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Green innovation output in the supply chain network with environmental information disclosure: An empirical analysis of Chinese listed firms

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ABSTRACT

Supply chain networks affect the ability of firms to obtain resources, and to meet the requirements of sustainable development, firms further seek green innovation from supply chain networks. Based on this context, we construct a supply chain network system, explore the influence of supply chain network power and network cohesion on corporate green innovation output, and discuss the potential moderating effect of corporate environmental information disclosure. We use an empirical sample comprising 1048 A-share listed firms in China from 2012 to 2019 to construct a supply chain network for focal firms. We also develop the focal firms' environmental information disclosure index via the environmental information revealed in the firms' annual and corporate social responsibility reports. Negative binomial model regression is adopted to analyse how supply chain network structures affect green innovation output. Our results show that both the network power and cohesion of the supply chain network positively influence corporate green innovation output, but the interaction of network power and cohesion negatively affects corporate green innovation, which suggests that excessive green knowledge and information can overload focal firms and reduce the efficiency of knowledge and information search. Furthermore, the empirical results indicate that environmental information disclosure positively moderates the relationship between network power and green innovation output as well as that between network cohesion and green innovation output. By analysing the factors influencing corporate green innovation output from a network perspective, we provide new guidance for sustainable corporate development.

1. Introduction

Green innovation connotes a series of innovative activities based on environmental friendliness and sustainable development (Huang and Chen, 2022). Chan et al. (2016) show that green innovation can bring profitability to firms, and it is a key competency for their competitiveness, as well as solutions to environmental and resource consumption problems in production. Firms engage in green innovation, on the one hand, to alleviate ecological pressures, while, on the other hand, they expect green market growth (Dangelico &Pujari, 2010). Green innovation has also attracted the attention of governments worldwide during periods of rapid economic growth (Shen et al., 2021). Moreover, Wang et al. (2021) state managers also take into account the interests of the community and environment, when making decisions. Therefore, it is necessary to study corporate green innovation output from its stakeholders' perspective.

Given the importance of green innovation, it is vital to explore the potential factors influencing green innovation. Lenox and Ehrenfeld (1997) state that green innovation capabilities arise from knowledge resources within the firm, external environmental impacts, and coordination and exchange of expertise in technology. A firm's own knowledge resources help discover and create new environmental knowledge through its organisational resources and exploratory activities, which contribute to the development of green innovation (Lenox and Ehrenfeld, 1997). The external environment includes the market, policy, institutional, and financial environments (Farza et al., 2021; Yalabik and Fairchild, 2011). A favourable external environment has a positive impact on firms' green innovation, such as consumers' demand for green

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products (Kammerer, 2009) and environmental regulators' demand for the legality of firms' production. Although the above literatures have discussed the internal and external factors that influence firms' green innovation output, an important branch of the supply chain network structures is overlooked.

Firms do not operate independently but are in a business ecosystem network. Xu et al. (2022) state firms are always constrained in a network of interdependencies with other organisations. Chang et al. (2012) emphases the importance of interaction among firms throughout the business ecosystem. For instance, from the perspective of supply chain, this interaction among firms can be captured as a supply chain network (Wang et al., 2021). The structure of a supply chain network and its structural characteristics describe the topological properties of the interaction, including the types and patterns of relationships between firms, different levels of relationships that arise from supply and delivery processes, and power, leadership, and the impact of these relationships on supply networks (Basol et al., 2018). The globalization of production and the complexities of market competition show that understanding and managing these relationships becomes even more important.

More and more firms improve their competitiveness through complex supply chain networks. Previous research has established that supply chain networks are the primary way through which firms obtain access to resources (Finne et al., 2015). They can bring new knowledge, technology, ideas, and concepts to firms, while generating revenue and bringing organisational advantages (Bellamy et al., 2020). Building high-quality relationships with a firm's supply chain partners is helpful for firms to promote interorganisational learning, knowledge creation, and the development of collaborative capabilities for effective supply chain execution (Basole et al., 2018). Lee and Choi (2021) suggest that supply chain networks can also provide information about the environment, such as investment in emission reduction and carbon emissions. For example, Apple Inc. estimates the carbon footprint of its supply network members and develops policies to achieve its goal to achieve carbon neutrality. Evidently, this is a trend to use supply chain network resources to achieve environmental goals and corporate sustainability in the context of the global quest for environmental friendliness.

Notwithstanding the significance of supply chain networks and green innovation, little is known about the relationship between them. In contrast to innovation in the traditional sense, green innovation focusses on reducing environmental impacts. Previous research has explored the relationship between supply chain networks and corporate innovation performance, which can be divided into the following three categories. First, the supply chain network has a positive relationship with innovation. Bellamy et al. (2014) find that supply network accessibility has a positive impact on innovation, while Potter and Wilhelm (2020) consider a supply network as a catalyst for supplier innovation. Second, the supply chain network has a U-shaped relationship with innovation. Liang and Liu (2018) explain that direct ties have an inverted U-shaped effect on innovation performance in collaborative networks. Third, the supply chain network has a negative relationship with innovation. Sharma et al. (2020) find that spatial complexity is negatively related to innovation performance in a supply network. However, lesser attention has been devoted to the theory of the relationship between supply chain networks and green innovation, and little is known about the impact of supply chain networks and their network structural characteristics on green innovation output, which is a key determinant of sustainable development. Given these gaps in research, developing a better understanding of the relationship between supply chain networks and green innovation output is a priority for scholars.

In addition to these operational networks, firms with different environmental disclosures may generate different green innovation outputs. Li et al. (2022) suggest that the environmental disclosure of individual firms can promote their green innovation output. Specifically, environmental information disclosure (EID) responds to public concerns about the environment, and when firms disclose environmental information, they are subject to external pressure from the public, government, and other stakeholders. The negative impact of EID can be eliminated when the firm meets the public's sustainable development goals through green innovation. Therefore, when considering the impact of the structural characteristics of supply chain networks on green innovation output, corporate EID should not be ignored. Based on the gaps in the existing research, we propose the following research questions:

Q1. How do the structural characteristics of the supply chain network affect the output of green innovation?

Q2. What is the role of EID on the relationship between the structural characteristics of supply chain networks and green innovation output?

To answer these questions, we adopt social capital theory to capture the ability of a firm's supply chain network to access organisational resources. Specifically, we describe the supply chain network structure from two aspects: (1) network power, which indicates the ability of the focal firm in the supply chain network to dominate and control other firms; and (2) network cohesion, which indicates the closeness of the links between firms in the supply chain network.

