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The impact of the collaborative innovation network embeddedness on enterprise green innovation performance

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As the market environment becomes increasingly competitive, enterprises that rely solely on internal research and development innovation are no longer sufficient to meet the demands of competition. Consequently, enterprises have broken down organizational boundaries and shifted from closed innovation to open collaborative innovation. The flow of knowledge across organizations facilitates the acquisition of heterogeneous resources from partners, promotes the integration and configuration of internal and external knowledge, thereby enhances the competitiveness of enterprises. However, some scholars argued that collaborative innovation does not always achieve win-win outcomes, and the existence of substitution effects between enterprises and their partners may hinder the innovation level of the focal enterprise. Therefore, based on the resource-based theory and the network embeddedness theory, this study constructs a theoretical model to investigate the effects of network embeddedness, network experience and partner diversity on enterprise green innovation performance in the Chinese green collaborative innovation network. The impact of network embeddedness on innovation performance is examined from two dimensions: structural embeddedness and relational embeddedness. The moderating effects of network experience and partner diversity are analyzed to further explain this phenomenon. Using Chinese green patent data from 2000 to 2015 as the research object, the collaborative innovation network of enterprises is constructed, and the network characteristic variables are calculated using social network analysis methods. Finally, negative binomial regression and robustness tests are conducted using STATA software. The research findings provide managerial implications for Chinese enterprises to achieve competitiveness and sustainable development.

KEYWORDS

collaborative innovation network, embeddedness, green innovation performance, heterogeneous resources, social network analysis

1 Introduction

Since the 21st century, professional knowledge and technological innovation capabilities have become significant criteria for measuring an enterprise's core competitiveness. The key to enterprise innovation lies in both internal research and development (R&D) and external resources acquisition. Internal R&D, as the most important means of enterprise innovation, mainly relies on the enterprise's professional knowledge and technological innovation capabilities to achieve knowledge reorganization and exploration. In addition, enterprises can also achieve independent innovation by acquiring external resources and transforming them into their own technologies. However, as the market environment becomes increasingly competitive, relying solely on internal R&D is no longer sufficient for enterprises to meet the demands of competition. Therefore, enterprises have been breaking organizational boundaries and shifting from closed innovation to open collaborative innovation. Through the flow of knowledge across organizations, enterprises can obtain heterogeneous resources from their partners, promote the integration and configuration of internal and external knowledge, and thus enhance their core competitiveness. However, some scholars hold a different opinion, as Xu et al. (2019) argued that collaborative innovation does not always achieve the expected win-win outcome, and if there are obvious substitution effects between the focal enterprise and its partners, innovation may be hindered. Therefore, it is a worthwhile issue to explore how enterprises can obtain the greatest utility and improve green innovation performance from their collaborative relationships.

To address the aforementioned issues, the resource-based theory and the network embeddedness theory provide appropriate perspectives for research. The resource-based theory emphasizes that establishing collaborative relationships with other organizations are a crucial resource for enhancing innovation performance. In this regard, enterprises that build collaborative networks with universities, research institutes, and other organizations can obtain essential resources and production factors, such as human and technological resources, experimental equipment, and educational resources. On the other hand, the network embeddedness theory suggests that the embedding of a focal enterprise in a suitable collaborative innovation network, and the establishment of sustainable collaborative relationships with partners can facilitate the acquisition of scarce resources and improve the success rate of technological innovation. Scholars have referenced (Granovetter, 1985) analyzed the characteristics of network embeddedness from two dimensions: structural embeddedness and relational embeddedness. The structural embeddedness refers to the extent to which an enterprise is structurally embedded in a collaborative innovation network, and a higher structural embeddedness score indicates that it is easier for the enterprise to acquire abundant resources from the network. This gives the enterprise unique competitive advantages to enhance its innovation performance (Granovetter, 1992). In addition, the relational embeddedness reflects the relationship characteristics of trust, commitment, and reciprocity between organizations. It helps to promote interaction and resource sharing between organizations, indirectly affect enterprise innovation performance.

Previous studies have primarily focused on analyzing the impact mechanism of network embeddedness on enterprise innovation performance (Zhang and Tan, 2014). Some scholars have used enterprises' collaborative experience as an explanatory or moderating variable, finding that it can improve enterprise's alliance formation, management capabilities, and enhance innovation performance. Although enterprises embedded in the network are equally situated, differences in innovation performance exist due to variations in the network resources and capabilities accumulated by existing partners. Additionally, while scholars have analyzed network embeddedness characteristics, they have typically treated all partners as equally important, neglecting the granularity of partner diversity. For example, enterprises with higher partner diversity can access more novel knowledge, skills, experience, and avoid falling into their own "technological trajectory trap" (Hagedoorn et al., 2018). Therefore, considering network experience and partner diversity can help us better understand the impact of these factors on enterprise green innovation performance within the context of collaborative innovation networks.

This study draws on the resource-based theory and the network embeddedness theory to investigate how the state and behavioral characteristics of enterprises in collaborative innovation networks affect green innovation performance. Firstly, considering that both structural embeddedness and relational embeddedness in collaborative innovation networks reflect essential capabilities of enterprises. As such, this study comprehensively investigated the impact of these two characteristics on green innovation performance, revealing the effects of different embeddedness characteristics in collaborative innovation networks on the green innovation of enterprises. Secondly, previous researchers have focused on the direct effect of network characteristics on innovation performance, without considering the influence of other situational conditions. To address this gap, we approached this study from the perspective of resource factors, introducing network experience and partner diversity as moderating variables in the theoretical model. This further allowed us to explore the contextual conditions when the network embeddedness characteristics of enterprises have an effect on green innovation performance. The model constructed in this study attempts to supplement the research gap in factors affecting green innovation performance of enterprises and enriches relevant theories such as green technology innovation and strategic management. Additionally, this study has practical value and management implications for enterprises to consider how to leverage collaborative network characteristics to improve green innovation performance.

Therefore, the innovation of this study can be identified in three aspects. 1) It expands the research on the impact mechanism of collaborative innovation embeddedness on enterprise green innovation performance. Previous studies have provided limited analysis on the impact of collaborative innovation networks embeddedness on the green innovation performance of enterprises. This study takes the perspective of Chinese green open innovation and clarifies the impact mechanism of the structural embeddedness and relational embeddedness characteristics of collaborative innovation networks on enterprise innovation performance. This study broadens and enriches the existing literature on innovation behavior of Chinese enterprises by adopting a new perspective of collaborative innovation, allowing for a better understanding of enterprises' innovation behavior through the aspects of network embeddedness. 2) It introduces the characteristics of network experience and partner diversity, which improves existing models that depict the situational conditions in which network embeddedness affects green innovation performance. This study aims to investigate these two characteristics as moderating variables to elucidate the interaction between network embeddedness and other characteristics from internal and external perspective, thus making theoretical

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contributions to the literature on collaborative management. 3) It studies the path to improve Chinese enterprises green innovation performance under the background of resource and environmental constraints and increasing market competition. This study is beneficial for enterprises to gain a better understanding of their own innovation, and thus effectively develop technology cooperation strategies and enhance the effectiveness of collaborative innovation.

The study is organized as follows. In Section 2, we present a literature review related to this research. In Section 3, we describe theoretical foundations and research hypotheses. In Section 4, we show the research design. In Section 5, we present empirical results and analysis. Finally, in Section 6, we draw the research conclusions and managerial implications of this study.

2 Literature review

2.1 The green innovation performance of enterprises

Fussler and James (1996) provided a definition for "green innovation" as the creation of new products and technologies that generate value for both consumers and businesses while simultaneously reducing environmental pollution. Chen et al. (2006) expanded upon this definition by including hardware and software innovations related to green products or processes, as well as innovations in energy conservation, pollution prevention, waste recycling, green product design, or enterprise environmental management. Tian and Pan (2015) argued that green innovation involves enhancing the environmental management aspects of an enterprise's products and production processes. Meanwhile, Li and Xiao (2020) emphasized that green innovation should focus on reducing environmental pollution, conserving energy, and promoting the coordinated development of enterprise competitiveness and environmental protection. Therefore, green innovation should aim to advance the development of green technologies and improve the ecological environment. This approach involves incorporating ecological concepts into the stages of product development, manufacturing, and management. By doing so, green innovation can effectively balance the relationship between economic growth and environmental protection, and contribute to the sustainable development of the social economy.

The measurement of green innovation performance in enterprises is an extension of traditional innovation performance, but a consensus on its measurement dimensions is lacking. From the perspective of the natural foundation theory, the green innovation performance of an enterprise is the outcome of the interaction between the external environment and internal organization in implementing green innovation. In recent years, some scholars have described the concept and performance of green innovation performance from different perspectives. For example, Anthony and Rene (2009) suggested that the environmental innovation performance of an enterprise comprises indirect performance mainly focused on efficiency improvement, direct performance mainly focused on innovative product revenue, and knowledge property mainly focused on green patents. Tariq et al. (2017) emphasized the importance of paying attention to environmental impact in technological innovation of enterprises. Ren et al. (2014) defined the performance of green innovation in enterprises as the sum of economic and environmental performance generated by green technological innovation. Tian and Pan (2015) divided the performance of enterprise green innovation into green product innovation performance related to environmental innovation and green process innovation performance related to production. Based on the above definitions by scholars, we believed that green innovation is a process of enhancing both economic and social value for enterprises. Therefore, adopting the definition proposed by Anthony and Rene (2009) makes the evaluation results of innovation performance more comprehensive.

