint, seeing them as an operational capability that enhances the efficiency of core business activities through digital technologies (Fang et al., 2024). From a resource-based view, DCs represent a competitive advantage derived from the effective utilization of digital resources (Coreynen et al., 2020b).

Business ecosystems are characterized by openness, blurred boundaries, and interactive coupling (Snihur and Bocken, 2022). Within these ecosystems, the development of DCs by enterprises is heavily reliant on extensive interactions with complementors, such as suppliers, intermediaries, customers, governments, and other stakeholders. Furthermore, the deep integration of digital technologies compels firms to adopt an ecosystem-based mindset and cultivate DCs centered around ecological business and digital innovation (Nasiri et al., 2023). In a business ecosystem where information flows and resources are coordinated and shared, enterprises utilize DCs such as intelligence, connectivity, and analytics to integrate internal resources and allocate external ones in response to environmental uncertainties (Lee and Roh, 2023). Innovation within a business ecosystem is a dynamic and evolving process, requiring the development of DCs that align with the organization's long-term sustainability and address the diverse needs at various stages (Khurana et al., 2022). This process necessitates substantial time for construction, refinement, and accumulation. Thus, in the context of the digital economy, cultivating DCs has become a critical strategy for enterprises to overcome challenges and achieve growth.

Existing literature generally agrees that DCs provide fresh impetus and pathways for improving enterprise performance. However, most studies focus on traditional contexts, with limited empirical research in the digital economy. In the digital economy, DCs enhance a company's responsiveness, enabling it to meet the evolving demands of customers more promptly and, in turn, drive revenue growth. Digital resources are critical for gaining competitive advantages in the digital economy (Velyako and Musa, 2024). Firms with stronger DCs can leverage these resources more effectively to reduce costs, thereby achieving a competitive edge through lower overall operational expenditures. Lee and Roh (2023) emphasize that DCs provide a valuable perspective for studying the digital innovation performance of enterprises within business ecosystems. By actively engaging with governance models in business ecosystems, firms can establish value networks that foster interactions with suppliers, customers, governments, and other stakeholders (Leviäkangas and Öörni, 2020). Companies adopt various resource orchestration models to promote the dynamic evolution of DCs (Linde et al., 2021), cultivate capabilities rooted in platform business models and digital innovation (Fenwick et al., 2019), and establish norms and trust to support collaboration and information sharing (Panahifar et al., 2018), unlocking the value of business ecosystems.

DCs encompass several dimensions, such as digital perceptual capability (DPC), digital operational capability (DOC), and digital resource coordination capability (DRCC), all aimed at facilitating digital innovation activities (Yi et al., 2022). Specifically, DPC refers to an enterprise's ability to recognize opportunities and threats in the digital economy by analyzing trends in digital transformation (Shen et al., 2022). This includes insights into the external digital environment—such as awareness of digital technologies, policy directions, market competition, and shifts in consumer demand—as well as the ability to manage internal digital transformation. These capabilities enable firms to identify opportunities within the evolving digital economy, allowing them to position themselves proactively in the market and capitalize on advantageous time windows through open innovation activities. DOC pertains to the ability to develop digital solutions related to research and development, production, distribution, marketing, management, and services by utilizing big data from industry and consumer insights (Roscoe et al., 2019). Firms apply DOC to drive product/service innovation and achieve digital business value through the conversion of opportunities into value creation, delivery, and capture. DRCC involves a firm's commitment to sharing digital information and achieving agility within the value chain by integrating and collaborating with both complementary and competitive internal and external resources. This breaks down data silos and facilitates the shared, co-created, and co-governed nature of digital resources.

In the digital economy, DCs represent a new set of requirements for firms, serving as a critical condition for driving digital innovation and achieving dynamic, sustainable development (Proksch et al., 2024). Firms must not only leverage their DCs for their own advancement but also integrate digital technologies with traditional industries to empower these sectors, ultimately expanding their business boundaries. Therefore, this study introduces DCs to explore how BEG influences the digital innovation performance of enterprises.

3. Research hypotheses

3.1. The impact of business ecosystem governance on complementary enterprises' digital innovation performance

In the digital economy, innovation activities extend beyond individual firms to include collaborations with external organizations. Enterprises no longer operate in isolation; instead, they leverage business ecosystems to integrate both internal and external innovation resources, establishing profit mechanisms that enable value co-creation and sharing (Avnimelech and Amit, 2024). Business ecosystem value propositions and modular architectures attract and integrate a diverse array of heterogeneous participants who are interconnected yet independent. To coordinate actions, mitigate conflicts, and sustain multilateral relationships in more flexible and effective ways, business ecosystems rely on a combination of hierarchical and non-hierarchical governance mechanisms to build and maintain the legitimacy of the focal firm (Gawer, 2014). Effective governance can reduce opportunistic behaviors, establish a unified cognitive foundation, and enhance the efficiency of relationship formation and utilization among partners (Hoetker and Mellewigt, 2009; Hallen and Eisenhardt, 2012). It can also alleviate governance dilemmas resulting from complexity and heterogeneity, ultimately improving the digital innovation performance of enterprises.

First, BEG helps mitigate opportunistic behaviors among complementary enterprises. From the perspective of transaction cost theory, the primary concern is minimizing transaction costs in the presence of asymmetric information and uncertainty within the ecosystem. Complementary enterprises may seek to exploit opportunistic behavior for profit during transactions (Patil et al., 2024). As a formal governance mechanism, contractual governance—such as contracts and franchise agreements—enables focal enterprises to regulate relationships among members and curb speculative behaviors (Wacker et al., 2016), thereby reducing uncertainty and risk associated with digital innovation (Pomegbe et al., 2021). Moreover, since contractual governance can help resolve conflicts of interest among member enterprises and digital innovation often requires significant investments in heterogeneous digital resources, clearly defined rights and obligations prevent resource collaboration conflicts. This fosters a stronger sense of identity among enterprises, enabling them to participate in digital innovation activities that generate positive innovation outcomes with sufficient resource investment.

However, the limited flexibility of contracts constrains their application (Um, 2024). Furthermore, interactions with partners are often confined to fulfilling the obligations defined in the contract, which hinders the flow of information between the parties. In contrast to the formal control emphasized by contractual governance, relational governance focuses on achieving control through informal mechanisms (Ilmudeen, 2024). BERG encourages open communication, extensive information sharing, and collaborative problem-solving among partners (Coskun-Setirek et al., 2024). Focal enterprises within the ecosystem must establish a trust-based relational governance mechanism to ensure continuous exchange of heterogeneous resources and co-creation of value, thereby optimizing their competitive and cooperative relationships with member enterprises and maintaining the dynamic flexibility of the

entire ecosystem. Relational governance fosters stronger interactions and communication among members, enhances mutual understanding and trust, and shapes collaborative intent. This reduces barriers and costs related to knowledge exchange in the digital innovation process and diminishes the likelihood of opportunistic behaviors (Bouncken et al., 2016; Rong et al., 2021).