To comprehensively explore the impact of supply chain network structures on the green innovation output of firms, we construct a large supply chain network via two main steps: (1) obtaining the supply relationships of listed firms, and (2) constructing a supply chain network based on the obtained information. In the first step, as Chinese listed firms establish extensive partnerships with external parties, we collect data from A-share listed firms in China from 2012 to 2019 and obtain information of their suppliers and customers. In the second step, we use Ucinte software to construct the supply chain network and calculate the network structure characteristics. In addition, we also develop an EID score using both corporate annual and social responsibility reports. Finally, we use negative binomial regression to test the hypothesis and explore its potential impact. The empirical results indicate that both supply chain network power and network cohesion are sources of green knowledge and information, which positively influence focal firms' green innovation output. However, the interaction between network power and network cohesion has a negative effect on green innovation output. In addition, EID positively moderates the relationship between the supply chain network structure and green innovation output.

We contribute to the green innovation stream of the supply chain network community by examining the corporate supply chain network structure as a source of green innovation in the following ways. First, the existing literature mainly discusses the factors of green innovation from the perspectives of environmental regulation, economic growth target constraints and financial innovation (Shen et al., 2021; Huang and Chen, 2022; Yuan et al., 2021). We extend the influencing factors of green innovation output by using empirical evidence from a supply chain network perspective, filling the gap in the positive impact of the structural characteristics of the supply chain network on the corporate green innovation output, which responds to the call for more attention to green innovation. Second, our study is the first to provide a different understanding of supply chain networks and theoretically explain how they affect green innovation output. Different from the existing research on the promotion of innovation by the supply chain network structure (Bellamy et al., 2014), we find that the large amount of knowledge and information brought by the supply chain network may cause information overload and inhibit green innovation output. Our empirical evidence supports this view by demonstrating that the interaction between network power and network cohesion negatively affects green innovation output, which add to the supply chain network literature. Third, this study explores the additional factors that affect firms' green innovation output. Specifically, higher levels of EID can facilitate the relationship between supply chain networks and green innovation output, thus extending the literature by examining how the supply chain network structure and a firm's EID jointly form the green innovation output of

Chinese listed firms, which extends Li et al.'s (2022) view of EID and provides a valuable reference for sustainable development.

The remainder of this paper is organised as follows: in Section 2, we discuss the relevant literature on green innovation, supply chain networks, and EID and develop the potential hypotheses. Section 3 details the methodology, and Section 4 presents our empirical analysis and results. We present our findings, including implications for theoretical and management practices, in Section 5. Section 6 summarises the study and proposes future research directions.

2. Theoretical background and hypothesis development

Supply chain networks are network-based structures consisting of manufacturers, suppliers, customers, and other partners (Bellamy et al., 2014), unlike the traditional linear structure between buyers and suppliers (Kim et al., 2011). Compared to the direct observation of buyer–seller interactions under a linear structure, network structures are more biased towards the firm's interaction with its network partner links that better reflect the complexity of firm behaviour and resource dependence in the supply chains. As Drees and Heugens (2013) suggest, relationships between firms are interdependent to the extent that organisations are heavily dependent on the critical resources provided by other organisations. In addition, supply chain networks can dynamically represent the interrelationships among organisational members within the supply chain system (Basole et al., 2018).

Social capital is a collection of resources embedded, available, and derived in the network of relationships held by an individual or organisation (Inkpen et al., 2005). For example, social capital has two main characteristics: (1) it is embedded in a social network, and (2) it is a resource that can be used. In other words, social capital is inseparable from social networks (Yu, 2013). Social capital theory is often applied in the study of societies and organisations. In social networks, social capital has communal properties, and firms can use the capital (resources) in the organisational network relationships (Inkpen et al., 2005) to achieve organisational advantage. That is, the core principle of this theory is that firms are embedded in larger network relationships and firms have access to unique resources, information, and influence (Basole et al., 2018).

Social capital usually includes relational, cognitive, and structural dimensions: (1) The relational dimension refers to trust and close interaction between the organisation and its partners in the network (Tsai and Ghoshal, 1998). This is beneficial to a firm's performance and competitiveness (Ahuja, 2000). (2) The cognitive dimension connotes the shared goals and vision among the members of the organisation that facilitate increased rewards for organisational members (Nahapiet and Ghoshal, 1998). (3) The structural dimension focusses on the overall pattern of connections and communications between firms. The proliferation of network structures from firms' ties provides a certain degree of access and limited resources and information that may not be available to competitors (Burt, 2001). Configurational elements such as hierarchy, density, and connectivity influence the flexibility and ease of knowledge exchange by affecting the degree of connection and accessibility among network members. Yli-Renko et al. (2001) emphasise that the benefits of social capital are derived from the characteristics of a firm's position in the network.

Pervious scholars have studied how network capabilities affect a firm's performance based on social capital theory. Basole et al. (2018) argue that networks are an important source of resources and a source of trust, and that network relationships affect the level of trust, which positively affects firm performance. Bellamy et al. (2014) argue that the benefits derived from access to knowledge, resources and information available in relational networks can lead to organisational advantages. Yu (2013) argue that more attention should be paid to network composition when studying the benefits of social capital. Thus, existing researches suggest that social capital theory provides a theoretical basis for analysing how network structure affects green innovation output.

2.1. Supply chain network as a source of green innovation

Green innovation refers to the development of environmentally friendly products or processes, including the use of green raw materials, adherence to ecological product design, reduction of material use, reduction of pollutant emissions, and reduction in the consumption of resources, such as water and electricity (Gunasekaran and Spalanzani, 2012).

Dangelico (2016) suggests that green innovation is affected by the establishment of collaborative networks within and outside the firm and the enhancement of knowledge and information flows. Suppliers, customers, and other partners with whom the firm does business further contribute to green innovation by sharing green resources, green knowledge learning, and information transfer through the supply chain (Song et al., 2020). For example, suppliers can provide firms with relevant green technologies, environmentally friendly production materials, and solutions that can reduce the environmental impact during the production process, whereas customers are sources of information on environmentally friendly products and environmental product requirements (Dangelico et al., 2013). Lenox and Ehrenfeld (1997) suggest that the diversity of knowledge resources encourages organisations to generate solutions to potential problems and that supply chain networks are a source of diverse knowledge. In conclusion, through supply chain networks, firms can fill in their capabilities to access green-related knowledge and information, and thus achieve green innovation.

From a structural dimension perspective, Burt (2001) states that the benefits of social capital are derived from the firm's position in the network. For example, supply chain networks are seen as an important source of resources, not only because of supply relationships but also because of the tangible and intangible resources they can bring, such as knowledge. In fact, these resources can also emanate from the supply chain network structure itself; in other words, they come from the firm's position in the network and characteristics of interorganisational relationships (Kim and Choi, 2015; Yli-Renko et al., 2001). Based on this, this research examines the impact of two characteristics of the supply chain network structure, namely, network power and network cohesion (Carnovale et al., 2019), and their interaction items on green innovation output.