2.2 Network embeddedness

"Embeddedness" is a critical concept in sociology and economics, which has been extensively researched and validated. Studies have demonstrated that "embeddedness" can help to understand the influence of social structure on economic behavior. Polanyi (1944) first proposed the concept of "embeddedness" to explain social structure in markets. Economic behaviors embedded in social networks exhibit positive or negative effects that interact among the subjects of the social network. In the social network, many behavior subjects (such as nodes) obtain various resources through collaborative information networks. When these behavior subjects use these network resources to achieve economic goals, embedded behavior occurs. Collaborative networks are formed by the interconnection of various behavior subjects, and "embeddedness" emphasizes the ability and process of behavior subjects to continuously obtain various resources in the network.

The reference Granovetter (1985) divided "embeddedness" into two dimensions: structural embeddedness and relational embeddedness. Structural embeddedness emphasizes the overall structural relationships of actors embedded in social networks, mainly measured by their position, network density, and scope. Network position is the core indicator for analyzing structural embeddedness, and different network structures represent different opportunities for actors to obtain new knowledge from the network. Centrality and structural hole indicators are generally used to measure structural embeddedness. Relational embeddedness refers to the binary relationships between actors in a network, such as trust and collaboration, and is measured in terms of the direction, strength, and continuity of the relationships. Granovetter proposed four indicators to measure the strength of the relationships between actors, including interaction frequency, intimacy, relationship duration, and mutual service content. Relational embeddedness affects inter-organizational collaboration, resource exchange, and the development of shared knowledge in various ways. By understanding both structural embeddedness and relational embeddedness, it is possible to gain insights into how social structures affect economic behavior and outcomes.

Many scholars have studied the relationship between network embeddedness and enterprise innovation behavior, using characteristics such as network density, centrality, structural holes, and relational strength to evaluate the impact of network embeddedness. For instance, Gilsing et al. (2008) analyzed the technical distance, enterprise network position (centrality), and overall network density in collaborative alliances to understand innovation embedding. Zhang (2010) constructed a conceptual model of the impact of network embeddedness on enterprise innovation performance, with structural embeddedness characteristic indicators including density, scale, and centrality, relational embeddedness characteristic indicators including contact frequency, persistence, and mutual trust. Gonzalez-Brambila et al. (2013) explored how different dimensions of network embeddedness affect scientists' research output and impact, including direct contacts and contact strength, as well as density, structural holes, centrality, and interdisciplinary contacts. Zhang and Tan (2014) found that enterprise resources, the strength of alliance relationships, and elements such as network density, enterprise network centrality, and structural holes all have a direct impact on collaborative innovation performance. Yang et al. (2019) studied the impact of knowledge networks and collaborative networks on innovation performance, with structural embeddedness measured by structural holes and relational embeddedness measured by node degree centrality. Yan et al. (2019) suggested that the "embeddedness paradox" may stem from different forms of network embeddedness and innovation forms, taking the innovator's network density as a structural embeddedness and the innovator's average collaborative centrality as relational embeddedness, and considering the mechanism by which overall network embeddedness affects innovation.

2.3 Research on the relationship between network embeddedness and enterprise green innovation performance

Green innovation is a growing research area that has been studied by scholars from various perspectives. Scholars from abroad have mainly focus on the driving factors, innovation outcomes, and competitive advantages of green innovation (Hojnik and Ruzzier, 2016; Abbas and Sağsan, 2019). Meanwhile, domestic scholars have mainly studied this topic through the viewpoints of international direct investment, environmental public opinion pressure, and environmental regulation (Yuan and Chen, 2019; Dai and Lu, 2020; Yang et al., 2020). However, the existing literature has primarily concentrated on the organizational or managerial level and has paid little attention to the inter-organizational level.

As the continuous deepening of green innovation research, scholars have recognized the crucial role of external networks in promoting an enterprise's innovation performance. For instance, Chen and Hung (2014) conducted a study on collaborative innovation and found that implementing open, collaborative, and shared innovation models can positively impact an enterprise's green innovation performance. Yu and Xing (2019) conducted an empirical test on a conceptual model that examined the relationship between network embedding, green innovation, and enterprise competitive advantage based on survey data from 216 manufacturing enterprises. Pang et al. (2019) explored the effect of external network relationships on exploratory and exploitative green innovation by examining innovation resources and critical knowledge in external networks. Zhou and Jin (2021) explored the impact and mechanism of network embeddedness on an enterprise's green innovation, and Xing et al. (2022) studied the relationship between network embeddedness and green innovation by incorporating dynamic capability theory, network embeddedness theory, and institutional theory. They also examined the mediating role of green dynamic capabilities and the moderating effects of environmental regulation and managerial environmental attention. In previous research, scholars primarily analyzed the relationship between network embeddedness and enterprise innovation performance, with foreign scholars focusing on structural position and relational strength (Ahuja, 2000; Shayan et al., 2018), while domestic scholars emphasized the effects of network centrality, structural holes, network density, and network relationships on enterprise innovation performance (Qian et al., 2010; Zhang and Tan, 2014; Yang et al., 2019).

Analysis of the above literature shows that the impact of network embeddedness on enterprise innovation performance has become a hot spot both domestically and internationally. Researchers have divided network embeddedness into two dimensions: structural embeddedness and relational embeddedness, when studying the internal structure of innovation networks, and have concluded that both dimensions have a certain impact on enterprise innovation performance. Although most scholars used Poisson regression models or negative binomial regression models to examine and measure the embeddedness characteristics of collaborative innovation networks through questionnaire surveys, the design of the questionnaire may possess some bias, which casts doubts on the authenticity of the research findings. Conversely, using social network analysis to construct collaborative innovation networks of enterprises and measuring the embeddedness characteristics of these networks based on patent data can produce more objective results. This study aims to elucidate the mechanism of the impact of collaborative innovation network embeddedness on enterprise innovation performance from the perspective of green open innovation in China, and intends to supplement the research on the factors that affect enterprise green innovation performance. This helps enrich related theories such as green technological innovation and strategic management, provide some guidance value and offer management enlightenment for enterprises to enhance their green innovation performance.

3 Theoretical foundations and research hypotheses

3.1 Theoretical foundations

3.1.1 Resource-based theory

The resource-based theory suggests that enterprises are composed of a combination of resources, and that possessing valuable, rare, inimitable, and non-substitutable resources provides a critical foundation for competitive advantage (Barney, 1991). The underlying assumption of this theory is that enterprises or other organizations make rational decisions when selecting and accumulating resources. However, in reality, these decisions may be influenced by factors such as limit information, bias, and causal ambiguity (Oliver, 1986). The goal of the theory is to elucidate how enterprises can maintain a unique and sustained competitive advantage in fierce environment. Its main arguments include: 1) an enterprise's competitive advantage stems from its possession of unique and heterogeneous resources; 2) an enterprise's sustained competitive advantage comes from its possession of non-substitutable resources. Therefore, internal resources should be given priority and leveraged to respond to changes in the external environment (Hoopes et al., 2003).

As market competition intensifies, enterprises cannot rely solely on their internal resources to maintain a competitive advantage. To address their deficiencies and promote knowledge integration innovation, they must urgently seek out relevant resources from external organizations. Drawing on the resource-based theory, inter-organizational collaboration is recognized as a form of organizational resource R&D alliance. Enterprises can share and exchange their own resources with other organizations through collaborative relationships, or integrate relevant resources to obtain competitive advantages that individual organizations lack, thereby creating greater value. In this process, organizations need to manage their collaborative relationships effectively to ensure that the external information resources they acquire can be integrated with their internal resources, resulting in the creation of new knowledge and value.

In studies of collaborative R&D alliances, resource-seeking behavior facilitates the establish alliances, organizational similarity and complementarity are important factors in building such alliances. The establishment of R&D alliances increases the transfer rates of resources between organizations and strengthens the closeness of alliance partnerships (Wang and Zajac, 2007). Scholars suggested that collaboration with upstream and downstream enterprises, customers, universities, and research institutes can help enterprises obtain proprietary technology, learning environments, and funding for innovation, which is beneficial for the interaction and sharing of collaborative resources. In a collaborative network, weak ties and low-intensity collaboration can easily obtain transferable innovation resources, while heterogeneous resources that are difficult to transfer require enterprises to establish strong collaborative partnerships to realize them (Rusanen et al., 2014).

3.1.2 Network embeddedness theory

The network embeddedness theory is a significant concept in various fields, including sociology, economics, and management. Polanyi (1944) first proposed the definition of embeddedness, stating that economic activities are not independent of specific economic environments but are embedded within them. Additionally, economic activities are not solely motivated by profit but can be influenced by non-economic factors as well. As research on embeddedness theory has developed, scholars have classified it according to specific themes, forming several classic analytical frameworks. Granovetter (1985) proposed the structural and relational embeddedness framework, Zukin and Dimaggio (1990) proposed the structural, cognitive, cultural, and political embeddedness framework, and Andersson et al. (2002) proposed the business and technological embeddedness analytical framework.

In the field of social network analysis, researchers have identified two dimensions of network embeddedness using Granovetter's method: structural embeddedness and relational embeddedness. Structural embeddedness pertains to the overall structure and function of connections among network actors and emphasizes the position of enterprises with the social network. This dimension encompasses multidimensional network relationships and focuses on how network density and an enterprise's position in the network impact its behavior and performance. Structural position in the network changes relatively slowly, and it is generally used as a static analysis of network embeddedness, with network position serving as the core indicator. Different network positions represent different opportunities for enterprises to acquire new knowledge (Qian et al., 2010). The primary variables of network position are centrality and structural hole measures (Powell et al., 1996; Zaheer and Bell, 2005). Centrality refers to the extent to which an enterprise occupies a core position in the network. High centrality indicates closer proximity to the core position of the network and access to abundant information and complementary resources from the network. On the other hand, a structural hole is a phenomenon where individuals in the network have no direct connection. The more structural holes an enterprise has in the network, the more advantageous its position in the entire information transmission network, which reflects the enterprise's "bridging role" in the network (Burt et al., 2013). Relational embeddedness focuses on binary relationships between actors in the network, such as trust relationships and collaborative relationships. The measurement indicators of relational embeddedness include the direction, strength, and continuity of the relationship. Relational embeddedness is a key indicator for measuring the impact of network structure on organizational economic behavior. The change in relational embeddedness is relatively fast, and it is generally used as a dynamic analysis of network embeddedness. Granovetter (1985) proposed four indicators to measure the strength of relationships between actors, including interaction frequency, intimacy, relationship duration, and mutual service content. Relational embeddedness affects inter-organizational collaboration, resource exchange and combination, and the development of shared knowledge in multiple ways. Consequently, it directly impacts an enterprise's current innovation performance and future collaboration.