Second, BEG facilitates the development of a unified cognitive foundation within the ecosystem. This foundation emerges through long-term collaboration among ecosystem members, embodying shared understandings and norms that enhance mutual recognition and belief among participants. Such governance reduces cognitive gaps, promotes greater understanding, improves the efficiency of relationship formation, and boosts the effectiveness of relationship utilization (Hallen and Eisenhardt, 2012; Burström et al., 2021). This, in turn, drives digital innovation within enterprises. In innovation activities powered by digital technologies, the relationships between enterprises become increasingly interdependent. During the digital innovation process, data and information flow bidirectionally between enterprises and their partners, fostering frequent exchanges (Tian and Lu, 2023). These exchanges deepen trust among enterprises, encouraging more profound engagement in digital innovation activities. Additionally, the rapid pace of technological advancements introduces uncertainty into the digital innovation process. Business ecosystem relational governance helps focal enterprises and their partners navigate the uncertainties faced during the innovation process (Aben et al., 2021). Therefore, relational governance enhances digital innovation performance by increasing trust levels among members, establishing stable partnerships, and coordinating resource sharing among participants (Cunningham et al., 2019).

In summary, under various governance mechanisms, business ecosystem members engaged in digital innovation exhibit strong collaborative willingness, driven by mutual trust and a shared understanding of rules, norms, and procedures. This reduces transaction costs and improves digital innovation performance. Based on these insights, the following hypotheses are proposed:

Hypothesis 1a. : BECG positively impacts the digital innovation performance of complementary enterprises.

Hypothesis 1b. : BERG positively impacts the digital innovation performance of complementary enterprises.

3.2. Business ecosystem governance, digital capabilities, and complementary enterprises' digital innovation performance

3.2.1. Business ecosystem governance and digital capabilities

Effective BEG facilitates the establishment of mutually beneficial internal and external relationships among member enterprises, thereby promoting the development of DCs (Lee and Roh, 2023). During the digital innovation process, to bridge the gap between innovation performance and the external environment, focal enterprises often leverage both formal contractual governance and informal relational governance mechanisms to "connect" various technologies. These mechanisms coordinate innovation activities within the business ecosystem, enabling technological innovation and the restructuring of complementary enterprises' digital innovation capabilities, thereby facilitating their integration into the digital realm (Song et al., 2023). This alignment ensures that the speed and scope of digital innovation align with the evolutionary direction of the business ecosystem.

BECG emphasizes coordinating partnerships through formal, legally binding rules, procedures, agreements, or contracts (Pomegbe et al., 2021). This governance fosters cooperation and trust among members, encouraging their willingness to collaborate and engage in transactions (Shipilov and Gawer, 2020), which contributes to the development of dynamic capabilities critical for adapting to digital innovation and technological shifts in the industry (Linde et al., 2021). Complementary enterprises often face resource bottlenecks, decision conflicts, and interest conflicts during the implementation of digital innovation (Zang et al., 2022). To address these challenges, they must leverage both contractual and relational governance within the business ecosystem to align decision-making processes related to opportunity identification and resource integration. This approach not only enhances the legitimacy of resource assembly but also supports digital transformation, effectively improving complementary enterprises' DPC, DOC, and DRCC.

Additionally, BECG clarifies the responsibilities and obligations of complementary enterprises, reducing external uncertainty and transaction costs (Li et al., 2022a). By leveraging digital technologies, complementary enterprises can establish a digital platform, fostering dynamic management capabilities that adapt to various innovation contexts and enhancing their understanding of the digital ecosystem (Wielgos et al., 2021). As a result, complementary enterprises utilize the boundary-less attributes of the digital platform to facilitate organizational transformation, institutional adjustments, knowledge sharing, and model innovation. This collaborative approach fosters a strong consensus on co-innovation, establishes shared behavioral norms, and enhances operational and resource synergy capabilities (Shipilov and Gawer, 2020; Inoue, 2021). Therefore, the following hypotheses are proposed:

Hypothesis 2a. : BECG positively influences complementary enterprises' DPC.

Hypothesis 2b. : BECG positively influences complementary enterprises' DOC.

Hypothesis 2c. : BECG positively influences complementary enterprises' DRCC.

BERG emphasizes shared values, trust, cooperation, joint problem-solving, and collective behavioral expectations as foundational elements driving firms to develop DCs. This governance framework enables the efficient flow of information and resources among ecosystem members (Ciasullo et al., 2020). Furthermore, the shared value orientations among members permeate the internal dynamics of the firms, facilitating the coordination of relationships and the establishment of common values and informal norms (Pomegbe et al., 2021). This alignment mitigates friction and opportunistic behaviors, enhancing the development of DCs within firms (Hoetker and Mellewigt, 2009). Trust plays a pivotal role in relationship governance within business ecosystems. As dominant players, focal enterprises are more likely to share market opportunities and demand information with their partners, as well as provide technical knowledge and insights gained from collaborative innovation processes, such as new product development and improvements to existing products. This exchange of information and resources deepens inter-firm relationships, facilitates the effective

integration of knowledge, and fosters the development of new capability systems (Capestro et al., 2024).

Moreover, BERG emphasizes the critical role of sociality in achieving stable and efficient governance. The business ecosystem consists of multiple entities, and the implicit behavioral norms that arise in social contexts will be incorporated into the system as new members join, gradually evolving into subjective norms that constrain the behavior of these entities (Rong et al., 2018). Under these informal behavioral guidelines, alignment among members strengthens, promoting cooperation and innovation, and creating an environment conducive to the development of DCs within firms (Ashiru et al., 2022). Additionally, member enterprises within the ecosystem exhibit diverse corporate cultures. Trust-based relational governance helps guide these firms to establish a cohesive innovation culture through communication and coordination, facilitating the sharing of new knowledge, enhancing cognitive consistency regarding digital innovation, and reducing the costs of resource exchanges and transactions. This, in turn, generates DCs for resource reconfiguration (Ashiru et al., 2022).

Consequently, BERG optimizes partnerships among member enterprises, enabling them to collaboratively navigate the complex and dynamic landscape of digital innovation, seize digital opportunities, access new knowledge and resources, and enhance their DCs. This ensures that digital innovation evolves in harmony with the ecosystem. Based on this reasoning, the following hypotheses are proposed:

Hypothesis 3a. : BERG positively influences complementary enterprises' DPC.

Hypothesis 3b. : BERG positively influences complementary enterprises' DOC.

Hypothesis 3c. : BERG positively influences complementary enterprises' DRCC.

3.2.2. Digital capabilities and complementary enterprises' digital innovation performance

The resource-based view theory (RBT) asserts that a firm's competitive advantage stems from its possession of valuable, rare, inimitable, and non-substitutable resources (Lau and Wong, 2024). DCs represent an organization's ability to effectively integrate digital resources with other organizational assets through digital technologies, facilitating systemic digital transformation and creating digital value (Kang et al., 2024). As a critical resource, DCs provide firms with a sustained competitive advantage (Barney, 2001). In the context of the evolving digital economy, enterprises must possess robust DCs to seize transient opportunities arising from rapid technological advancements. Tortora et al. (2021) argue that improving the ability to recognize opportunities within digital innovation processes significantly enhances the likelihood of achieving successful outcomes. Strengthened DCs increase a firm's responsiveness, allowing it to swiftly meet changing market demands and, as a result, drive revenue growth (Aghazadeh et al., 2024). Firms with stronger DCs emphasize the synergy between digital and traditional resources (Bhandari et al., 2023), focusing on leveraging digital technologies to enhance competencies in procurement, manufacturing, and marketing (Savastano et al., 2022). Additionally, these firms restructure organizational processes to drive process innovation through digital technologies (Zhu et al., 2022) and may develop digital business models to increase organizational agility (Soluk et al., 2021). This adaptability enables enterprises to respond more quickly than competitors, thereby improving innovation performance in the dynamic external environment of the digital era.