2.2. Supply chain network structure and green innovation output

Social networks are composed of nodes and links, where nodes represent entities, individuals, or firms, and links represent one or more links between entities, including collaboration, strategic alliances, marketing agreements, and so on (Wasserman and Faust, 1994). In supply chain networks, nodes represented by suppliers, manufacturers, customers, and other partners are connected through raw material procurement, use, and transformation. From the social capital perspective of the supply chain network, the two-way flow of knowledge and information in the network is not uniform (Burt, 2009). One party may occupy a more dominant position, and this dominance or dominant behaviour is associated with the power of the firm. Firms can use their power to obtain the resources they need from the supply chain network effectively. However, when network efficiency is high, firms can obtain the resources they need using a timely and accurate approach. In a more cohesive supply chain network, firms can increase (expand) their speed (scope) of access to resources (Potter and Wilhelm, 2020), resulting in better performance. In summary, network power and network cohesion are important for resource access; thus, we hypothesise that these two characteristics of the supply chain network have an impact on a firm's green innovation output.

2.2.1. Supply chain network power

Power has long been considered as an important aspect of firm interactions in business networks, and previous research has defined this network power as 'an actor's attempt to use its current position in a multi-actor network to allocate and decouple actors, resources, and activities according to its own interests' (Olsen et al., 2014, p. 2580). That is, network power emphasises that a firm has a significant influence over the entire network by virtue of its position and relationships in the network. We use degree to capture network power because degree measures the number of links to a firm, thereby reflecting the visibility of the firm in the network and the degree of influence a firm has on the operational decisions or strategic behaviours of other firms in the supply chain network (Kim et al., 2011), which is consistent with the connotation of network power. When the focal firm has high network power, it means that the firm has numerous direct contacts in the network, a favourable position, and a strong influence on other firms.

We hypothesise that network power impacts green innovation output for several reasons. First, focal firms are directly connected to more supply chain networks, meaning that knowledge exchange between firms becomes easier. There are more channels for knowledge and information exchange, which enhances the two-way flow of green knowledge and green information among network members. Second, firms with strong network power have stronger capabilities to manage their supply base and enhance their ability to acquire and allocate resources (Kim and Bettis, 2014). The essence of green innovation is green knowledge acquisition and technological advancement. When firms have strong network power, their position allows them to have more power and control over the flow of knowledge in the network (Baum et al., 2010), which promotes the development of green innovation output. Third, given that in supply chain networks, innovativeness occurs more frequently in firms that have more connections with other organisations (Gao et al., 2015), that is, when firms have more network power, they have more connections in the supply chain network, which is regarded as an important prerequisite for firm-level innovation outcomes (Leenders and Dolfsma, 2016), network power can facilitate green knowledge creation and enhance innovation activities by controlling the flow of green knowledge and access to resources. Thus, we propose the following hypothesis:

Hypothesis 1. Network power has a positive effect on green innovation output in a supply chain network.

2.2.2. Supply chain network cohesion

The speed with which firms acquire resources is also very important. Specifically, network cohesion reflects the extent to which firms in a network are linked to each other (Carnovale et al., 2019). To represent this network characteristic, we use closeness centrality to measure network cohesion. Closeness centrality refers to the closeness between a firm and all members of its supply chain network (Freeman, 1979), which is consistent with the connotation of network cohesion. Closeness centrality is generally expressed as the 'distance' between the focal firm and upstream/downstream firms in the network. Firms with high closeness centrality are usually able to acquire resources quickly and efficiently from their partners (Potter and Wilhelm, 2020). That is, when a firm has greater network cohesion, it can obtain the required resources quickly and effectively in the network.

We hypothesise that network cohesion affects firms' green innovation output because the distance between members and focal firms in a supply chain network affects the speed of focal firms' access to resources to some extent (Potter and Wilhelm, 2020). When firms are far away from each other, network cohesion is low, and the focal firm has low efficiency and a small range of access to resources. As the network cohesion of the supply network increases, the focal firm can not only access relevant resources effectively but also obtain more marginal knowledge and information (Fleming et al., 2007), as well as expand its scope of access to resources. Additionally, focal firms can generate stronger network connectivity with other firms (Walker et al., 1997) and enhance the depth of resource exchange. In conclusion, higher network cohesion facilitates firms' transfer of knowledge, acquisition of relevant information, and reduction of information distortion (Kim et al., 2011).

The efficient flow of knowledge and information in supply chain networks has been used to study firms' financial performance, such as improving return on assets and cash turnover (Carnovale et al., 2019). Similarly, firms with high network cohesion can acquire knowledge and information from hard-to-reach networks (Fleming et al., 2007) and create green innovation based on their strengths. Therefore, when the cohesiveness of the supply chain network is higher, firms have more opportunities to acquire new green knowledge and new information or obtain environmental knowledge more quickly and efficiently. Therefore, we propose the following hypothesis:

Hypothesis 2. Network cohesion positively affects green innovation output within a supply chain network.

2.2.3. Interaction between supply chain network power and network cohesion

Network power affects the ability and scope of a focal firm's access to knowledge, while network cohesion affects the speed of a focal firm's access to resources, both of which have the potential to impact green innovation output. We further hypothesise that their interactions will have an impact on the green innovation output of a focal firm. In a supply chain network, if network power helps a firm obtain more green knowledge and information and network cohesion helps it improve the speed of the firm's access to green resources, then the firm can quickly obtain a large amount of green-related knowledge and information, and the firm is more likely to be overwhelmed by the abundant knowledge it obtains from the network. To develop green innovation effectively and efficiently, firms should conduct problem search, which is a focused search process for solutions to specific problems (Greve, 2003). To enable to obtain better green innovation output, firms should focus on the most useful and relevant knowledge for the green innovation, rather than dealing with all available knowledge. Otherwise, workers with limited rationality are likely to be counterproductive, because they have serious constraints and suffer from information overload. Therefore, due to the effective and efficient search of the knowledge required for green innovation, exposure to excessive knowledge from an interfirm knowledge network can lead to information overload (John and Yang, 2016), which will ensue an increase in the cost of its search for information and reduce the efficiency of searching for green knowledge, thus having the possibility of reducing green innovation output. Therefore, we propose the following hypothesis:

Hypothesis 3. The interaction between network power and network cohesion has a negative effect on green innovation output.

2.3. Moderator of environmental information disclosure

Although the effect of the supply chain network structure on green innovation output has been discussed, we further investigate the moderating effect of EID on green innovation output. EID is a common way for firms to present environmental information to external parties, and it often appears in firms' annual or corporate social responsibility (CSR) reports (Wang et al., 2019). Although the structural characteristics of supply chain networks can influence the quantity and quality of knowledge acquired by firms, we expect that firms' EID will affect the relationship between the supply chain network structure and green innovation output. We discuss the moderating effect of EID in terms of two main mechanisms: (1) reducing information asymmetry and enhancing inter-firms trust; and (2) responding to firms' ability to collect and organise information. In the following sections, we further discuss each of these mechanisms.