The theory of network embeddedness is a valuable framework for understanding collaborative innovation networks among enterprises. Such networks are defined as consisting of enterprises and other partners connected by collaborative relationships through jointly applying for patents. In these cross-organizational networks, an enterprise's ego-centric network plays a crucial role in achieving technological innovation through social relationships. By exchanging heterogeneous resources embedded in social networks, enterprises can compensate for their own resource limitations and enhance their innovation performance. The structural functions of the collaborative innovation network can be used to facilitate the acquisition of innovation resources, thereby improving the enterprise's innovation performance. Thus, the theory of network embeddedness provides a theoretical foundation for this study, helping to clarify the impact of network embeddedness on an enterprise's innovation performance mechanism.

3.2 Research hypotheses

3.2.1 Network embeddedness and enterprise green innovation performance

Green innovation refers to the adoption of new processes, products, and technologies to reduce environmental pollution. Drawing to the natural resource-based theory, green innovation performance is the result of an enterprise's green innovation efforts in both the internal organization and external environment. Today, the rapid development of technology makes enterprises difficult to independently and efficiently complete product research. By embedding enterprises into collaborative innovation networks, they can obtain complementary resources from the network, establish long-term trust, mutual benefit relationships with partners, and achieve critical knowledge sharing. Therefore, network embeddedness can significantly improve an enterprise's innovation performance (Li et al., 2017). Enterprises embedded in appropriate network structures can obtain valuable information and resources, thereby consolidating their development capabilities (Zaheer and Bell, 2005). Collaborative R&D among enterprises helps to acquire complementary resources, share risk costs, and utilize external knowledge spillovers, among other direct effects. Using Granovetter's network embeddedness research framework, this study analyzes from two perspectives: the relationship between structural embeddedness and enterprise green innovation performance, and the relationship between relational embeddedness and enterprise green innovation performance.

(1) Structural embeddedness and enterprise green innovation performance

As an informal relationship between network behavior subjects, structural embeddedness focuses on examining the position of an enterprise in the collaborative innovation network, providing an effective way for information transmission between organizations. The higher the degree of structural embeddedness of an enterprise in the network, the more significant its dominant position becomes, and the easier it is to obtain scarce network resources, providing a unique competitive advantage that can promote innovation performance (Granovetter, 1992). Existing literature mainly focused on two network position characteristics, namely, centrality and structural holes, and scholars believed that studying the characteristics of structural holes is particularly principal. In a collaborative innovation network, when two separated nodes need to be connected, a third entity must participate. This entity occupies a structural hole and plays the role of a "bridge", providing non-redundant and controlling resource advantages. An enterprise occupying more structural holes indicates that it plays an essential role and strategic position as a bridge in the collaborative innovation network.

Enterprises that occupy more structural holes can promote their innovation performance through two mechanisms. Firstly, researches have shown that non-redundant collaboration is most effective in different types of collaborative relationships, which usually bring heterogeneous resources (Burt et al., 2013; Marlow and McAdam, 2015). As the number of structural holes increases, enterprises have more opportunities to acquire novel innovative resources. By contacting more partners, enterprises can obtain non-redundant innovation resources in the network and achieve cross-disciplinary integration of multiple knowledge fields. Therefore, the large amount of heterogeneous resources obtained through structural holes can stimulate the production of innovation performance. Secondly, occupying a structural hole helps enterprises avoid falling into the "cognitive trap". Enterprises with more structural holes can explore innovative resources such as technology and knowledge that have a greater gap with their original cognition. These heterogeneous resources are conducive to breaking the enterprise's technology, which helps to improve the enterprise's green innovation performance. In summary, we propose the following hypotheses:

H1: Structural embeddedness has a positive effect on enterprise green innovation performance.

(2) Relational embeddedness and enterprise green innovation performance

In collaborative innovation networks, relational embeddedness refers to the connections between network actors, which reflect relationship characteristics such as trust, commitment, and reciprocity between organizations. Relational embeddedness is conducive to promoting interaction and information sharing between organizations. When the degree of relational embeddedness is low, the resources obtained by organizations through interaction and information sharing may not meet the knowledge required for enterprise innovation. In such case, the relationship between relational embeddedness and enterprise innovation performance becomes disconnected, and the knowledge obtained through relational embeddedness may not realize its full potential. However, as the degree of relational embeddedness gradually increases, the ability of enterprises to acquire heterogeneous knowledge is enhanced. Enterprises can achieve innovation performance through the effective absorption and transformation of this knowledge (Baum et al., 2000).

The "weak ties" school represented by Granovetter (1992), proposed that strong relational embeddedness consists of behavior subjects with similar knowledge backgrounds who are very familiar with each other. The results in constraints on the heterogeneity of resources in the network, leading to redundant knowledge and technology flowing within the network. Conversely, weak connections in network relationships (long-distance, infrequent contacts) are advantageous for enterprises to acquire new technology from the external environment due to the differences in knowledge fields and backgrounds. Therefore, low relational embeddedness avoids "cognitive lock-in" caused by "relationship lock-in", enabling enterprises to maintain independence in collaborative relationships and gain new knowledge from new partner relationships (Hansen, 1999). Additionally, when studying the impact of excessive relational embeddedness on the innovation process, Yang et al. (2013) demonstrated that excessive relational embeddedness suppresses access to entrepreneurial resources. Thus, as the openness of green innovation activities increases, it becomes crucial for enterprises to engage in collaborative innovation with upstream and downstream enterprises, subsidiaries, universities, and research institutes in the innovation network. In the field of green innovation, enterprises are more inclined to repeat collaboration with existing partners, which can save the search and selection costs of partners and establish long-term collaborative trust relationships. However, this can also lead to the problem of heterogeneous resources redundancy. In summary, we propose the following hypothesis:

H2: Relational embeddedness has a negative effect on enterprise green innovation performance.

(3) The moderating effect of network experience

Gulati (1999) found that enterprises can improve their innovation performance by engaging in more collaborative experiences. Koka and Prescott (2002) suggested that social capital is composed of the quantity, diversity, and richness of information, with information richness being dependent on the level of collaborative experience between enterprises and their partners. Network experience refers to the experience gained by enterprises through collaboration with different partners in the patent development process. As the heterogeneity of knowledge possessed by partners is a crucial resource for collaborative innovation, utilizing network experience can assist enterprises develop diverse practices and ideas, build a broader knowledge base, and enhance their technological innovation capabilities, ultimately promoting their innovation performance.

Network experience can enable enterprises to acquire valuable knowledge resources. Szeto (2000) research highlights that a continuous supply of innovation and accumulation of innovative knowledge contribute to enhancing an enterprise's innovation performance. When enterprises are embedded in collaborative networks and utilize heterogeneous resources, they require the ability to search for and manage knowledge and convert it into knowledge that is relevant to the enterprise. In the context of industry-university collaboration, Lin and Yang (2020) have shown that enterprises with extensive collaborative experience possess greater professional knowledge and are more willing to transfer or exchange knowledge. Furthermore, enterprises tend to spend more time in establishing strong relationships with their key partners, which not only reduces partner search and selection costs, but also enhances their understanding of their partners, thus improving the stability and sustainability of their collaborations. Hence, enterprises with network experience accumulate abundant innovative knowledge, which strengthens their knowledge exchange with key partners and enhances their innovation performance.

Furthermore, network experience enables enterprises to access abundant potential partner resources, thereby facilitating a continuous supply of innovation resources. As partners' characteristics are often ambiguous and uncertain, Chapman et al. (2018) has suggested that enterprises can benefit from attractiveness and reliability built with past partners. The network resources generated by an enterprise's previous collaborative experience can help it obtain information on potential partners, thus reducing partner search costs and certain opportunistic risks (Hoenig and Henkel, 2015). Additionally, enterprises can develop and refine their partner search programs through collaborative experience to enhance the efficiency of identifying new collaborative opportunities. Therefore, a abundant network experience can empower enterprises to rapidly expand their external collaborations, acquire relatively more valuable knowledge, and consequently, enhance their innovation performance. Based on these arguments, we propose the following hypotheses:

H3a: Network experience moderates the relationship between collaborative network structural embeddedness and enterprise green innovation performance.

H3b: Network experience moderates the relationship between collaborative network relational embeddedness and enterprise green innovation performance.

(4) The moderating effect of partner diversity

According to the resource-based theory, partner diversity in a collaborative innovation network refers to the degree of diversification of the types of collaborating partners of a focal enterprise, which enables the focal enterprise to obtain non-redundant technological knowledge from an expanded resource pool. In a collaborative innovation network, different types of partners possess unique knowledge resources such as information, skills, and experience. When an enterprise collaborates with partners of various types for R&D, it gains heterogeneity of resources from external partners (Hagedoorn et al., 2018). For instance, research-oriented universities can provide fundamental and exploratory knowledge to the enterprise (Raesfeld et al., 2012), vocational universities can supply employees with professional skills, and research institutes can offer the industry-critical technologies to the enterprise. In an embedded network, as the degree of partner diversity increases, the focal enterprise can access a more diversified pool of external knowledge resources, thereby enhancing its innovation performance (Lahiri and Narayanan, 2013). Furthermore, partner diversity in a collaborative innovation network is advantageous for creating and integrating complementary resources both internally and externally. Strong knowledge complementarity exists between the enterprise and its collaborative partners, such as universities and research institutes. The recombination and integration of new ideas, new technologies, and internal knowledge elements possessed by external partners can help the enterprise break through its existing thinking patterns, avoid being constrained by past knowledge, and form synergies (Yin and Shao, 2017). This further illustrates that partner diversity in an embedded network can assist enterprises in restructuring and integrating complementary internal and external knowledge, thereby promoting their innovation performance.