First, the process of digital innovation within the evolving business ecosystem introduces uncertainty and complexity (Senyo et al., 2019). Enterprises must possess DPC to anticipate and navigate trends in industrial technology, macro policy shifts, and changes in industry development and user demand. This enables firms to identify implicit knowledge resources that align with their strategic positioning, create new value pathways (Abbate et al., 2022), and drive model innovation, ultimately enhancing their innovation performance. Second, the dynamic nature of digital innovation activities relies heavily on enterprise operations for effective execution and implementation (Tang et al., 2023). Firms with robust digital operational capabilities can integrate the necessary elements of digital innovation into actionable plans, transforming digital resources and environmental opportunities into commercial value, thereby improving digital innovation performance. Third, in the highly platform-oriented, open, and shared environment of the digital economy, a strong DRCC is crucial for an enterprise's survival and growth (Li et al., 2022b). This capability facilitates the establishment of effective communication and interaction mechanisms, enabling firms to leverage the network effects of platforms to access both internal and external digital resources. This, in turn, reshapes digital value creation processes, expanding the scope and depth of digital innovation performance. Based on this reasoning, the following hypotheses are proposed:

Hypothesis 4a. : DPC positively influences complementary enterprises' digital innovation performance.

Hypothesis 4b. : DOC positively influences complementary enterprises' digital innovation performance.

Hypothesis 4c. : DRCC positively influences complementary enterprises' digital innovation performance.

3.2.3. The mediating role of digital capabilities

The preceding discussion outlines research hypotheses concerning the relationships among BEG, digital innovation performance, and DCs. On one hand, it is clear that DCs mediate the impact of BEG on digital innovation performance. On the other hand, although complementary enterprises are vital participants in the business ecosystem (Oh, 2023), they do not automatically benefit from it. These enterprises must actively respond to BEG and embrace its influence to develop DCs that enable them to acquire and effectively utilize the scarce resources needed for digital innovation, thus unlocking the business ecosystem's value for their growth (Geurts and Cepa, 2023). Moreover, DCs empower complementary enterprises to integrate resources from the ecosystem with digital technologies and other internal and external resources, enabling them to adapt more swiftly to rapidly evolving market demands (Zhang and Hao, 2024).

Amid increasing uncertainty and risk associated with digital innovation, BEG acts as an institutional safeguard, enhancing

enterprises' capacity and fostering innovation transformation, ultimately leveraging DCs to improve digital innovation performance (Lee and Roh, 2023). On the one hand, business ecosystems rely on formal contractual governance to establish entry thresholds for participants, helping enterprises accumulate the digital innovation resources and capabilities required, thereby providing dynamic capabilities to support digital innovation (Pomegbe et al., 2023). On the other hand, the business ecosystem mitigates risks related to behavioral and environmental uncertainties through trust-based relational governance, creating an environment conducive to innovation. This approach integrates the cultural perspectives of different enterprises, reduces potential conflicts in collaboration, and motivates firms to develop digital competencies (Salovaara et al., 2019), thereby enhancing the likelihood of achieving digital innovation. Based on this reasoning, the following hypotheses are proposed:

Hypothesis 5a. : DPC mediates the relationship between BECG and complementary enterprises' digital innovation performance.

Hypothesis 5b. : DOC mediates the relationship between BECG and complementary enterprises' digital innovation performance.

Hypothesis 5c. : DRCC mediates the relationship between BECG and complementary enterprises' digital innovation performance.

Hypothesis 6a. : DPC mediates the relationship between BERG and complementary enterprises' digital innovation performance.

Hypothesis 6b. : DOC mediates the relationship between BERG and complementary enterprises' digital innovation performance.

Hypothesis 6c. : DRCC mediates the relationship between BERG and complementary enterprises' digital innovation performance.

3.2.4. The moderating role of technological dynamism

Technological dynamism refers to the instability and unpredictability of the external technological environment that enterprises face during their development, primarily characterized by uncertain technological evolution trends and the continuous upgrading and iteration of innovations (Coreynen et al., 2020a). In the digital economy, the rapid progression of digital technologies has made changes in the external technological environment a critical contingency factor for enterprises involved in digital innovation activities within the business ecosystem (Troise et al., 2022). As enterprises navigate an increasingly complex and turbulent external technological landscape, digital innovation exhibits characteristics such as boundary ambiguity, decentralized innovation actors, and the interaction between innovation processes and outcomes (Nambisan et al., 2017). Consequently, BEG becomes more vulnerable to shifts in the external environment. To survive and thrive within the ecosystem, enterprises must develop DCs that enable them to effectively tackle the challenges posed by digital innovation.

Technological dynamism refers to the rapid pace and unpredictability of technological innovation, which can significantly influence governance activities and outcomes within a business ecosystem. The selection of governance mechanisms in such ecosystems must prioritize the technological environment, choosing appropriate mechanisms to enhance existing digital resources and capabilities within enterprises, thus ensuring alignment between governance strategies and the technological landscape (Wareham et al., 2014). In the fast-paced and competitive realm of digitalization, enterprises often guided by traditional survival-of-the-fittest principles tend to focus excessively on short-term gains (Zhou and Wu, 2010), neglecting long-term strategic planning. When addressing technological innovations within the business ecosystem, enterprises typically adopt a conservative approach centered on internal markets and competitors. As a result, participants in the ecosystem may prefer a low-risk stance during contract negotiations, which can stifle the creative potential of contractual mechanisms (Pittino and Mazzurana, 2013). Moreover, as technological dynamism intensifies, enterprises feel increasing pressure to survive and grow, which can lead them to engage in 'free-riding' behaviors, fostering opportunism that undermines the positive relationships based on social connections and future value (Pomegbe et al., 2021). This intensifies vicious competition among ecosystem members, exacerbating technological dynamism and further reducing the effectiveness of BEG in fostering digital innovation performance. Consequently, this hampers the willingness of enterprises to pursue capability upgrades and engage in innovation activities.

Thus, the following hypotheses are proposed:

Hypothesis 7a. : Technological dynamism negatively moderates the relationship between BECG and complementary enterprises' DPC.

Hypothesis 7b. : Technological dynamism negatively moderates the relationship between BECG and complementary enterprises' DOC.

Hypothesis 7c. : Technological dynamism negatively moderates the relationship between BECG and complementary enterprises' DRCC.

Hypothesis 8a. : Technological dynamism negatively moderates the relationship between BERG and complementary enterprises' DPC.

Hypothesis 8b. : Technological dynamism negatively moderates the relationship between BERG and complementary enterprises' DOC.

Hypothesis 8c. : Technological dynamism negatively moderates the relationship between BERG and complementary enterprises' DRCC.

Based on the theoretical discussions presented above, the theoretical hypothesis model for this study is illustrated in Fig. 1.