First, EID is a concern information, which reflects the public concern about the environment (Li et al., 2022). In supply chain networks, there is information asymmetry between focal firms and their partners, the accurate information is critical for firms' decision to operate effectively (Wang et al., 2022a,b). EID helps to narrow the green information gap between them. This green information can be diffused to other firms in the network, providing new ideas for firms to solve green environmental problems. At the same time, EID can effectively alleviate environmental regulatory pressure, gain environmental legitimacy (Shi et al., 2021), and enhance the level of trust among firms in the network. EID has an effective combinatorial impact on the structural and relational dimensions of social capital, which enhances the impact of supply chain networks on their green innovation output.

In addition, EID reflects a firm's ability to collect and compile information and transform it into its own use. Specifically, Bellamy et al. (2020) argue that the degree of EID of a focal firm depends on its ability to obtain and compile information from internal and external sources. At the same time, Bellamy et al. (2014) states that the combination of accessibility and absorptive capacity of information in the network is important for the focal firm to develop its innovation capacity from external knowledge. That is, the higher the degree of EID of firms, the more capable they have, to collect and compile information and convert it into their own use. Firms can better organise and compile knowledge and information obtained from the supply chain network structure; improve the efficiency of knowledge search; and combine it with internal knowledge to gain inspiration for new knowledge generation and enhance green innovation output.

In conclusion, a higher level of EID can facilitate the relationship between supply chain networks and green innovation output through reducing information asymmetry, enhancing inter-firms trust; and responding to firms' ability to collect and organise information. Therefore, we propose the following hypotheses, which are detailed in Fig. 1.

Hypothesis 4. EID positively moderates the relationship between network power and green innovation output.

Hypothesis 5. EID positively moderates the relationship between network cohesion and green innovation output.

3. Methodology

3.1. Research design and data collection

This study focusses on the influence of the supply chain network structure on green innovation output, and the moderating role of EID. Based on this context, three types of variables are used in this research: characteristics of the supply chain network structure, corporate green innovation output, and levels of EID.

To construct the supply chain network structure, we extract data of A-share listed firms from 2012 to 2019 from the China Stock Market & Accounting Research (CSMAR) database. The CSMAR database contains detailed information on various types of partners and provides a snapshot of the supply chain network structure. A-share listed firms are characterized by their extensive ties with external partners. Information on A-share firms is more open and transparent, and the information disclosed by firms is more accurate and comprehensive, which makes it convenient to obtain data and study the relationship between them more

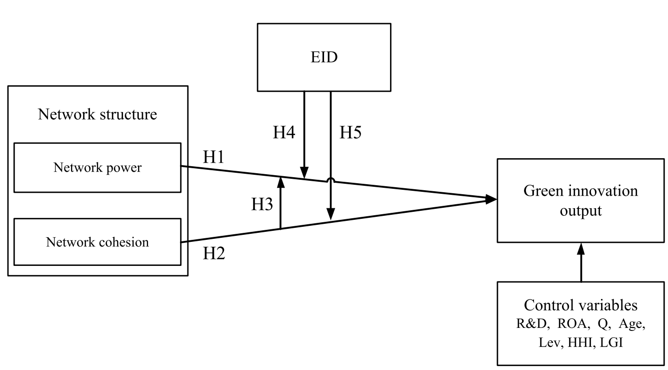

Fig. 1. Research framework.

rigorously, and these justify our selection of A-share listed firms. The process of collecting data and constructing the network structure is described in the following steps.

Step 1. We identify all A-share listed firms from 2012 to 2019 and collect information and data on the firm based on its name and stock code.

Step 2. Based on the name and stock code of the firm, we obtain the names and stock codes of the corresponding major suppliers and customers from this database. All suppliers and customers obtained are listed firms. The major suppliers or customers are determined based on the firm's purchase or sales volume for the year, and we select the top five suppliers or customers of the firm.

Step 3. We collect the required information in the database based on the names and codes of the suppliers and customers of the screened listed firms. We manually collect missing data from the official website of the firms, including authoritative reports, such as annual and semi-annual reports. Some firms whose data were undiscoverable were eliminated during the process.

Step 4. We built a supply chain network table of 'A-share listed firms-suppliers(customers)' based on the supply relationship between the obtained firms and imported the table into the Ucinet software to build a supply chain network. Based on the constructed supply chain network, we calculate the characteristics of the supply chain network structure (network power and cohesion). As the supply chain network is fluid, the number of firms varies yearly. Finally, we identified 1048 focal firms with 2393 observations.

Notably, some major suppliers or customers of focal firms are unlisted firms, and the information disclosed by these unlisted firms differs from that of listed firms; thus, we exclude them. Second, our data comes from CSMAR database. Due to the limitation of the database, we can only obtain the data of the top five suppliers or customers of the focus firms, Huang et al. (2022) have also used this methodology.

3.2. Dependent variable

Unlike traditional innovation, green innovation has a double meaning: knowledge utilisation and environmental friendliness (Ren et al.,). Through new knowledge and technology, green innovation minimises energy consumption, reduces environmental pollution and carbon emissions, and achieves harmonious economic and environmental development. Therefore, we choose green patents, which better reflect knowledge and technology, to measure green innovation. Generally, patents are key indicators of a firm's innovation (Comino and Graziano, 2015). Although green patents cannot fully measure a firm's green innovation output level, they are the main output of green innovation and an important display of a firm's green innovation achievement. Existing studies have also adopted green patents to measure green innovation output (Zheng et al., 2021). This study uses the total number of green invention patents and green utility model patents as a measure of green innovation. Belderbos et al. (2010) suggests that patent applications can reflect a firm's innovation output in a given year. While the period between patent application and patent grant usually takes two to three years, simultaneously, many patents are not granted, not because the patent is not sufficiently novel or useful but perhaps because of issues such as cost. Therefore, the total number of green invention patents and green utility model patents is used as a substitute indicator.

The number of green patent applications is obtained from the patent database of the State Intellectual Property Office (SIOP), and we collect these data according to the following steps. (1) Obtain the International Patent Classification (IPC) numbers of the green patents listed in the list of green patents provided by the World Intellectual Property Organisation. (2) Match the IPC classification numbers with the patents in SIOP to obtain the number of green patent applications of the target firm.

3.3. Independent variables

3.3.1. Network power

Network power is defined as the number of direct connections to other nodes, we use degree to capture it and we adapt this indicator as follows:

$$Network\ power = \sum_{j=1, i \neq j}^{n} n_{ij}$$

where n_{ij} is equal to 1 if there is a direct link between n_i and n_j; otherwise, it is equal to 0 (Kim et al., 2011). This definition reflects the amount of relational activity: when a firm has more direct connections with other firms, it has high power in the self-centred network (Kim et al., 2011). Conversely, if a firm has a low or zero rating, removing that point from the network has little or no impact (Kim et al., 2011).