A considerable amount of literature has demonstrated the significant impact of enterprise embeddedness in networks on their economic and innovative performance (Owen-Smith and Powell, 2004). A high degree of structural embeddedness facilitates the acquisition of scarce network resources, thereby providing a competitive advantage for promoting innovation. Moreover, a high degree of relational embeddedness enables enterprises to access heterogeneous knowledge from the

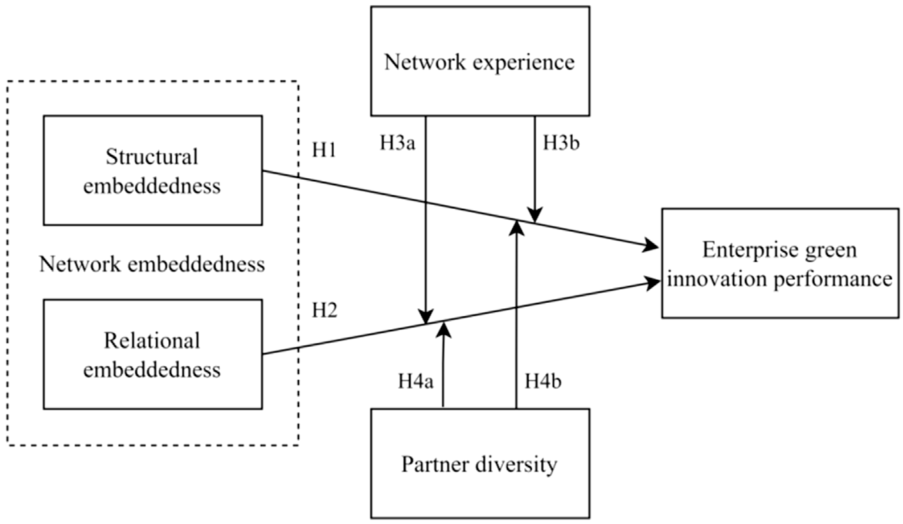

FIGURE 1
Theoretical model framework.

outside world and enhance innovation performance through effective absorption and transformation (Baum et al., 2000). However, the existing research mainly focuses on analyzing the position and strength of enterprise relationships in networks from the perspective of network embeddedness, lacking differentiation of fine-grained characteristics such as partner diversity. Specifically, compared to enterprises with low partner diversity, enterprises with high partner diversity that have similar network embeddedness characteristics can access more knowledge and problem-solving solutions, enabling them to overcome "technological trajectory trap". Additionally, partner diversity in embeddedness networks strengthens enterprises' knowledge base, promotes the recombination and creation of complementary knowledge, and drives the improvement of green innovation performance. Therefore, the following hypotheses are proposed:

H4a: Partner diversity moderates the relationship between network structural embeddedness and enterprise green innovation performance.

H4b: Partner diversity moderates the relationship between network relational embeddedness and enterprise green innovation performance.

3.3 Theoretical model

According to the resource-based theory and the network embeddedness theory, this study aims to investigate the impact of collaborative innovation network embeddedness on enterprise's innovation performance, as well as the moderating role of network experience and partner diversity in this relationships. Based on these discussions, we propose a theoretical model framework, as shown in Figure 1.

4 Research design

4.1 Sample selection and data source

In December 2022, the National Development and Reform Commission and the Ministry of Science and Technology of China jointly issued the "Implementation Plan for Further Improving the Market-Oriented Green Technology Innovation System (2023–2025)". This plan emphasizes that technological innovation is the core driving force for promoting green and low-carbon transformation, and should be market-oriented to accelerate the construction of a green technological innovation system. Against the backdrop of advocating for green economic development, green technological innovation can promote the green transformation of SMEs, achieve coordinated and sustainable development of enterprise competitiveness and environmental protection. Although scholars have employed various classification standards for enterprise green innovation, the primary classifications typically include green technology innovation, green product innovation, and green process innovation (Xie and Zhu, 2021). As the main carrier of technological innovation achievements, patents are a significant indicator for measuring enterprise green innovation and have attracted the attention of scientists and scholars (Li and Xiao, 2020; Hu et al., 2021). Moreover, the World Intellectual Property Organization (WIPO) has defined the scope of green innovation and related technologies in detail as well. Therefore, this study uses enterprise green patent data as the research object to empirically test the above hypotheses.

The data sources used in this study include: 1) the website of the China National Intellectual Property Administration (CNIPA)[1]; 2)

1 http://epub.cnipa.gov.cn/

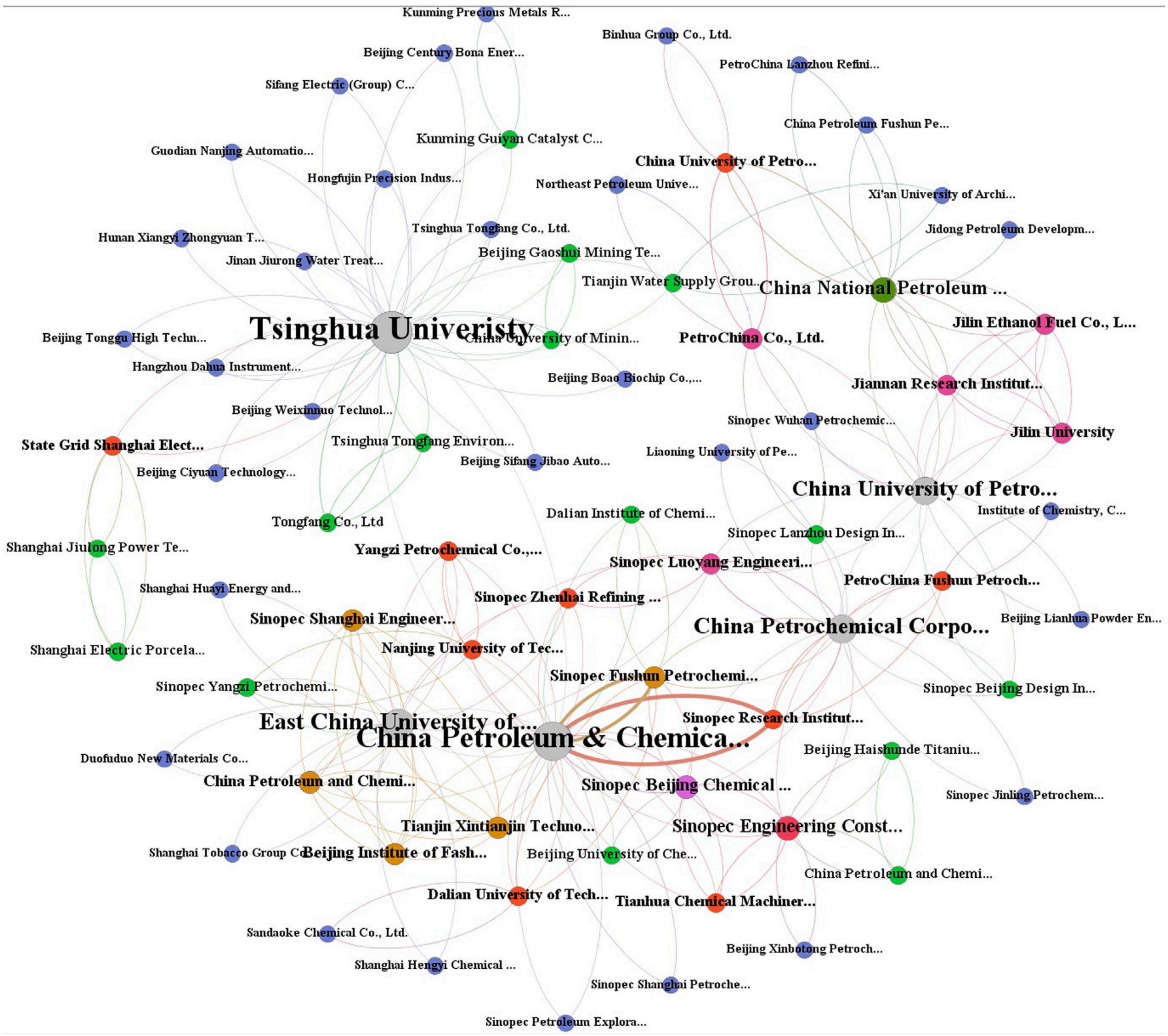

FIGURE 2
Example of the enterprise collaborative innovation network constructed from 2000 to 2004.

the "Green Patent List" published by the WIPO; 3) the basic business information of enterprises from the Qichacha website. Firstly, patent data granted between 1985 and 2020 were searched from the CNIPA platform. Then, the international patent classification (IPC) codes were matched with the "Green Patent List" published by WIPO to extract information on 539,297 Chinese green patents, such as patent number, application date, patentee, IPC code. Finally, the basic business information of enterprises were obtained from the Qichacha website.