4. Methodology and analysis

4.1. Research sample and data collection

The selection criteria for research subjects are based on the presence of a distinct business ecosystem within their respective sectors. Following the framework proposed by Li et al. (2022b), this study focuses on complementary enterprises within business ecosystems that pursue development in specific niche markets and exhibit functional complementarity and dependency on the ecosystem. The data collection questionnaire targets mid-level and senior managers with sufficient access to relevant company information and data. It includes screening questions to identify the role of each enterprise within the ecosystem, ensuring that responses are solely from complementary enterprises. Consequently, this study examines complementary enterprises within the iFLYTEK business ecosystem in China. The selection of iFLYTEK is primarily due to its established leadership in utilizing digital technologies, such as intelligent voice and AI, to drive industry growth. Founded in 1999, iFLYTEK has integrated over 4.2 million ecosystem partners through its open platform, spanning sectors like education, healthcare, urban development, automotive, and home applications. The company has emerged as a leader in its ecosystem, leveraging internationally advanced technology within the digital economy. Within the iFLYTEK ecosystem, five primary actors are identified: technology providers, technology users, cooperative competitors, investors, and research institutions. Among them, technology users, accounting for 63.5 %, represent the largest group of complementary enterprises.

To refine the clarity and comprehensibility of the questionnaire, a pre-survey was conducted with 50 companies sourced from the MBA and EMBA programs of the institution before the formal distribution (September to October 2023). Adjustments to the questionnaire were made based on the feedback from this pre-survey, leading to the final version. These 50 companies, representing diverse sizes, ages, and industries, all focus on concentrating their core resources in a few niche markets where they showcase their expertise. For the main study, 800 questionnaires were distributed *via* the Credamo platform, yielding 684 responses, which resulted in an 85.5 % response rate. The basic characteristics of the sample are presented in Table 1.

4.2. Variable measurement

The measurement items in this study are adapted from established scales in the literature and utilize a seven-point Likert scale (1= strongly disagree, 7= strongly agree). BEG is the independent variable. Based on the works of Ferguson et al. (2005), de Reuver and Bouwman (2012), and Pomegbe et al. (2021), five items measure BECG, while four items assess business ecosystem relational governance. Digital innovation performance serves as the dependent variable, with five items drawn from the studies of Tang et al. (2023), Arias-Pérez and Vélez-Jaramillo (2022), and Khin and Ho (2018) to evaluate it. DCs act as the mediating variable, comprising three dimensions: digital perceptual capability, DOC, and DRCC. Each dimension is assessed using five items, as outlined in the research of Warner et al. (2019) and Heredia et al. (2022). Technological dynamism is the moderating variable, with three items measuring this construct, based on the work of Chen et al. (2015) and Huo et al. (2024). Additionally, this study controls for three variables—company age, company size, and company nature—that are known to influence digital innovation performance, though they are not the primary focus of the research.

4.3. Empirical analysis

4.3.1. Common-menthod bias analysis

Given that the questionnaire is primarily completed by individual respondents within the companies, concerns regarding common-

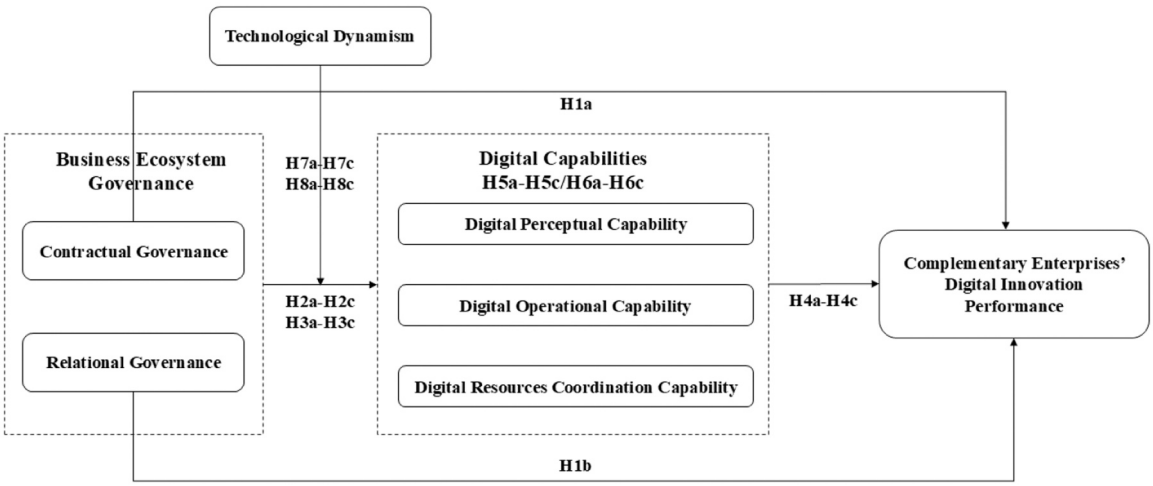

Fig. 1. Theoretical framework.

Table 1
Sample distribution characteristics.

Features	Categories	Quantities	Proportions
Respondent's position	Senior management/technical personnel	369	53.95 %
	Middle management/technical personnel	315	46.05 %
Age of the enterprises	5 years and below	46	6.73 %
	6–10 years	152	22.22 %
	11–15 years	182	26.61 %
	16–20 years	179	26.17 %
	20 years and beyond	125	18.27 %
Enterprises scale	500 persons and below	205	29.97 %
	501–1000 persons	190	27.78 %
	1001–3000 persons	159	23.25 %
	3000 persons and beyond	130	19.00 %
Nature of the enterprises	Private enterprises	259	37.87 %
	Joint-stock enterprises	140	20.47 %
	Joint enterprises	124	18.13 %
	State-owned enterprises	151	20.08 %
	others	12	1.75 %
Complementary enterprises	Technology providers	126	18.42 %
	Technology users	434	63.45 %
	Cooperative competitors	90	13.16 %
	Investors	24	3.5 %
	Research institutions	10	1.5 %

method bias (Podsakoff et al., 2003) may arise. To address this, firstly, Harman's single-factor test was applied to assess potential bias. A principal component factor analysis was performed on the measurement items for all variables using SPSS 24.0 software. The results show that the cumulative variance explained by the first rotated principal component is 20.86 %, well below the 40 % threshold recommended by prior research. Secondly, a test involving the addition of latent factors revealed that the variance in model fit was not significant ($\Delta(x^2/df) = -0.005$, $\Delta CFI = 0.001$, $\Delta TLI = 0.001$, $\Delta RMSEA = 0.000$). In summary, common method bias is not present in this study. This outcome suggests that the hypotheses related to main, mediation, and moderation effects are unlikely to be significantly affected by common-method bias.

4.3.2. Reliability and validity test

The exploratory factor analysis yielded a KMO value of 0.852. To further assess the stability and internal consistency of the scale, confirmatory factor analysis (CFA) was conducted to evaluate its reliability and validity. The results indicate a satisfactory model fit ($\chi^2 = 665.18$, df = 443, χ^2/df = 1.502, $p < 0.001$, CFI = 0.95, TLI = 0.945, IFI = 0.951, RMSEA = 0.042). As shown in Table 2, most items exhibit standardized factor loadings greater than 0.7, with a few approaching 0.7, all well above the 0.6 threshold, indicating strong convergent validity. Both the Cronbach's alpha coefficient and composite reliability (CR) exceed 0.8, confirming excellent internal consistency. Furthermore, all items demonstrate an average variance extracted (AVE) greater than 0.5, and the square root of the AVE exceeds the correlations between each variable and others, supporting robust discriminant validity. In conclusion, the scale's reliability and validity, along with the overall fit of the theoretical model, meet the required standards.