3.3.2. Network cohesion

To operationalize network cohesion of firms in supply chain network, we use closeness centrality which is the inverse of the average distance from the focal firm to other firms as follows:

$$Network\ cohesion = \frac{n-1}{\sum_{j \neq i}^{n} g(n_i, n_j)}$$

where $\frac{n-1}{\sum_{j \neq i}^{n} g(n_i, n_j)}$ is the average distance between n_i and all the other nodes. This indicator can reflect the ability of a focal firm to navigate freely in the supply chain network, and thus obtain resources in a timely manner (Kim et al., 2011). Firms with high network cohesion have relatively short distances between their upstream and downstream partners and can access the required information and knowledge in a timelier manner (Potter and Wilhelm, 2020), while also reducing knowledge and information distortions (Kim et al., 2011).

3.4. Moderating variable

EID can enhance the transparency of corporate environmental behaviour and alleviate information asymmetry among stakeholders. In 2008, the former State Environmental Protection Administration issued the Measures for EID (Trial), which set out the most basic requirements for corporate EID and urged listed firms to actively fulfil their social responsibility to protect the environment. In 2010, the Chinese Ministry of Environmental Protection further issued the Guidelines for Environmental Information Disclosure by Listed Companies (Draft for Public Comments), which presented an outline and details of the annual environmental reports of listed firms.

To obtain the EID score, we draw on Xia and Wang, information disclosure index of environmental protection. Meanwhile, we consider that most listed firms do not require green mining and ecological restoration in Xia and Wang, thus we adjust the EID index into three primary indicators with a total of ten secondary indicators as follows: (1) environmental management and investment, which includes four indicators of environmental, management system, staff environmental training, environmental incident response mechanism, and environmental investments; (2) environmental performance, which includes three indicators of pollutant emission and reduction, environmental improvement measures, and environmental protection philosophy and purpose; (3) environmental regulation, which includes three indicators of government supervision and incentives, environmental agency certification, and the 'three simultaneous' system (The 'three simultaneous' system is clearly stipulated in the Environmental Protection Law of the People's Republic of China, and it refers to the environmental protection facilities that the construction project needs to support, which must be designed, constructed and operation simultaneously with the main project). Table 1 presents the index system for EID.

Next, we use textual analysis to score each indicator and scoring criteria based on Xia and Wang,. Specifically, we find qualitative or quantitative descriptions related to the indicators in the annual or CSR report and score them according to their descriptions. If there is no information related to the indicator described in the annual or CSR report, the score is 0. If there is a simple description of the relevant indicator, the corresponding indicator is rated 1. If there is a detailed qualitative or quantitative description (monetary- or numerical-type description), the indicator is rated as 2. The scoring details are presented in Table 2. Each indicator has a maximum score of 2, a minimum score of 0, and a maximum total score of 20. Finally, based on the abovementioned indicators and scores, the scores for all indicators are summed to calculate the final total EID score.

Table 1
Environmental information disclosure.

First-level	Secondary	Implication
Environmental management and investment	System construction	Describe of the internal environmental protection system of the firm and measures to deal with environmental problems
	Staff publicity and education	Disclosure of environmental protection concepts and technical training provided by the firm to employees, such as environmental protection training on employees
	Risk identification and control	Explained the firm's identification and control of possible environmental risks, and formulated emergency plans for environmental problems, such as occurrence of major environmental problems
	Environmental investment	Disclosure the specific amount of environmental protection investment or energy saving and emission reduction project input
Environmental performance	Pollutant emissions and emission reduction	Describe pollutant emissions; describe wastewater discharge; describe exhaust emissions
	Environmental improvement measures	Describe implementation of cleaner production in firms
	Environmental protection concepts	Describe the environmental concepts and environmental goals
Social supervision and government subsidies	Government grants and incentives	Describe environmental-related subsidies or incentives received from the government
	Environmental certification	Description of the environmental institutional Certification, such as ISO14001; ISO9001 and so on
	Implementation of the 'three simultaneous' system	Describe of the implementation of the 'three simultaneous' system

3.5. Control variables

To avoid the interference of other potential influencing factors in the regression results, we also control for the following variables that may affect green innovation output: firm R&D intensity, return on assets,

Table 2
Scoring criteria.

Description	Sore
None	0
Brief description	1
Detailed qualitative description or with quantitative description (monetary or qualitative)	2

Tobin's Q, corporate age, leverage, industry concentration, and local government intervention. **(1) R&D intensity (R&D)**: Green innovation is financed mainly by firms' R&D investment. R&D investment can improve firms' utilisation and absorption of external knowledge, which is conducive towards increasing the added value of innovation output and promoting firms' innovation output. The existing literature suggests that R&D activities contribute to green innovation output (De Marchi, 2012). We use the ratio of R&D expenditure to total sales to express the R&D investment intensity of firms. **(2) Return on assets (ROA)**: We control for firm profitability using ROA. Higher-margin firms can afford to undertake more expensive projects, such as those related to green innovation (Arena et al., 2018). This is measured as the ratio of operating income to total assets. **(3) Tobin's Q (Q)**: This is used to study corporate investment decisions and measure the effectiveness of corporate investments, which we measure as the ratio of the market value of total assets to the book value of total assets. **(4) Corporate age (Age)**: Newer firms are likely to make more use of new knowledge and technology, whereas older firms may show more organisational inertia and are less likely to innovate (Ren et al.,). **(5) Leverage (Lev):** When the leverage is higher, the firm receives a higher rate of return and uses more funds for R&D investment. We use total debt divided by the market value of total assets to measure leverage (Chu et al., 2019). **(6) Industry concentration (HHI)**: Industry may affect the firm's patents (Bellamy et al., 2014). We use Herfindahl-Hirschman Index to control different industries. **(7) Local government intervention (LGI)**: The degree of government regulation of the market may influence the green innovation activities of firms. We use the government-market relationship index from the "China Provincial Marketization Index Report (2021)" published by X.L Wang et al. (2021) to measure the degree of local government intervention in the province where the firm has its address. This index is also captured in Ren et al.,.

We control for the age of the firm using the logarithm of the difference between the firm's year of establishment and the current year. Table 3 lists all the variables used in this research.