Determining the research object. Following the method used by (Yan et al., 2019), we construct a collaborative innovation network based on the patentee relationships of the collaborative patents. As the start time of inter-organizational collaboration is uncertain, but the collaborative relationship usually lasts for 3–5 years (Guan et al., 2016), we use a rolling time window of 5 years, and divide the patentee collaborative network into 12 periods (2000–2004, 2001–2005, 2011–2015). This study focuses on analyzing patents owned by enterprises. The selection of research objects followed a set of rules: 1) Only patents owned by enterprises and their partners were retained, while those owned by individuals were excluded; 2) To ensure accuracy, we check the patentee's name for previous names and correct to the latest name; 3) To ensure the representativeness of the research object, the top 10% of enterprises ranked by patent volume in each rolling time window were selected as the research object. For instance, in the collaborative innovation network from 2000 to 2004, a total of 1,205 patents were retrieved, of which the top 10% of enterprises covered 987 patents, accounting for 82% of the patents. Similarly, in the collaborative innovation network from 2011 to 2015, a total of 24862 patents were retrieved, of which the top 10% of enterprises covered 19647 patents, accounting for 79% of the patents. The average proportion of patents covered by the top 10% of enterprises in the 12 collaborative innovation networks obtained using this method was 77%, demonstrating the effectiveness of this method in ensuring the representativeness of the research object.

Construction of a collaborative innovation network among enterprises. In patent applications, multiple organizations such as enterprises, universities and research institutes can apply jointly, and one organization can also apply for many patents. A patent with N patentees represents a direct collaborative relationship among these N patentees, and collaborative relationship edges need to be established between them. In this study, we utilize this method to search for all green patents of collaborative invention and construct a collaborative innovation network related to enterprises. Figure 2 illustrates the largest connected sub-graph of the collaborative innovation network with a time window of 2000–2004, where the size of the nodes represents the number of patents invented by the respective entities, and the width of the edges denotes the strength of the collaborative invention between the entities. From the figure, it can be seen that “China Petroleum and Chemical Corporation” (“中国石油化工股份有限公司”) had the most collaborative innovation patents from 2000 to 2004, and it had a strong collaborative relationship with “Sinopec Research Institute of Petroleum Processing” (“中国石油化工股份有限公司石油化工科学研究院”) and “Sinopec Fushun Petrochemical Research Institute” (“中国石油化工股份有限公司抚顺石油化工研究院”). In addition, many enterprises actively participate in Chinese green technology innovation by establishing collaborative relationships with “Tsinghua University” (“清华大学”). By calculation, it was found that “Tsinghua University” (“清华大学”) has the most structural holes, followed by “China Petroleum and Chemical Corporation” (“中国石油化工股份有限公司”).

Previous scholars primarily employed questionnaire surveys to measure the embeddedness characteristics of collaborative innovation networks. However, the designed survey questionnaires had a certain level of bias, which questioned the authenticity of the results. Against questionnaire surveys, this study utilizes socail network analysis method can facilitate better comprehension of a enterprise’s innovation collaboration relationships, which can identify opportunities and potential collaboration, and provide effective research approaches for scientific research. Therefore, using social network analysis methods can obtain network characteristic variables of collaborative innovation networks and provide relevant data foundations for this study.

4.2 Variable definition and measurement

4.2.1 Dependent variable

Green innovation performance. Following the approach of Ahuja (2000) and other scholars, we measure enterprise green innovation performance by the number of green patents granted to an enterprise in year t. According to Li and Xiao (2020), green patents are deemed as a critical component of green innovation for enterprises. The use of granted patents is preferred due to their higher quality, and we choose patents applied for in year t to timely reflect the enterprise’s innovation performance. To effectively address the issue of endogeneity caused by reverse causality, we lag the dependent variable by one period.

4.2.2 Independent variables

The concept of network embeddedness is a critical variable in social network analysis, which results from the establishment of connections between organizations. Variations in network position within an enterprise’s collaborative innovation network indicate opportunities for the enterprise to obtain new knowledge for innovation activities, implying that network embeddedness significantly impacts enterprise behavior and innovation performance (Tsai, 2001). Scholars typically analyzed network embeddedness from two dimensions: structural embeddedness and relational embeddedness in the collaborative network (Zhang, 2010; Yan et al., 2019; Zhang and Liu, 2021).

Structural embeddedness. Scholars have used network position variables such as centrality and structural holes to analyze the structural embeddedness of networks, as discussed in relevant literature (Powell et al., 1996; Zaheer and Bell, 2005). Structural holes are a significant structural attribute, indicating the absence of direct connections between entities in a network. The more structural holes a particular entity has in the network, the more advantageous its position is in terms of maintaining and controlling information in the entire network (Burt et al., 2013). The concept of structural holes examines non-redundant contacts of network nodes. Burt’s structural hole index, which is applicable to the overall network, includes effective size, efficiency, constraint, and hierarchy. Among them, constraint is the most commonly used indicator, which refers to the extent to which actors in the network have the ability to use structural holes. The higher the level of constraint of an entity, the fewer structural holes it occupies. Therefore, to measure structural holes, we use the difference between “1” and the score of constraint (Alletto et al., 2017). The measurement method is as follows:

$$SE_i = 1 - \sum_j \left(p_{ij} + \sum_{k \in N(j)} p_{ik} p_{kj} \right)^2 \tag{1}$$

Where SE_i represents the structural embeddedness of enterprise i, p_{ij} denotes the proportion of resources of enterprise i that are tied to partner j, p_{ik} represents the proportion of resources of enterprise i that are tied to partner k, and p_{kj} represents the proportion of resources of partner k that are tied to partner j. All independent variables are measured based on the inter-organizational collaborative network during the observation period spanning from t-5 to t-1 year. For instance, in the case of analyzing the enterprise collaborative innovation network between 2000 and 2004, the structural hole index for each node in the network was calculated.

Relational embeddedness. The analysis of relational embeddedness in collaborative networks focuses on the strength of binary relationships between network entities. Based on the partnership theory, scholars typically use measures of relationship strength to access the level of relational embeddedness of enterprises (Yan and Guan, 2018). Interactions between a focal enterprise and its collaborators allow the former to acquire and use the information and resources embedded in these relationships. Establishing strong partnerships enables both parties to better understand each other, leading to more mature and dependent relationships that foster trust. Therefore, relationship strength can be calculated using various methods. We following the approach of Zheng and Yang

(2015) to calculate the focal enterprise's relational embeddedness strength by computing the number of repeated collaborations with its partners and taking the geometric mean. The calculation formula is as follows:

$$RE_i = \left(\prod_j R_j\right)^{1/N} \quad (2)$$

Where RE_i represents the relational embeddedness strength of enterprise i, R_j denotes the repeated collaboration times between enterprise i and the related partner j in the observation period of t-5 to t-1, and N represents the number of all partners of enterprise i. The variable RE_i measures the strength of the collaborative relationship between enterprise i and its related partners, whereby a higher value indicates a higher level of engagement of the enterprise in recurrent collaborative R&D activities.

4.2.3 Moderating variables

Network experience. Collaborative experience refers to the extent of the focal enterprise's previous collaborative activities, highlighting the breadth and depth of its collaborations, which is often quantified by the number of past collaborations. In this study, we introduce the concept of network experience, which focuses on the collaborative network perspective, measuring the number of collaborations between focal enterprise i and various partners over a specified period of time. To ensure an accurate assessment of the abundant of the focal enterprise's past collaborative experiences, we exclude the number of repeated collaborations with the same partner. Therefore, we adopt the count of the collaborative relationships between focal enterprise i and different technological entities within the collaborative network established by focal enterprise i during the 5-year preceding the observation period (t-10 ~ t-6) as the measure of network experience.

Partner diversity. Partner diversity refers to the extent of diversity in the types of organizations that collaborate with the focal enterprise, and it has a significant impact on the enterprise's innovation performance. Different types of partners possess heterogeneous resources, and it is useful to analyze the moderating effect of partner diversity on enterprise innovation performance. To measure partner diversity, we adopted the method from Yoon et al. (2015) and used the Herfindahl-Hirschman Index (HHI). The HHI is calculated by squaring the proportion of each organizational type (i.e., enterprises, universities, and research institutes) that collaborate with the focal enterprise during the observation period (t-5 ~ t-1) in the collaborative network and then summing these values. A lower HHI indicates a stronger partner diversity of the enterprise. To simplify the interpretation, we define the partner diversity of focal enterprise i as "1" minus the value of HHI. The specific formula is provided below:

$$PD_i = 1 - HHI_i = 1 - \sum_j \left(\frac{W_{ij}}{N}\right)^2 \quad (3)$$

Where PD_i represents the partner diversity of enterprise i, W_{ij} represents the number of partners of enterprise i that belong to organization type j, and N represents the total number of partners of enterprise i. A value of 0 for PD_i indicates that the partners of enterprise i belong to only one type of organization. As the value of PD_i increases, it indicates that the enterprise has improved its level of partner diversity.

TABLE 1 Research variables and measurement methods.

Variable name	Measurement method
Green innovation performance	Total number of green patents granted to the enterprise in year t
Structural embeddedness	Measurement of structural holes in the enterprise's collaborative network using data from years t-5 to t-1
Relational embeddedness	Measurement of relationship strength in the enterprise's collaborative network using data from years t-5 to t-1
Network experience	Number of different partners that the enterprise had collaborated with during t-10 to t-6 years
Partner diversity	1 - Herfindahl-Hirschman Index for partner types
Knowledge stock	Number of green patents granted by the enterprise prior to year t
Knowledge breadth	The number of IPC four-digit classification codes included in the green patents granted by the enterprise in t-5 to t-1 year
R&D age	The time span from the year of the enterprise's first application for a green patent to year t
Enterprise type	Whether the enterprise is a parent enterprise or subsidiary

4.2.4 Control variables

Various factors influence enterprise innovation performance, including the quality of innovation elements, industry organization, industry agglomeration level, industry innovation orientation, and technological factors. However, the impacts of factors such as policies, funding, technological advantages, and technological opportunities on enterprise innovation performance can be effectively controlled by enterprise characteristics, technological factors, and environmental factors (Leiponen, 2008). Hence, this study includes four control variables, namely, knowledge stock, knowledge breadth, R&D age, and enterprise type.