Additionally, SPSS 24.0 software is used to analyze the correlations among the various variables. As shown in Table 3, significant correlations are observed between BECG, business ecosystem relational governance, DPC, DOC, DRCC, technological dynamism, and digital innovation performance. The Pearson correlation coefficients are all below 0.7, and the Variance Inflation Factor (VIF) values are under 2, indicating that multicollinearity is not a concern within this dataset. Thus, it is appropriate to proceed with the regression analyses.

4.3.3. Endogeneity test

This paper uses the Durbin-Wu-Hausman test to assess endogeneity (Tang and Rai, 2012). According to the linkage equation, since digital perceptual capabilities, digital operation capabilities and digital resource coordination capabilities are mediating latent variables, it can be seen that only the endogeneity of the moderating variables needs to be tested. Regression analyses were conducted with technological dynamism as the moderating variable, business ecosystem governance and other control variables as the independent variables, and the residuals of the moderating variable technological dynamism were obtained and retained. Subsequent regressions were performed on digital innovation performance to obtain the aforementioned residual coefficients. The results show that the regression coefficient of the technological dynamism residuals on digital innovation performance is insignificant ($\beta = 0.032$, $p > 0.05$), indicating that endogeneity is better controlled in this study.

4.4. Hypothesis test

4.4.1. Main and mediating effects test

This study employs hierarchical regression analysis to sequentially include control variables, independent variables, and mediating variables in the model to examine both the main and mediation effects, as shown in Table 4. Models M1 and M5 represent the

Table 2
Reliability and validity tests results of variables.

Subjects	Standardized factor loading values
Contractual Governance (CG) (Cronbach $\alpha = 0.838$, CR = 0.839, AVE = 0.511)	
A formal contract or agreement exists between the enterprise and its partner, which clearly delineates the collaborative framework for both parties.	0.731
A formal contract or agreement exists between the enterprise and its partner, outlining the penalties for non-compliance by both parties.	0.648
A formal contract or agreement exists between the enterprise and its partner that clearly specifies the content of the service and the applicable service standards.	0.73
A formal contract or agreement exists between the enterprise and its partner that outlines the roles of both parties in the collaboration.	0.688
A formal contract or agreement exists between the enterprise and its partner that outlines the obligations of both parties in the collaboration.	0.770
Relational Governance (RG) (Cronbach $\alpha = 0.844$, CR = 0.844, AVE = 0.576)	
The relationship between a firm and its partner entails the ability to respond flexibly to demands, enabling both parties to adopt a more adaptable approach compared to adhering to a strict contract.	0.725
The relationship between the enterprise and its partners can be adapted in response to changes in the external environment, such as price fluctuations and alterations in modes of cooperation during epidemics.	0.755
Various types of information are regularly shared and exchanged between enterprises and their partners.	0.805
Enterprises and their partners prioritize mutually beneficial outcomes over individual interests.	0.747
Digital Perceptual Capabilities (DPC) (Cronbach $\alpha = 0.854$, CR = 0.856, AVE = 0.544)	
Enterprises can gain insights and identify data sources that hold business value.	0.801
Enterprises can stay informed about the latest developments in external technology and product production.	0.736
Enterprises can detect changes in the competitive environment of the market through big data technologies.	0.661
Enterprises can assess their level of digitization with greater accuracy.	0.729
Enterprises can align digital improvement programs with the strengths and weaknesses of their management capabilities.	0.753
Digital Operational Capabilities (DOC) (Cronbach $\alpha = 0.869$, CR = 0.87, AVE = 0.572)	
Enterprises can analyze digital information for precise market targeting in an abstract manner.	0.753
Enterprises can utilize digital tools to optimize business processes and resource allocation.	0.767
Enterprises can develop digital marketing management strategies for market analysis and enhancing customer experience.	0.704
Enterprises can perform real-time dynamic analysis of services and resources for flexible adjustments.	0.745
Enterprises are enhancing the efficiency of their business intelligence decisions through digital tools and components.	0.810
Digital Resource Coordination Capabilities (DRCC) (Cronbach α= 0.858, CR = 0.859, AVE = 0.549)	
A unified interface exists for exchanging information between the business systems of an enterprise.	0.729
Enterprises can aggregate internal and external digital resources in accordance with their innovation needs.	0.727
Enterprises can share the organization's internal and external information as required for collaboration.	0.769
Well-coupled interactions and diverse collaborations are established between firms and stakeholders.	0.719
Enterprises can collaboratively optimize essential aspects of the organization's key processes.	0.758
Digital Innovation Performance (DIP) (Cronbach $\alpha = 0.901$, CR = 0.902, AVE = 0.648)	
Enterprises leverage digital technologies to create innovative products and services.	0.851
Enterprises aim to introduce new products developed through digital technologies into existing markets.	0.819
Enterprises are already enjoying the benefits of the new digital products they have introduced to the market.	0.735
Enterprises can swiftly capitalize on potential digital opportunities in the marketplace.	0.807
Enterprises can effectively leverage the distribution channels established by digital technology.	0.810
Technological Dynamism (TD) (Cronbach $\alpha = 0.844$, CR = 0.845, AVE = 0.645)	
The industry in which the company operates is characterized by rapid technological change.	0.806
Technological changes present significant opportunities for our industry.	0.779
Technological breakthroughs in our industry have facilitated the development of numerous new product concepts.	0.824

Table 3
The mean value, standard deviation, and correlation of variables.

Variable	Averages	Standard deviation	CG	RG	DPC	DOC	DRCC	TD	DIP
CG	6.11	0.41	**0.715**						
RG	6.00	0.45	0.311**	**0.759**					
DPC	6.02	0.42	0.476*	0.590**	**0.738**				
DOC	5.98	0.44	0.402*	0.531*	0.665*	**0.756**			
DRCC	6.03	0.46	0.421*	0.566*	0.689*	0.641*	**0.741**		
TD	6.03	0.48	0.379**	0.475*	0.609**	0.568*	0.431*	**0.803**	
DIP	5.81	0.95	0.253*	0.430**	0.571*	0.414*	0.505*	0.394**	**0.805**

Note: * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$, two-tailed test.

regression models of control variables on digital innovation performance and DCs, respectively, while Model M2 investigates the effect of BEG on digital innovation performance. The results indicate that both contractual governance ($\beta = 0.318$, $p < 0.05$) and relational governance ($\beta = 0.807$, $p < 0.001$) significantly and positively influence digital innovation performance, thus supporting hypothesis H1. Model M3 incorporates the three dimensions of DCs along with control variables in relation to digital innovation performance. The

findings reveal that DPC ($\beta = 0.978$, $p < 0.001$) and DRCC ($\beta = 0.431$, $p < 0.05$) significantly and positively impact digital innovation performance, whereas DOC (β = -0.001, p = -0.007) has a negative, but non-significant, effect, confirming hypotheses H4a and H4c, while H4b is not supported. Models M6, M7, and M8 represent the regression analysis of the two dimensions of BEG on the three dimensions of DCs. Specifically, contractual governance significantly and positively influences digital perception capabilities ($\beta = 0.334$, $p < 0.001$), digital operational capabilities ($\beta = 0.285$, $p < 0.001$), and digital resource collaboration capabilities ($\beta = 0.323$, $p < 0.001$), while relational governance significantly and positively affects digital perception capabilities ($\beta = 0.460$, $p < 0.001$), digital operational capabilities ($\beta = 0.445$, $p < 0.001$), and digital resource collaboration capabilities ($\beta = 0.489$, $p < 0.001$), thus supporting hypotheses H2 and H3.