3.6. Model specification

The number of patents we use is a non-negative integer, in which case, a linear regression model is not appropriate, and Poisson regression or negative binomial regression is more feasible for our study (Demirkan and Deeds, 2013). The Poisson regression assumes that the mean and variance are equal, but there is excessive dispersion in our patent data. In the presence of bias, the standard errors of the coefficients are often underestimated, which leads to high significance levels. Negative binomial model regression is an extension of the Poisson distribution that accounts for and corrects for overdispersion and helps to avoid the underestimation of standard errors. Therefore, this study uses a negative binomial regression. Previous studies have also used negative binomial model regressions on dependent variables such as the overdispersion of patents Bellamy et al. (2014) and Guan and Liu (2016).

$$L_1 = \sum_{i=1}^{n}\left\{ y_i \ln\left(\frac{\alpha_1 \exp(x_i{}'\beta_1)}{1+\alpha_1 \exp(x_i{}'\beta_1)}\right) - \frac{1}{\alpha_1}\ln(1+\alpha_1 \exp(x_i{}'\beta_1)) + \ln\Gamma\left(y_i+\frac{1}{\alpha_1}\right) - \ln\Gamma(y_i+1) - \ln\Gamma\left(\frac{1}{\alpha_1}\right)\right\}$$

The equation shown above represents the log-likelihood function of the negative binomial model: where y_i is the number of green patents and x_i is the independent and control variables, which include network power or network cohesion, R&D, ROA, Q, Age, Lev, HHI and LGI. We use two independent models to estimate the effects of network power and cohesion on green innovation output. α_1 denotes the value of the overdispersion parameter and β_1 refers to the coefficient of the model.

To better verify the moderating effect of EID, inspired by Bellamy et al. (2014) and Shi et al. (2021), we establish the following equation:

$$L_2 = \sum_{i=1}^{n}\left\{ y_i \ln\left(\frac{\alpha_2 \exp(x_i{}'\beta_2)}{1+\alpha_2 \exp(x_i{}'\beta_2)}\right) - \frac{1}{\alpha_2}\ln(1+\alpha_2 \exp(x_i{}'\beta_2)) + \ln\Gamma\left(y_i+\frac{1}{\alpha_2}\right) - \ln\Gamma(y_i+1) - \ln\Gamma\left(\frac{1}{\alpha_2}\right)\right\}$$

where y_i is the number of green patents, and x_i is the independent, moderating, and control variables. Similarly, we use two independent equations to investigate the moderating effects of EID. And x_i includes supply chain network structures, EID, supply chain network structures*EID, R&D, ROA, Q, Age, Lev, HHI, LGI. α_2 denotes the value of the overdispersion parameter and β_2 refers to the coefficient of the model.

4. Results

4.1. Descriptive statistics and collinearity test

The descriptive statistics and correlations of the main variables are presented in Table 4. The mean value of green innovation in our sample is 7.898 and the standard deviation is 57.450. The variance exceeds the mean for the green innovation output variable and indicates that the dependent variable suffers from over-dispersion, which is suitable for using negative binomial regression (Liang and Liu, 2018). The mean values of network power and cohesion are 32.190 and 24.350, respectively. In addition, the correlation coefficients of network power and cohesion with green innovation are positive and significant at the 1% level. The difference between the maximum and minimum values of EID is large, indicating that the level of EID varies significantly among firms. The significant difference between the maximum and minimum EID values indicates that the level of EID differs significantly between firms and is suitable as a moderating variable. Moreover, we calculate the variance inflation factor (VIF) for each variable with a mean value of 1.200, which is much less than 10; thus, we can assume that there is no multicollinearity problem in the data used.

The regression results of the main effects are presented in Table 5. First, we introduce the control variables in Model 1 and the network power in Model 2 with a coefficient of 0.028 and significant at the 1% level, which indicates a positive relationship between network power and green innovation output. In other words, an increase in network power raises the level of green innovation, thus supporting Hypothesis 1. In Model 3, we introduce network cohesion, whose coefficient is 0.095 and is significant at the 1% level, indicating that network cohesion has a significant contribution to green innovation output; thus, Hypothesis 2 is supported. In addition, we verify the interaction between network power and network cohesion with a coefficient of −0.002 at the 1% level, indicating that the interaction between network power and network cohesion has an inhibitory effect on green innovation.

Table 3
Variables and its descriptions.

Variable	Symbol	Type	Measurement
Green innovation	Green innovation	Dependent	Number of green patent applications
Network power	Network power	Independent	$Network\ power = \sum_{j=1,i\neq j}^{n} n_{ij}$
Network cohesion	Network cohesion	Independent	$Network\ cohesion = \frac{n-1}{\sum_{j\neq i}^{n} g(n_i, n_j)}$
Environmental information disclosure index	EID	Moderator	The total score of the year
R&D intensity	R&D	Control	R&D expenditure/Total sales
Return on Assets	ROA	Control	Net income/Total assets
Tobin's Q	Q	Control	Market value/Total assets
Corporate age	Age	Control	Logarithm of the number of years the firms has been in operation
Leverage	Lev	Control	Total debt/the market value of total assets
Industry Concentration	HHI	Control	Herfindahl-Hirschman Index
Local government intervention	LGI	Control	Index of the relationship between the government and market

Specifically, when the focal firm receives more information, its management of information and knowledge is more demanding, and when the firm cannot better manage the received green information and knowledge, it will complicate the firm's knowledge and information management, which instead inhibits green innovation output, which is consistent with Hypothesis 3.

4.2. Empirical results of moderating effects

In Models 6 and 7, we introduce the independent variable network power and the moderating variable EID and the interaction term network power*EID, respectively. The coefficient of the interaction term Network power*EID is 0.001 and has a significant effect at the 5% level, indicating that EID has a moderating and positively promoting effect between network power and green innovation; thus, Hypothesis 4 is supported. In Models 8 and 9, we introduce the independent variable Network cohesion and the moderating variable EID and the interaction term Network cohesion*EID. We find that the coefficient of Network cohesion*EID is 0.004 and statistically significant at the 10% level. This indicates that EID positively moderates the relationship between network cohesion and green innovation, hence supporting Hypothesis 5. Table 6 presents the empirical results for the moderating effects.

To show the moderating effect more visually, we present the moderating effect of EID on the relationship between network power and green innovation output, as well as that between network cohesion and green innovation output in Figs. 2 and 3, respectively. The contributions of network power or cohesion to green innovation output are more pronounced for firms with higher levels of EID.

4.3. Robustness tests

4.3.1. Replacing test model

We use a zero-inflated negative binomial model to test instead of a negative binomial model. The zero-inflated negative binomial model can duly explain the presence of numerous zeros in our explanatory variables (Demirkan and Deeds, 2013). Green innovation has emerged in recent years, and it is a work in progress that leads to the presence of zeros. Thus, zero-inflated negative binomial model is more appropriate to apply in this research. To test the applicability of this model, we examine the value of the Voung statistic. When the Voung value is greater than 1.96, the model is considered applicable (Bellamy et al., 2014). Tables 7 and 8 present the regression results. The Voung statistics are both greater than 1.96, and our data are applicable to the zero-inflated negative binomial model. Table 7 shows the effect of network power and cohesion on green innovation, and Table 8 shows the moderating effect of EID on green innovation. The regression results are consistent with our results when regressing using the negative binomial model, thus supporting our hypotheses.