Knowledge stock. Accumulated knowledge is crucial for the success of an enterprise's innovation performance. Therefore, it is essential to consider the knowledge created in previous periods when investigating the impact of factors on innovation performance. In this study, we adopt the number of green patents granted to the enterprise in the year t-1 as a proxy for the knowledge stock of the enterprise. The number of green patents granted indicates the extent to which the enterprise has accumulated knowledge related to green technologies and can be used as a control variable to capture the enterprise's existing innovation performance.

Knowledge breadth. The knowledge breadth of an enterprise reflects its diversity of knowledge and has a positive impact on its innovation performance (Li et al., 2021). To measure knowledge breadth, we count the number of technical fields involved in the enterprise's innovation activities. Specifically, we calculate the total number of four-digit IPC codes included in the green patents authorized by the focal enterprise in the 5 years preceding the observation period (t-5 ~ t-1). This approach aligns with previous research by Zhang and Liu (2021) and enables us to capture the diversity of technical knowledge domains in which the enterprise has been active.

R&D age. The age of an enterprise's R&D activities reflects the accumulated knowledge in the field and indicates the enterprise's technological capabilities, which can impact its innovation performance. Thus, we measure R&D age by using the year of the enterprise's first green patent application as its year of entry into the field and calculate the number of years from the year of entry to the current year t as a measure of R&D age.

Enterprise type. To classify enterprises based on ownership structure, we distinguish between parent enterprises and subsidiaries by utilizing data from industrial and commercial records.

The measurement methods for all research variables are summarized in Table 1.

4.3 Empirical research methods

The aim of this study is to establish inter-organizational collaborative innovation networks for enterprises from 2000 to 2015. The network data of 12 periods were analyzed using a rolling 5-year time window and econometric methods. Upon observing the characteristics of the final sample data, we found that the dependent variable is the total number of granted patent applications for enterprises in year t, which belongs to count data. Therefore, simple linear regression models cannot be used for simulation, and Poisson regression models or negative binomial regression models should be used instead. Poisson regression models require that the variance of the variable be equal to the expected value, while negative binomial regression models are more suitable when the count data exhibits over-dispersion. In the sample data, the expected value of the dependent variable is 20.74, and the variance is 95.30, indicating over-dispersed distribution characteristics. Furthermore, the applicability of the two models was judged by alpha testing, and the result showed that the alpha test value is significant, indicating that the negative binomial regression model should be used. When analyzing panel data, it is necessary to consider whether to choose a fixed-effect or a random-effect model. Based on the Hausman test results ($p = 0.00$), the null hypothesis is rejected. Therefore, a fixed-effect negative binomial regression model is selected for analysis.

5 Empirical results and analysis

5.1 Descriptive statistical analysis

This study utilizes STATA 16.0 as the analytical tool to analyze the data. Table 2 presents the descriptive statistics for all variables, including their means, standard deviations, Pearson correlation coefficients, and variance inflation factors (VIF). The results of the descriptive statistics for all variables indicate that the mean value of green innovation performance is 20.74, while the mean value of structural embeddedness in the collaborative network is 0.5, suggesting a moderate degree of structural embeddedness among enterprises. The mean value of relational embeddedness is 6.91, indicating that enterprises tend to engage in repeated collaborative innovation with the same partners based on their relationship capital. The mean value of network experience is 0.95, indicating that enterprises have relatively few long-term partners engaged in continuous R&D. The mean value of partner diversity is 0.18, suggesting that enterprises tend to collaborate with a single type of partner in innovation activities. The average value of knowledge stock is 78.49, with a standard deviation of 341.2, and normalization is adopted to standardize the measurement units. The mean value of knowledge breadth is 10.98, indicating that enterprises are involved in a wide range of technological innovation areas. The mean R&D age is 6 years, suggesting that focal enterprises that establish collaborative networks have some level of green innovation experience. The mean value of enterprise type is 0.82, indicating that enterprises prefer to conduct patent R&D as a parent enterprise. Moreover, the correlation coefficients between all variables showed that there is no serious multicollinearity problem among the independent variable (all correlation coefficients are less than 0.8). Therefore, it is reasonable to include all variables in the regression equation. Furthermore, the maximum VIF value for the variable is 2.30, which is much less than 10, indicating that there is no collinearity problem among variables.

5.2 Regression results analysis

This study examines the effects of structural embeddedness and relational embeddedness on enterprise green innovation

TABLE 2 Descriptive statistics and correlation analysis results.

Variable	Mean	Std	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	VIF
(1) Green innovation performance	20.74	95.30	1									-
(2) Structural embeddedness	0.50	0.35	0.16	1								1.72
(3) Relational embeddedness	6.91	13.18	0.01	−0.38	1							1.33
(4) Network experience	0.95	2.75	0.35	0.25	−0.04	1						1.74
(5) Partner diversity	0.18	0.21	0.06	0.45	−0.21	0.12	1					1.27
(6) Knowledge stock	78.49	341.2	0.77	0.13	0.09	0.55	0.06	1				2.14
(7) Knowledge breadth	10.98	11.47	0.66	0.28	0.15	0.52	0.13	0.68	1			2.30
(8) R&D age	6.39	4.37	−0.02	−0.23	0.01	0.04	−0.18	−0.04	0.03	1		1.31
(9) Enterprise type	0.82	0.38	0.17	0.17	0.08	0.45	0.09	0.32	0.37	0.01	1	1.12

TABLE 3 Regression results of the direct effects on enterprise green innovation performance.

	Model 1	Model 2	Model 3	Model 4
Structural embeddedness		0.797***		0.499***
		(0.110)		(0.119)
Relational embeddedness			−0.012***	−0.010***
			(0.002)	(0.002)
Knowledge stock	−0.175	−0.023	−0.866	−0.596
	(0.444)	(0.422)	(0.445)	(0.436)
Knowledge breadth	0.014***	0.012***	0.020***	0.017***
	(0.003)	(0.003)	(0.003)	(0.003)
R&D age	0.027***	0.011	0.025**	0.015
	(0.008)	(0.008)	(0.008)	(0.008)
Enterprise type	−0.594***	−0.393**	−0.404***	−0.334**
	(0.120)	(0.121)	(0.117)	(0.119)
Constant	0.680***	0.221	0.615***	0.358**
	(0.114)	(0.131)	(0.111)	(0.128)
Wald χ^2	135.772***	205.367***	240.534***	260.281***
Log-likelihood	−5,255.677	−5,228.150	−5,219.716	−5,210.727
Sample size	2,368	2,368	2,368	2,368

Notes: Standard errors are shown in parentheses; * denotes $p < 0.05$, ** denotes $p < 0.01$, *** denotes $p < 0.001$.

performance in collaborative networks. Furthermore, moderating variables such as network experience and partner diversity are introduced to explore whether they have a moderating effect on the relationship between network embeddedness and enterprise green innovation performance.

5.2.1 Direct effects testing

Table 3 presents the empirical results regarding the impact of collaborative network embeddedness on enterprise green innovation performance. Model 1 considers the impact of all control variable on enterprise green innovation performance. Model 2 and Model 3 add the variables of structural embeddedness and relational embeddedness in the collaborative network to access their direct effects on enterprise green innovation performance, respectively. Model 4 represents the comprehensive model of the entire regression analysis.

Model 2 shows that structural embeddedness has a significant direct effect on enterprise green innovation performance ($\beta = 0.797, p < 0.001$), which supports **H1**. This indicates that occupying more structural holes in the collaborative innovation network enables enterprises to obtain non-redundant innovation resources from a range of heterogeneous sources, thus achieving cross-disciplinary integration of multiple knowledge domains and promoting enterprise green innovation performance. In Model 3, it is revealed that relational embeddedness also has a significant negative impact on enterprise green innovation performance ($\beta = -0.012, p < 0.001$), which supports **H2**. This indicates that strong relational embeddedness is generally composed of collaborating partners with similar knowledge backgrounds and familiarity, which restricts the flow of heterogeneous resources in the network and leads to redundancy of knowledge in the network. Enterprises with low relational embeddedness can avoid "cognitive lock-in" caused by "relational lock-in", and are more likely to acquire new knowledge from new partner relationships, which is consistent with the view of Hansen (1999) and Yang et al. (2013).

The results of comprehensive Model 4 confirm the stability of the significant positive correlation between structural embeddedness in the collaborative innovation network and enterprise green innovation performance ($\beta = 0.449, p < 0.001$), as well as the significant negative correlation between relational embeddedness and enterprise green innovation performance ($\beta = -0.010, p < 0.001$). The coefficients in Model 4 have changed compared to Model 2 and Model 3, but their significance remains unchanged, suggesting that both structural embeddedness and relational embeddedness have a direct impact on enterprise green innovation performance, **H1** and **H2** remain valid. Furthermore, the impact of knowledge breadth on enterprise green innovation performance is significantly positive in these four models, indicating that enterprises with greater knowledge breadth have better green innovation performance. However, the impact of enterprise type is significantly negative, indicating that subsidiary are more inclined to collaborate on green technology innovation R&D.

5.2.2 Moderating effect testing

The moderating effect analysis aimed to investigate the moderating roles of network experience and partner diversity in the relationship between network embeddedness and enterprise

TABLE 4 Regression results of the moderating effects of network experience.