Model M4 serves as a comprehensive regression model that incorporates control variables, two dimensions of BEG, and three dimensions of DCs to examine the mediating effect of DCs on digital innovation performance. Compared to Model M2, the introduction of mediating variables reveals that both DPC ($\beta = 0.956$, $p < 0.001$) and DRCC ($\beta = 0.408$, $p < 0.001$) significantly and positively impact digital innovation performance. In contrast, DOC ($\beta = 0.176$, p = 1.325) does not exhibit a statistically significant positive effect on digital innovation performance. While both contractual governance (β = -0.127, p = -0.98) and relational governance (β = 0.176, p = 1.325) show positive influences on digital innovation performance, their effects are not statistically significant. These findings suggest that DPC and DRCC fully mediate the relationship between BEG and digital innovation performance, whereas DOC does not act as a mediating variable. Therefore, hypotheses H5a, H5c, H6a, and H6c are supported, while H5b and H6b are not. Additionally, the robustness of the mediation effect was tested using the Process macro in SPSS (Table 5), treating DCs as an integrated variable to assess its mediating role in the relationship between BEG and digital innovation performance. At a 95 % confidence level, the total mediation effect of DCs in the relationship between contractual governance and digital innovation performance is 0.371, with a confidence interval of [0.091, 0.251]. For the relationship between relational governance and digital innovation performance, the total mediation effect is 0.563, with a confidence interval of [0.182, 0.360], both of which do not include 0. This indicates that DCs, as an integrated variable, significantly mediate the relationship between BEG and digital innovation performance.

4.4.2. Moderating effects test

To validate the moderating effect of technological dynamism, interaction terms between the independent and moderating variables were standardized before conducting the regression analysis. The results, presented in Table 6, demonstrate that in models M9, M10, and M11, the interaction terms between contractual governance and technological dynamism have a significant negative effect on all three dimensions of DCs (β = -0.277, $p < 0.001$; β = -0.423, $p < 0.001$; β = -0.363, $p < 0.001$), as shown in Figs. 2–4, supporting hypothesis H7. In contrast, models M12, M13, and M14 reveal that the interaction terms between relational governance and technological dynamism negatively affect the three dimensions of DCs; however, these effects are not statistically significant (β = -0.112, p = -1.565; β = -0.141, p = -1.776; β = -0.132, p = -1.516), thus not supporting hypothesis H8. Furthermore, when DCs are treated as an integrated variable, the impact of the interaction terms between BEG and technological dynamism on DCs was explored. Models M12 and M16 show that the interaction terms between contractual governance and technological dynamism significantly and negatively impact DCs (β = -0.354, $p < 0.001$), while the interaction term between relational governance and technological dynamism negatively affects DCs, though this effect is not statistically significant (β = -0.128, p = -1.734).

To more clearly demonstrate the moderating effect of technological dynamism on the relationship between contractual governance and DCs, moderation effect diagrams are presented (Figs. 2–4). The results of the slope analysis reveal that under high technological dynamism, the slope is significantly steeper than under low technological dynamism, effectively illustrating the negative moderating effect of technological dynamism in the relationship between contractual governance and DPC, DOC, and DRCC. These findings further validate hypothesis H7.

Table 4
Regression model and results.

Variable	Dependent variable: DIP				Intermediary variable: DC			
	M1	M2	M3	M4	M5	M6	M7	M8
Control variable								
Enterprise scale	-0.044	0.004	-0.051	-0.051	-0.001	0.035*	0.041*	0.055**
Enterprise year	0.063	0.045	0.081	0.073	-0.073	-0.028	-0.037	-0.004
Enterprise nature	-0.044	0.008	0.005	0.008	-0.035	-0.000	0.005	0.000
Independent variable								
CG		0.318*		-0.127		0.334***	0.285***	0.323***
RG		0.807***		0.176		0.460***	0.445***	0.489***
Intermediary variable								
DPC			0.978***	0.956***				
DOC			-0.001	-0.021				
DRCC			0.431**	0.408**				
R^2	0.009	0.203	0.359	0.365	0.013	0.453	0.358	0.405
Adjusted R^2	−0.002	0.189	0.345	0.347	0.013	0.443	0.346	0.394

Note: * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$, two-tailed test.

Table 5
Results of the robustness test of the mediating role of digital capabilities.

Paths	Effect value (standardized)	Standard error	*p*	95 % confidence interval		Test Conclusion
				Lower limit	Upper limit	
CG=>DC=>DIP	0.371	0.041	0.000	0.091	0.251	Fully intermediated
RG=>DC=>DIP	0.563	0.045	0.000	0.182	0.360	Fully intermediated
CG=>DPC=>DIP	0.319	0.037	0.000	0.071	0.216	Fully intermediated
CG=>DOC=>DIP	-0.006	0.022	0.792	-0.045	0.044	Non-intermediary effect
CG=>DRCC=>DIP	0.132	0.030	0.000	0.005	0.121	Fully intermediated
RG=>DPC=>DIP	0.440	0.049	0.000	0.114	0.309	Fully intermediated
RG=>DOC=>DIP	-0.009	0.037	0.806	0.075	0.071	Non-intermediary effect
RG=>DRCC=>DIP	0.200	0.041	0.000	0.012	0.173	Fully intermediated

Table 6
Test results of technical dynamism adjustment effect.

Variable	DPC	DOC	DRCC	DC	DPC	DOC	DRCC	DC
	M9	M10	M11	M12	M13	M14	M15	M16
Control variable								
Enterprise scale	0.008	0.013	0.033	0.018	0.004	0.011	0.029	0.015
Enterprise year	-0.000	-0.009	0.022	0.004	-0.017	-0.024	0.001	-0.013
Enterprise nature	-0.001	0.005	-0.009	-0.002	0.005	0.011	-0.001	0.005
Independent variable								
CG	0.252***	0.173**	0.299***	0.242***				
RG					0.345***	0.310***	0.453***	0.369***
Moderator variable								
TD	0.424***	0.424***	0.278***	0.375***				
CG*TD	-0.277**	-0.423***	-0.363***	-0.354***				
TD					0.356***	0.353***	0.181***	0.297***
RG*TD					-0.112	-0.141	-0.132	-0.128
R^2	0.462	0.409	0.305	0.489	0.495	0.423	0.366	0.536
Adjusted R^2	0.451	0.396	0.290	0.478	0.484	0.410	0.353	0.526

Note: * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$, two-tailed test.

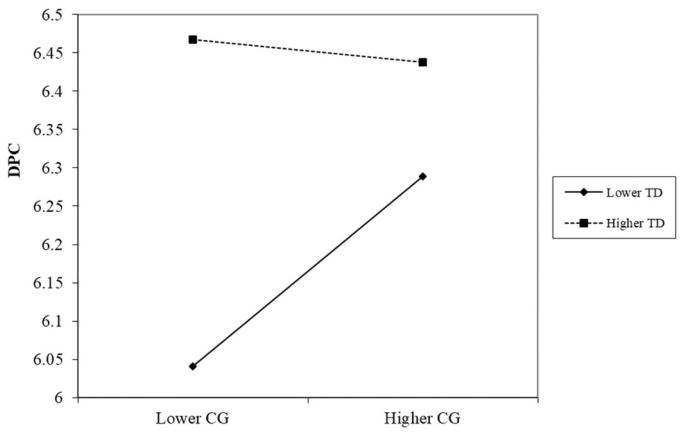

Fig. 2. The moderating effect of technological dynamism on the relationship between contractual governance and DPC.