4.3.2. Different measurements of green innovation output

In the analysis presented above, we use green innovation, measured by the number of joint applications for green invention patents and green utility model patents. Green invention patent applications could be another indicator of a firm's level of knowledge and information utilisation, so we use the number of green invention patent applications as a proxy for the explanatory variables. Tables 9 and 10 show the effects of network power and cohesion on green invention patents and the moderating effect of EID. The coefficient of the interaction term of Network cohesion * EID is 0.003 but does not significant, and the interaction effect in this scenario may not have been found. Specifically, compared with green utility model patents, green invention patents have more stringent requirements for technological innovation and for the use of knowledge and resources from supply chain network.

4.3.3. Replacing the empirical sample

We use A-share listed firms as our sample, which includes firms with a high demand for technological inventions, such as computers, communications, and other electronic equipment manufacturing, special

Table 4
Descriptive statistics and correlations.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) Green innovation	1										
(2) Network power	0.173***	1									
(3) Network cohesion	0.081***	0.372***	1								
(4) EID	0.142***	0.144***	0.181***	1							
(5) R&D	−0.021	−0.032	0.013	−0.150***	1						
(6) ROA	0.061***	0.045**	−0.027	0.145***	−0.234***	1					
(7) Lev	0.032	0.062***	0.051**	0.259***	−0.197***	−0.019	1				
(8) Q	−0.058***	−0.012	0.054***	−0.251***	0.222***	−0.061***	−0.390***	1			
(9) Age	0.038*	0.158***	0.399***	0.206***	−0.107***	0.034*	0.149***	−0.068***	1		
(10) HHI	0.134***	0.095***	−0.058***	0.214***	−0.129***	0.114***	0.174***	−0.141***	−0.088***	1	
(11) LGI	0.035*	−0.050**	0.018	−0.064***	0.060***	0.023	−0.102***	0.073***	−0.043**	−0.014	1
Mean	7.898	32.190	24.350	5.120	4.031	0.691	0.731	1.936	2.748	0.150	6.644
S.D.	57.450	18.080	5.916	4.292	5.749	0.489	1.056	2.310	0.365	0.125	1.450
Minimum	0	16.100	1.610	1	0	0.003	0.002	0.087	1.099	0.002	−9.030
Maximum	1532	200.500	33.900	20	169.400	7.161	10.810	41.080	4.779	0.779	9.220

Note: (a) The sample includes firm-year observations from 2012 to 2019, n = 2392; (b) * denotes statistical significance at the 10% level.

Table 5
Negative binomial regression model: impact of supply chain network structure on green innovation.

	(1)	(2)	(3)	(4)	(5)
Control variables					
R&D	0.113***	0.110***	0.111***	0.108***	0.109***
	(4.65)	(4.80)	(4.82)	(4.91)	(4.97)
ROA	0.868***	0.789***	1.005***	0.897***	0.912***
	(5.00)	(4.79)	(5.85)	(5.45)	(5.60)
Q	−0.381***	−0.366***	−0.412***	−0.389***	−0.392***
	(-10.01)	(-10.03)	(-11.17)	(-10.84)	(-10.93)
Age	0.710***	0.464***	0.124	0.074	0.049
	(4.87)	(3.21)	(0.75)	(0.46)	(0.31)
Lev	0.091	0.035	−0.060	−0.065	−0.054
	(1.00)	(0.42)	(-0.75)	(-0.87)	(-0.72)
LGI	0.148***	0.212***	0.098***	0.149***	0.148***
	(4.35)	(6.24)	(2.77)	(4.23)	(4.20)
HHI	2.794***	0.975**	2.591***	1.266***	1.316***
	(7.05)	(2.11)	(7.10)	(2.97)	(3.03)
Main effects					
Network power		0.028***		0.021***	0.058***
		(7.31)		(6.08)	(4.35)
Network cohesion			0.095***	0.081***	0.130***
			(9.19)	(7.71)	(6.86)
Network power * Network cohesion					−0.002***
					(-3.01)
Constant	−2.180***	−2.581***	−2.552***	−2.897***	−4.001***
	(-4.42)	(-5.41)	(-5.18)	(-6.04)	(-6.63)
Observations	2392	2392	2392	2392	2392
Log likelihood	−4684.336	−4648.955	−4644.525	−4620.800	−4616.119
LR test	288.710***	359.470***	368.330***	415.780***	425.140***

Note: (a) Dependent variable: green innovation; (b) *p < 0.1, **p < 0.05, ***p < 0.01.

equipment manufacturing, and automobile manufacturing, as well as firms with a low demand for technological innovation, such as insurance, catering, and warehousing, which may affect our regression results to some extent. We now exclude firms with lower requirements for technological innovation and further observe our regression results. The results are presented in Tables 11 and 12, respectively. Again, the results of this regression are consistent with the regression results given above, supporting all the hypotheses.

Table 6
Negative binomial regression model: moderating effect of EID.

Variables	(6)	(7)	(8)	(9)	(10)
Control variables					
R&D	0.108***	0.107***	0.105***	0.104***	0.104***
	(4.93)	(4.90)	(4.75)	(4.68)	(4.87)
ROA	0.632***	0.603***	0.726***	0.724***	0.680***
	(4.10)	(3.93)	(4.49)	(4.49)	(4.41)
Q	−0.302***	−0.296***	−0.339***	−0.332***	−0.313***
	(-8.41)	(-8.26)	(-9.23)	(-9.03)	(-8.71)
Age	0.299**	0.315**	0.059	0.075	0.052
	(2.02)	(2.15)	(0.35)	(0.44)	(0.32)
Lev	−0.052	−0.050	−0.109	−0.101	−0.092
	(-0.76)	(-0.73)	(-1.56)	(-1.45)	(-1.38)
LGI	0.152***	0.148***	0.080**	0.066*	0.112***
	(4.52)	(4.39)	(2.37)	(1.89)	(3.22)
HHI	0.320	0.176	1.981***	1.992***	0.581
	(0.75)	(0.41)	(5.64)	(5.70)	(1.40)
Independent variables					
Network power	0.022***	0.014***			0.010**
	(6.56)	(2.74)			(2.13)
Network cohesion			0.069***	0.047***	0.031*
			(6.57)	(2.87)	(1.85)
Moderating variable					
EID	0.142***	0.093***	0.130***	0.028	−0.042
	(10.21)	(3.31)	(9.01)	(0.47)	(-0.70)
Moderate effects					
Network power*EID		0.001**			0.001**
		(2.00)			(1.99)
Network cohesion*EID				0.004*	0.005**
				(1.80)	(2.02)
Constant	−2.246***	−1.970***	−2.209***	−1.622***	−1.626***
	(-4.69)	(-3.98)	(-4.44)	(-2.71)	(-2.80)
Observations	2392	2392	2392	2392	2392
Log likelihood	−4594.265	−4592.157	−4601.820	−4600.224	−4576.773
LR test	468.850***	473.070***	453.740***	456.940***	503.840***

Note: (a) Dependent variable: green innovation; (b) *p < 0.1, **p < 0.05, ***p < 0.01.