	Model 5	Model 6	Model 7	Model 8
Structural embeddedness	0.548***	0.782***		0.515***
	(0.119)	(0.108)		(0.116)
Relational embeddedness	−0.009***		−0.013***	−0.010***
	(0.002)		(0.002)	(0.002)
Network experience	0.035***	0.119***	0.055***	0.118***
	(0.006)	(0.013)	(0.007)	(0.013)
Structural embeddedness × Network experience		−0.198***		−0.174***
		(0.030)		(0.032)
Relational embeddedness × Network experience			0.006***	0.003**
			(0.001)	(0.001)
Knowledge stock	−0.833*	−0.101	−1.258**	−0.646
	(0.387)	(0.391)	(0.391)	(0.398)
Knowledge breadth	0.014***	0.011***	0.018***	0.016***
	(0.003)	(0.003)	(0.003)	(0.003)
R&D age	−0.002	−0.013	0.008	−0.008
	(0.008)	(0.009)	(0.008)	(0.009)
Enterprise type	−0.317**	−0.356**	−0.399***	−0.314**
	(0.119)	(0.123)	(0.118)	(0.120)
Constant	0.681***	0.836***	0.684***	0.762***
	(0.115)	(0.117)	(0.115)	(0.117)
Wald χ^2	322.782***	314.227***	312.716***	361.673***
Log-likelihood	−5,193.679	−5,186.935	−5,192.463	−5,168.260
Sample size	2,368	2,368	2,368	2,368

Notes: Standard errors are shown in parentheses; * denotes $p < 0.05$, ** denotes $p < 0.01$, *** denotes $p < 0.001$.

green innovation performance. To avoid multicollinearity issues, all independent and moderating variables were centered before creating the interaction terms.

(1) Moderating effect of network experience

This study examined the moderating effect of network experience on the relationship between network embeddedness and enterprise green innovation performance. The regression results are presented in Table 4, where Model 5 adds the moderating variable of network experience to Model 4. Model 6 and Model 7 add the moderating variable of network experience and its interaction term with independent variable to Models 2 and Model 3, respectively. Model 8 is the comprehensive model with complete interaction terms. Model 6 shows that structural embeddedness enhances enterprise green innovation performance ($\beta = 0.782, p < 0.001$), and the coefficient of the interaction term between structural embeddedness and network experience is significantly negative ($\beta = -0.198, p < 0.001$). This indicates that enterprises with abundant network experience play a negative moderating role in the relationship between structural embeddedness and enterprise green innovation performance, thus supporting **H3a**. Results from Model 7 reveal that relational embeddedness reduces enterprise green innovation performance ($\beta = -0.013, p < 0.001$), the coefficient of the interaction term between relational embeddedness and network experience is significantly positive ($\beta = 0.006$; $p < 0.001$), suggesting that enterprises with abundant network experience positively moderate the relationship between relational embeddedness and enterprise green innovation performance, thus supporting **H3b**. The results of the comprehensive Model 8 confirm that network experience has a moderating effect on the relationship between network embeddedness and enterprise green innovation performance, supporting both **H3a** and **H3b** as well.

Based on the above analysis, we believe that network experience can weaken the positive effect of network embeddedness on

TABLE 5 Regression results of the moderating effect of partner diversity.

	Model 9	Model 10	Model 11	Model 12
Structural embeddedness	0.698***	1.111***		0.832***
	(0.126)	(0.126)		(0.134)
Relational embeddedness	−0.010***		−0.016***	−0.009*
	(0.002)		(0.004)	(0.004)
Partner diversity	−0.728***	−0.820***	−0.231	−0.879***
	(0.148)	(0.164)	(0.139)	(0.166)
Structural embeddedness × Partner diversity		1.499**		1.754**
		(0.523)		(0.535)
Relational embeddedness × Partner diversity			−0.029	0.011
			(0.021)	(0.019)
Knowledge stock	−0.860*	−0.038	−2.119***	−0.628
	(0.436)	(0.422)	(0.450)	(0.432)
Knowledge breadth	0.018***	0.012***	0.029***	0.017***
	(0.003)	(0.003)	(0.002)	(0.003)
R&D age	0.016*	0.011	0.034***	0.015
	(0.008)	(0.008)	(0.007)	(0.008)
Enterprise type	−0.389**	−0.414***	−0.580***	−0.354**
	(0.120)	(0.123)	(0.081)	(0.121)
Constant	0.585***	0.612***	0.442***	0.529***
	(0.113)	(0.117)	(0.092)	(0.116)
Wald χ^2	284.834***	230.404***	480.395***	293.224***
Log-likelihood	−5,198.554	−5,214.053	−5,247.618	−5,193.019
Sample size	2,368	2,368	2,638	2,368

Notes: Standard errors are shown in parentheses; * denotes $p < 0.05$, ** denotes $p < 0.01$, *** denotes $p < 0.001$.

enterprise green innovation performance. Hoppmann et al. (2019) found that network inertia increases the likelihood of recurrent connections between focal enterprises and their existing partners. The negative moderating effect of network experience on the relationship between network embeddedness and enterprise green innovation performance may stem from network inertia, which weakens an enterprise's network influence. When a focal enterprise establishes more and longer collaborative relationships with a stable set of partners, its structural embeddedness autonomy is constrained, and the enterprise becomes part of a highly closed network that limits the diffusion of knowledge within the network. Furthermore, the enterprise has high relational embeddedness, which indicates that it has established frequent and deep repeated contacts in the collaborative network, thus reducing collaboration with other network partners. The interplay between stability and repetition restricts the flexibility of the enterprise, and network connections based on strong relationships generate more demand for green innovation, thereby limiting the external network effects of the enterprise and hindering the development of its knowledge influence.

(2) Moderating effect of partner diversity

This study also examined the moderating effect of partner diversity on the relationship between network embeddedness and enterprise green innovation performance, and the regression results are shown in Table 5. Model 9 adds the moderating variable of partner diversity to Model 4, while Model 10 and Model 11 add the moderating variable of partner diversity and its interaction term with the independent variable to Model 2 and Model 3, respectively. Model 12 is the comprehensive model with complete interaction terms. The results of Model 10 show that structural embeddedness enhances enterprise green innovation performance ($\beta = 1.111, p < 0.001$) and the coefficient of the interaction term with the moderating variable is significantly positive ($\beta = 1.499, p < 0.001$), indicating that enterprises with high partner diversity positively moderate the relationship between structural embeddedness and enterprise green innovation performance, thus supporting **H4a**. The results of Model 11 reveal that relational embeddedness weakens enterprise green innovation performance ($\beta = -0.016, p < 0.001$), and the coefficient of the interaction term with partner diversity is negative but not significant

TABLE 6 Robustness test of a random-effect negative binomial regression model.

	Model 13	Model 14	Model 15	Model 16
Structural embeddedness		1.005***	0.911***	1.287***
		(0.098)	(0.096)	(0.110)
Relational embeddedness		−0.005**	−0.005**	−0.003
		(0.002)	(0.002)	(0.003)
Network experience			0.120***	
			(0.012)	
Partner diversity				−0.708***
				(0.144)
Structural embeddedness × Network experience			−0.217***	
			(0.030)	
Relational embeddedness × Network experience			0.002*	
			(0.001)	
Structural embeddedness × Partner diversity				1.866***
				(0.472)
Relational embeddedness × Partner diversity				0.016
				(0.017)
Knowledge stock	−1.569***	−1.570***	−1.336***	−1.450***
	(0.455)	(0.422)	(0.399)	(0.415)
Knowledge breadth	0.025***	0.024***	0.022***	0.023***
	(0.003)	(0.002)	(0.002)	(0.002)
R&D age	0.034***	0.017*	0.002	0.018**
	(0.007)	(0.007)	(0.007)	(0.007)
Enterprise type	−0.664***	−0.352***	−0.348***	−0.362***
	(0.079)	(0.078)	(0.079)	(0.079)
Constant	0.511***	0.358***	0.558***	0.343***
	(0.092)	(0.089)	(0.093)	(0.092)
Wald χ^2	349.699***	612.482***	720.710***	649.061***
Log-likelihood	−8,285.055	−8,196.989	−8,152.935	−8,179.287
Sample size	2,638	2,638	2,638	2,638

Notes: Standard errors are shown in parentheses; * denotes $p < 0.05$, ** denotes $p < 0.01$, *** denotes $p < 0.001$.

($\beta = -0.029$, $p > 0.05$), suggesting that the influence of partner diversity on the relationship between relational embeddedness and enterprise green innovation performance is not significant, which contradicts **H4b**. Since relational embeddedness measures the strength of the relationships between focal enterprises and their partners, the "weak tie" theory suggests that the strong embedding characteristics are composed of members with similar knowledge backgrounds, which suppress the generation of heterogeneous resources in the network. In contrast, high partner diversity contributes to the diversity of information in the network, which is opposite to the "weak tie" theory. Therefore, the interaction term between the two cannot determine their role in the relationship between relational embeddedness and enterprise green innovation performance, resulting in insignificant results. The results of the comprehensive Model 12 confirm that partner diversity has a moderating effect on the relationship between structural embeddedness and enterprise green innovation performance, while there is no moderating effect in the relationship between relational embeddedness and enterprise green innovation performance, which supports **H4a** and contradicts **H4b**.

In summary, we believe that partner diversity can facilitate the moderating effect of structural embeddedness on green innovation performance. Hagedoorn et al. (2018) demonstrated that different types of partners possess unique information, skills, and experience. When a focal enterprise collaborates with a variety of partner types, it can obtain heterogeneous resources from the outside organization. Additionally, Yin and Shao (2017) based on the resource-based theory, argued that low partner type diversity indicates high technological similarity between partners, and it is difficult to achieve breakthrough innovation results in the same field, leading to relatively low innovation performance of the enterprise. Therefore, partner diversity from the perspective of network granularity, not only considers the positional characteristics of the focal enterprise in the collaborative network, but also takes into account the characteristics of partner types, which helps the focal enterprise restructure and integrate complementary knowledge both internally and externally, thereby promoting green innovation performance. To summarize, partner diversity has a moderating effect on the relationship between structural embeddedness and enterprise green innovation performance, the moderating effect of partner diversity in the relationship between relational embeddedness and enterprise green innovation performance is not significant.