4.5. Robustness testing

To strengthen the reliability of the empirical results, this study employs alternative models for robustness testing. Structural Equation Modeling (SEM) is applied to assess the impact of various factors, as depicted in Fig. 5. The model fit indices satisfy the required criteria ($\chi^2/df = 1.567$, CFI = 0.949, IFI = 0.933, TLI = 0.943, RMSEA = 0.045). As shown in Fig. 5, with only minor variations in some coefficients, the results of the hypothesis testing remain consistent with those previously presented. This consistency further affirms the robustness of the conclusions drawn from the study.

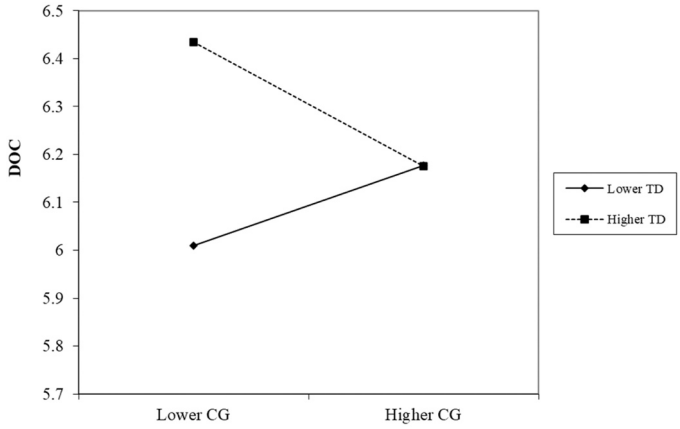

Fig. 3. The moderating effect of technological dynamism on the relationship between contractual governance and DOC.

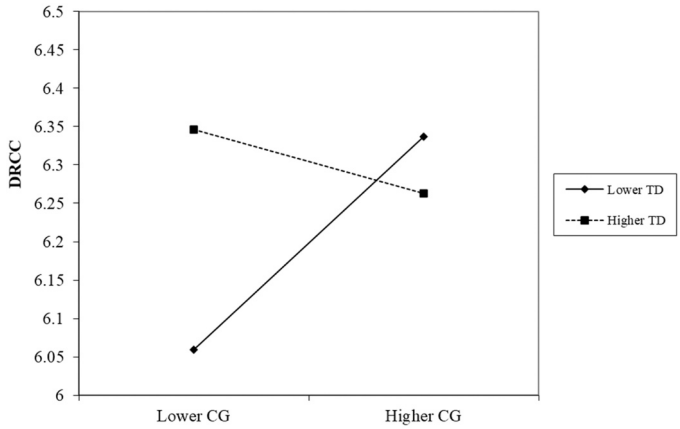

Fig. 4. The moderating effect of technological dynamism on the relationship between contractual governance and DRCC.

5. Discussion and conclusion

5.1. Discussion

In the digital economy, the boundaries of value creation for enterprises are continuously expanding, leading to a shift from a bilateral partnership framework to a more intricate and dynamic business ecosystem (Clarysse et al., 2014). This study examines complementary enterprises within the business ecosystem, focusing on the mechanisms through which BEG influences digital innovation performance. It also explores the mediating roles of DPC and DRCC, along with the moderating effect of technological dynamism. The key research findings are as follows:

First, both contractual governance and relational governance within the business ecosystem have a significant positive impact on the DCs and digital innovation performance of complementary enterprises. This finding extends the research by Liu et al. (2022), which examined the mechanisms of relational governance in the co-evolution of innovation ecosystems, offering a new perspective on contractual governance and enhancing the understanding of BEG. Furthermore, it aligns with the argument by Hou et al. (2024) that combining relational and contractual governance improves innovation performance. As business ecosystems move away from traditional closed innovation models (Rong et al., 2015) in favor of open innovation models that remove boundaries and attract potential collaborative firms, the system fosters complementary innovations between focal and complementary firms (Gawer and Cusumano, 2014). This model effectively supports firms in conducting innovation activities within the digital economy. The study highlights that relational governance within the business ecosystem plays a pivotal role in enhancing the DCs and innovation performance of complementary firms. This finding further substantiates the work of (Bounchen et al. (2016) and Rong et al. (2021), emphasizing that a strong, trust-based relationship among ecosystem members is a key mechanism for the stable development and evolution of the ecosystem. Through relational governance, which is built on trust, complementary enterprises attract partners more effectively, facilitating mutual understanding of goals and market behaviors. This strengthens their ability to perceive, operate, and collaborate with digital resources and market opportunities, thereby driving digital innovation performance.

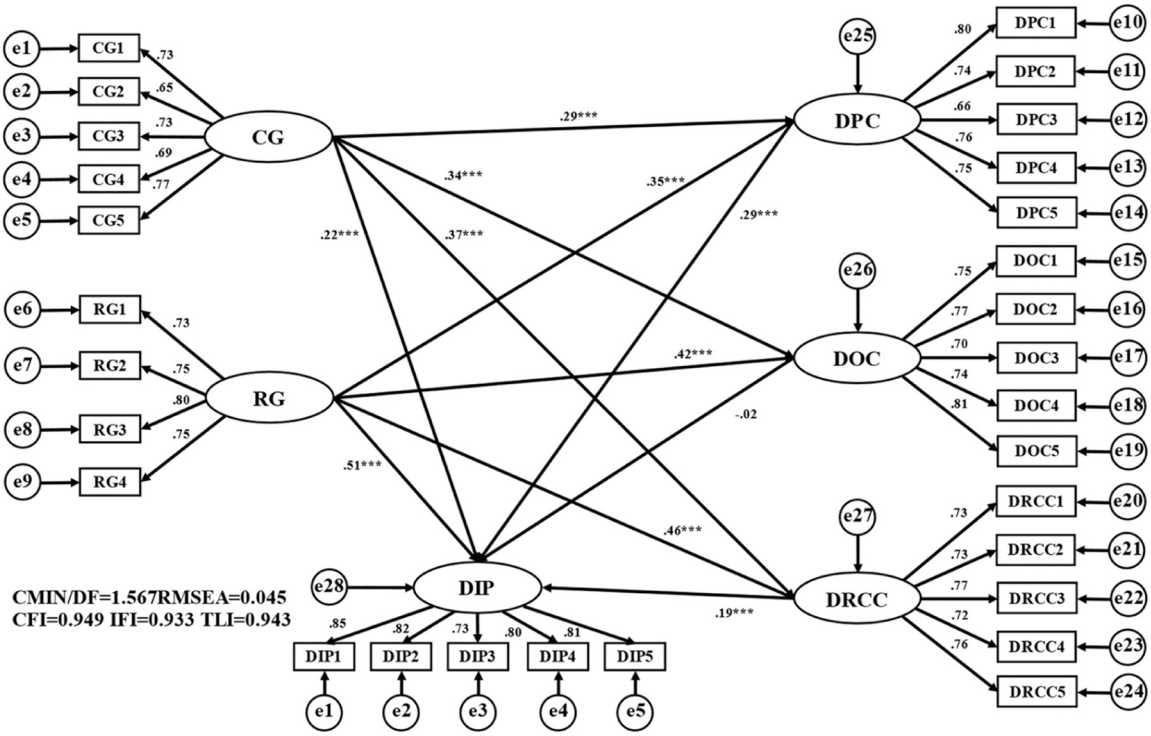

Fig. 5. Structural equation modeling.

Second, both DPC and DRCC significantly and positively impact the digital innovation performance of complementary enterprises, serving as complete mediators in the relationship between BEG (contractual and relational governance) and digital innovation performance. Unlike prior studies that typically adopted a singular perspective, this research integrates contractual governance, relational governance, and digital innovation performance within a unified analytical framework, demonstrating that both forms of governance exert a significant positive influence on digital innovation performance through the mediation of DCs. By introducing the concept of DCs into the discussion of the relationship between BEG and digital innovation performance, the study underscores the importance of DCs for complementary enterprises within the ecosystem. This finding aligns with the calls of scholars such as Annarelli et al. (2021) for further exploration of the impact of DCs. In the realm of digital innovation, BEG does not directly drive digital innovation performance; instead, complementary firms must cultivate and leverage both internal and external digital resources and market opportunities to identify digital opportunities, utilize digital technologies, and collaborate to integrate digital resources, thereby enhancing digital innovation performance. However, the study found no validation for the positive impact of DOC on digital innovation performance, nor for its mediating role between BEG and digital innovation performance. This may be due to the high levels of uncertainty, dynamism, and complexity surrounding digital innovation and transformation activities. While complementary firms may perceive existing digital resources and opportunities, the inability to effectively convert these elements into executable plans may lead to missed opportunities, preventing the monetization of digital resources and hindering short-term improvements in digital innovation performance.

Third, technological dynamism negatively moderates the relationship between contractual governance in the business ecosystem and DCs, while its moderating effect on the relationship between relational governance and DCs is not statistically significant. This moderation effect clarifies the boundary conditions under which contractual governance enhances DCs, enriching the contextual understanding of corporate DC development and addressing the perspective of Zirena-Bejarano et al. (2024) on the moderating role of technological dynamism in shaping corporate capabilities. In environments with high technological dynamism, the optimistic expectations established by contractual governance weaken its positive effects on DCs, increasing the likelihood of opportunistic behavior between governance and the development of DCs. Thus, standardized contractual governance is essential for firms aiming to strengthen their DCs when operating in low-dynamism external technological environments.

5.2. *Theoretical contributions*

First, this study extends the research on the relationship between governance mechanisms and digital innovation performance in the digital economy. Previous literature has largely focused on the impact of bilateral governance within a singular value chain in the industrial economic era (de Reuver and Bouwman, 2012; Bouncken et al., 2016). In contrast, this paper examines BEG from a multilateral perspective, revealing that both contractual governance and relational governance within the business ecosystem

significantly and positively influence the digital innovation performance of complementary enterprises.

Second, this study introduces the perspective of complementary enterprises into the discussion on BEG and digital innovation performance. Existing research has primarily concentrated on the roles of focal enterprises, such as foundational and dominant firms, within BEG (Li et al., 2022a), while insufficient attention has been given to the numerous complementary enterprises within these ecosystems. This gap has made it difficult to understand how complementary enterprises can respond to BEG to engage in digital innovation and achieve innovation performance. This study addresses this gap to a considerable extent.

Finally, this study systematically elucidates the complex mechanisms through which BEG influences the digital innovation performance of complementary enterprises. The findings indicate that the impact of BEG on digital innovation performance primarily occurs through the mediating roles of DPC and DRCC, with technological dynamism negatively moderating the relationship between contractual governance and DCs. While prior literature has emphasized the role of DCs in enhancing innovation performance (Heredia et al., 2022), this study reveals that within business ecosystems, lower technological dynamism enhances the importance for complementary firms to recognize the value of their DCs.

5.3. Managerial implications

This study offers several managerial implications for complementary enterprises within the context of BEG. First, complementary enterprises should not only focus on bilateral governance with stakeholders, such as customers, regarding their digital innovation performance but also recognize the importance of governance within the broader business ecosystem. In the digital economy, it is essential for complementary firms to proactively engage with, embrace, and respond to the multilateral governance present in business ecosystems. They should actively identify and seize business opportunities arising from collaboration among ecosystem members during the value co-creation process to enhance their digital innovation performance.

Second, complementary enterprises should prioritize the development of DPC and DRCC as key leverage points for responding to BEG and accessing strategic resources within the ecosystem. By utilizing both contractual and relational governance within the ecosystem, they can cultivate these capabilities, fostering a digital mindset that enables dynamic awareness of consumer demand and strengthens the coordination and integration of digital resources. This, in turn, will facilitate digital innovation and improve overall innovation performance.

Finally, complementary enterprises should dynamically adjust their digital innovation strategies based on the external technological environment of the business ecosystem. When external technological dynamism is low, complementary firms should reinforce the role of contractual governance in enhancing their DCs. Conversely, in environments characterized by rapid technological advancements, firms should reduce their reliance on contractual agreements to strengthen DCs and place greater emphasis on building trust with partner firms. They should actively pursue potential opportunities within the dynamic environment, integrate both internal and external digital resources, and leverage diverse technological reserves to drive capability upgrades.

5.4. Limitations

This study has several limitations: (1) The research primarily focuses on the artificial intelligence industry, which limits the generalizability of the findings. Future studies could broaden the scope to include a wider range of industries and enterprises to enhance the applicability of the conclusions. (2) Grounded in dynamic capabilities theory, this study investigates the mediating role of DCs in the relationship between BEG and digital innovation performance in complementary enterprises. However, numerous pre- and post-conditions influence this relationship. Future research could explore these dynamics from alternative theoretical perspectives, considering additional mediating and moderating factors. (3) The reliance on questionnaire data restricts the ability to rigorously establish causal relationships between BEG and digital innovation performance and to deeply examine the configurational mechanisms underlying their relationship. Future research might adopt a configurational approach to explore how complementary enterprises enhance their digital innovation performance within the ecosystem.

5.5. Conclusion

Despite these limitations, this study provides key insights. Both contractual governance and relational governance within business ecosystems significantly and positively impact the digital innovation performance of complementary enterprises. Notably, this effect is indirect rather than direct, with DPC and DRCC fully mediating the influence of both forms of governance on digital innovation performance. Additionally, technological dynamism emerges as an important contingency factor in the relationship between contractual governance and DCs. However, it does not alter the relationship between relational governance and DCs, instead negatively moderating the impact of contractual governance on the DCs of complementary enterprises.

CRediT authorship contribution statement

Jingtao Liu: Writing – original draft, Supervision, Methodology, Data curation, Conceptualization. **Qifang Gao:** Writing – original draft. **Lidong Zhu:** Writing – review & editing, Formal analysis.

Declaration of Competing Interest

The 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.

Acknowledgements

This research was funded by Social Science Fund of Anhui Province (Grant No. AHSKQ2024D026), the Hefei Normal University School-Level Research Projects (Grant No. 2024KY21) and the National Natural Science Foundation of China (Grant No. 72202002). We are also grateful for all the key informants who contributed to this study.

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