5.3 Robustness test

To ensure the reliability of our research findings, we implement the following measures: 1) we introduce a one-period lag in the dependent variable to minimize endogeneity issues resulting from causal relationships; 2) we utilize a random-effect negative binomial model, as presented in Table 6; 3) we adjust the dependent variable's time horizon to 2 years covering the period from t to t+1, to represent the number of authorized patent applications; 4) we adopt the total number of citations received by enterprise-related patents within 5 years as the dependent variable; 5) we remove all control variables. These measures are implemented to ensure the robustness of our results. It found that the regression results do not significantly change after implementing these measures, indicating that our findings are reliable and robust.

Table 6 presents the results of the robustness tests conducted using a random-effect negative binomial regression model. Model 13 examines the impact of all control variables on enterprise green innovation performance, while Model 14 investigates the direct effects of the variables of structural embeddedness and relational embeddedness on enterprise green innovation performance. Model 15 and Model 16 introduce the moderating variables of network experience and partner diversity, respectively, along with the interaction terms between moderating variables and independent variables, to analyze the moderating effects of the moderating variables on the relationship between network embedding and enterprise green innovation performance. The results obtain using a random-effect is consistent with those obtained using a fixed-effect regarding the direction and significance of the correlation coefficients, with only slight variations in the magnitude of the coefficients. The results of the stability test are satisfactory.

6 Conclusion

6.1 Research conclusions

As market competition becomes increasingly fierce, whether enterprises can obtain heterogeneous resources from external collaborations and improve their innovation performance has become a research hotspot in academia. Hence, this study constructs a theoretical model to examine the impact of network embeddedness, network experience, and partner diversity in Chinese collaborative networks on enterprise green innovation performance. The theoretical model considers the effect of embeddedness on enterprise green innovation performance from two dimensions: structural embeddedness and relational embeddedness, and further examines the moderating effects of network experience and partner diversity. To test the model, Chinese green patents jointly invented between 2000 and 2015 were analyzed, and network characteristic variables were calculated using social network analysis methods, which provides more objective and effective data for this study. Furthermore, through empirical analysis can aid in exploring the impact of collaborative R&D on the innovation performance of enterprise It is a worthwhile issue to explore how enterprises can obtain the greatest utility and improve green innovation performance from their collaborative relationships. The research findings of this study are presented as follows:

(1) Structural embeddedness has a positive effect on enterprise green innovation performance. It implies that enterprises with greater structural holes in the collaborative network are able to access more heterogeneous sources, this finding is consistent with Granovetter (1992). By collaborating with more partners, enterprises can obtain non-redundant innovation resources in the network. In addition, enterprises with greater structural holes can avoid the "cognitive trap" by gaining access to new technologies and knowledge that differ significantly from their existing knowledge (Contino et al., 2017). Through the integration of internal and external knowledge, these enterprises can enhance their innovation performance.

(2) Relational embeddedness has a negative effect on enterprise green innovation performance. This finding suggests that in the context of green innovation, enterprises tend to engage in repeat collaborations with their existing partners to save on search and selection costs, and to establish long-term trust relationships. However, this strong relational embeddedness may limit access to heterogeneous resources in the collaborative network, leading to resource redundancy. Conversely, enterprises with lower levels of relational embeddedness are less likely to experience "relationship lock-in" and "cognitive lock-in" (Hansen, 1999). They are more likely to acquire new resources from new partner relationships, which ultimately contributes to enhancing their green innovation performance.

(3) Network experience plays a moderating role in the relationship between network embeddedness and enterprise green innovation performance. Specifically, the study finds that network experience has a negative moderating effect on the relationship between structural embeddedness and enterprise green innovation performance, and a positive moderating effect on the relationship between relational embeddedness and enterprise green innovation performance. In general, network experience weakens the positive effect of network embeddedness on enterprise green innovation performance. This suggests that network experience can lead to

collaborative inertia and skill rigidity, causing enterprises to establish repetitive collaborations with existing partners and reducing their influence in the network. In the green innovation field, enterprises are inclined to spend more time building and maintaining strong relationships with existing partners. This approach can save search and selection costs, deepen understanding of partners, and improve collaborative stability and sustainability, this view is consistent with Hoenig and Henkel (2015). However, It can also result in enterprises being embedded in highly closed collaborative networks, limiting the flow of knowledge within the network and exploration of external collaborative opportunities, which can ultimately affect enterprise green innovation performance.

(4) Partner diversity positively moderates the relationship between structural embeddedness and enterprise green innovation performance, but it does not moderate the relationship between relational embeddedness and enterprise green innovation performance. Collaborative networks typically consider the position structure and relational strength of the enterprise in the network, rather than finely differentiating the types of partners involved. However, different types of partners possess unique heterogeneous resources. By collaborating with partners of multiple types in R&D, the focal enterprise can obtain more diverse external resources (Hagedoorn et al., 2018). This enables the enterprise to overcome its "technological trajectory trap", positively moderating the relationship between structural embeddedness and enterprise green innovation performance. However, the "weak ties" theory suggests that strong relational embeddedness may inhibit enterprises' absorption of heterogeneous information, which contradicts the findings on partner diversity. Therefore, the interaction term does not moderate the relationship between relational embeddedness and enterprise green innovation performance.

6.2 Managerial implications

In the context of promoting the development of green economy, facilitating the green transformation of SMEs through technological innovation can enable a sustainable and coordinated development between enterprise competitiveness and environmental protection. In today's increasingly competitive market environment, relying solely on internal resources is no longer sufficient for enterprises to meet market demands. To remain competitive, enterprises need to adopt a more open-minded approach and leverage external resources to obtain innovative resources. By promoting the flow of knowledge among organizations, internal and external resources can be integrated and leveraged to enhance the green innovation performance of enterprises (Li and Xiao, 2020). Based on the above background, this study aims to investigate the influence of collaborative innovation networks on enterprise green innovation performance, with the objective of providing some management insights for enterprises.

Firstly, network embeddedness plays a significant role in enhancing enterprise green innovation performance. Therefore, it is recommended that enterprises actively construct external social networks centered on themselves, fully leverage their subjective initiative, and systematically build a collaborative network that aligns with their development needs and goals. To fully exploit the potential of network embeddedness, enterprise should consider adjusting their structural embeddedness and relational embeddedness. Specifically, 1) in the collaborative innovation network, enterprises should aim to occupy a more central position, which can help them control the flow of effective information and resources, gain more innovative opportunities, and gradually establish their competitive advantages in the network; 2) enterprises should strengthen their emotional ties with their collaborative partners and appropriately expand the network scale to ensure the acquisition of more heterogeneous resources.

Secondly, it is important to maintain an appropriate level of relational embeddedness with collaborative partners. In uncertain environments, enterprises tend to seek out partners in the innovation network to acquire heterogeneous information, which can be absorbed and transformed into the enterprise's internal competitiveness. As partners interact and establish trust, it promotes resource interaction and information sharing between organizations and disperses the risks of failure as well. However, high levels of trust can lead to self-interested behavior that harms the interests of collaborating organizations. Excessive sharing of information can also impede the entry of new knowledge, and the enterprise may not be able to obtain more diverse information. There is an optimal point for an enterprise's embedding in the external network, beyond which the "embedding paradox" occurs and may affect the enterprise's green innovation performance (Yan et al., 2019). Therefore, it is necessary to selectively establish the most suitable network relationships based on the enterprise's characteristics, resources, and capabilities.

Thirdly, enterprises should correctly treat their network experience. Network experience is a double-edged sword. On one hand, enterprises can utilize their existing partnerships to establish long-term relationships built on trust. On the other hand, such experience can lead to the formation of network inertia. When meeting new partners, it may cause insufficient flexibility and adaptability, which is not conducive to exploring new opportunities and knowledge. To overcome this issue, enterprises should learn to apply what they have learned from previous collaborations, accumulate heterogeneous knowledge in each partnership, and convert it into their own skills in a timely manner to better manage and acquire knowledge. This helps enterprises improve their network status and core competitiveness by enabling them to remain flexible and adaptive to changes in the external environment.

Fourthly, it is essential for enterprises to consciously establish collaborative relationships with partners of different types in order to acquire and utilize heterogeneous resources that can enhance their resource integration efficiency and improve their innovation performance. However, it should be noted that partner diversity is not always beneficial, as excessive diversity can lead to uncertainty and increased costs for resource integration, utilization, and management. Therefore, enterprises should selectively establish collaborative relationships with network partners based on their own network characteristics, and keep partner diversity at an appropriate level.

Despite the contribution of this study, there are still several limitations that need to be addressed in future research. 1) This study only examined the impact of network embeddedness on enterprise green innovation performance and the moderating effect of network experience and partner diversity, while other potentially moderating and mediating variables are not considered, such as the variable of knowledge diffusion (Kim and Park, 2009). Thus, future research should explore additional variables to gain a more comprehensive understanding of the relationship between network embeddedness and enterprise green innovation performance. 2) This study used patents as the sole indicator of enterprise collaboration, but in practice, enterprise collaboration may take many other forms such as alliances, acquisitions, and mergers (Benhayoun et al., 2020). Therefore, when building a collaborative innovation network, it is necessary to consider these diverse forms of inter-enterprise collaboration to enhance enterprise innovation. 3) The network structures and relationships in which enterprises are embedded are subject to constant change. This study does not investigate how changes may affect enterprise green innovation performance. Hence, future research should deep analyze this issue as well.

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

XpL and XmL computed the results; XpL wrote the original draft; XmL wrote the review draft; XpL performed modeling; XmL contributed to conceptualization; XpL and XmL performed validation. All authors contributed to the article and approved the submitted version.

Conflict of interest

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

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