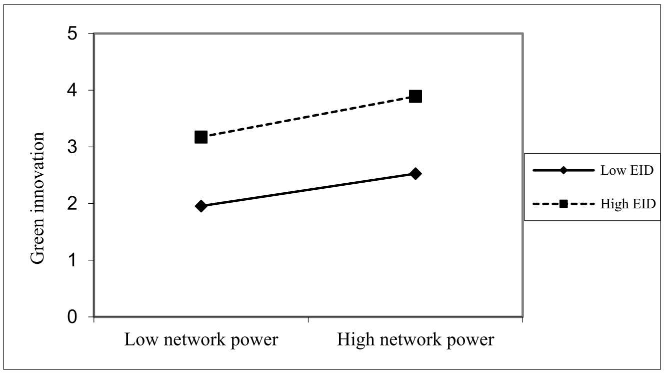

Fig. 2. Moderating effect of EID on network power.

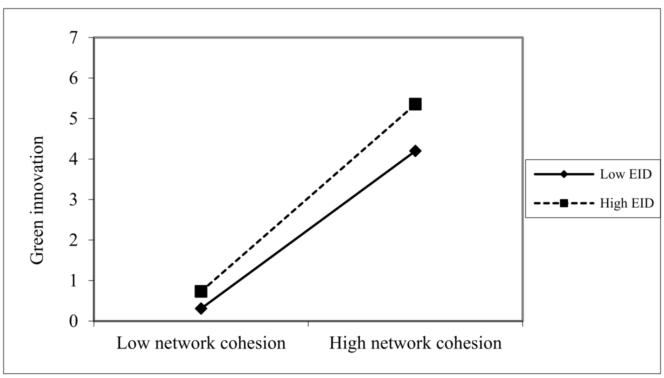

Fig. 3. Moderating effect of EID on network cohesion.

5. Discussion

This study investigates the influence of the structural characteristics of supply chain networks consisting of network power and cohesion on corporate green innovation output. We find that network power and cohesion have a significant positive relationship with firms' green innovation output, but the interaction between network power and cohesion has an inhibitory effect on green innovation. In addition, we establish the moderating effect of EID. The empirical results show that EID positively moderates the relationship between network power and green innovation output, as well as the relationship between network cohesion and green innovation output.

5.1. Theoretical implications

Our study investigates corporate green innovation output by introducing supply chain network resources, which is conducive for analysing the influencing factors of green innovation output from a network perspective and addressing the research gap in supply chain networks, EID, and green innovation output. First, we find that the structural characteristics of the supply chain network (network power and cohesion) contribute to green innovation output. The reason is sufficient because a firm's position in the supply chain network affects its ability to access resources. Firms with higher network power can obtain more resources from their supply chain network members, and firms with higher network cohesion can quickly obtain the required resources from their supply chain network members and reduce information and knowledge distortion in the process. Bellamy et al. (2014) and Carnovale et al. (2019) examine the impact of access to resources on innovation output or firm performance, and Ren et al., study the impact of environmental certification on corporate green innovation. Compared with these two types of studies, this study considers the additional properties of green innovation output as environmentally friendly and environmentally sustainable, and systematically examines other factors affecting green innovation by integrating the perspectives of resource acquisition ability and supply chain network, contributes to the

Table 7
Zero-inflated negative binomial model: impact of supply chain network structure on green innovation.

Variables	(1)	(2)	(3)	(4)	(5)
Control variables					
R&D	0.002	0.004	0.005	0.006	0.006
	(0.20)	(0.35)	(0.48)	(0.56)	(0.58)
ROA	0.505***	0.438***	0.599***	0.508***	0.523***
	(3.70)	(3.42)	(4.50)	(4.02)	(4.16)
Q	−0.275***	−0.252***	−0.298***	−0.270***	−0.272***
	(-8.32)	(-7.78)	(-9.25)	(-8.48)	(-8.56)
Age	0.581***	0.370***	0.070	0.031	0.013
	(4.71)	(3.12)	(0.48)	(0.24)	(0.10)
Lev	−0.108*	−0.121**	−0.212***	−0.198***	−0.195***
	(-1.71)	(-2.09)	(-3.78)	(-3.68)	(-3.63)
LGI	0.124***	0.191***	0.074**	0.132***	0.131***
	(4.26)	(6.67)	(2.46)	(4.43)	(4.41)
HHI	1.895***	0.120	1.790***	0.432	0.450
	(6.46)	(0.35)	(6.60)	(1.36)	(1.41)
Main effects					
Network power		0.025***		0.020***	0.037***
		(9.08)		(7.80)	(4.05)
Network cohesion			0.083***	0.070***	0.095***
			(10.13)	(8.45)	(6.39)
Network power * Network cohesion					−0.0007**
					(-2.01)
Constant	0.084	−0.429	−0.260	−0.714*	−1.259***
	(0.20)	(-1.10)	(-0.64)	(-1.82)	(-2.64)
Observations	2392	2392	2392	2392	2392
Log likelihood	−3496.795	−3444.914	−3448.896	−3411.229	−3409.192
LR test	240.250***	344.020***	336.050***	411.390***	415.460***
Voung	90.790***	86.310***	81.460***	78.880***	77.740***

Note: (a) Dependent variable: green innovation; (b) *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Table 8
Zero-inflated negative binomial model: moderating effect of EID.

Variables	(6)	(7)	(8)	(9)	(10)
Control variables					
R&D	0.006	0.005	0.005	0.004	0.004
	(0.52)	(0.44)	(0.46)	(0.37)	(0.43)
ROA	0.366***	0.339***	0.468***	0.461***	0.398***
	(3.00)	(2.77)	(3.64)	(3.60)	(3.28)
Q	−0.204***	−0.200***	−0.252***	−0.242***	−0.215***
	(-6.22)	(-6.10)	(-7.65)	(-7.35)	(-6.61)
Age	0.274**	0.287**	0.038	0.072	0.062
	(2.29)	(2.41)	(0.28)	(0.51)	(0.48)
Lev	−0.153***	−0.151***	−0.227***	−0.216***	−0.193***
	(-2.90)	(-2.86)	(-4.28)	(-4.10)	(-3.80)
LGI	0.148***	0.146***	0.060**	0.042	0.096***
	(5.14)	(5.07)	(2.05)	(1.37)	(3.22)
HHI	−0.209	−0.313	1.466***	1.493***	0.085
	(-0.64)	(-0.96)	(5.49)	(5.63)	(0.27)
Independent variables					
Network power	0.022***	0.015***			0.012***
	(8.42)	(3.52)			(2.95)
Network cohesion			0.069***	0.038***	0.020
			(8.05)	(2.69)	(1.42)
Moderating variable					
EID	0.081***	0.049**	0.069***	−0.045	−0.109**
	(7.77)	(2.42)	(6.30)	(-1.03)	(-2.43)
Moderate effects					
Network power*EID		0.001*			0.001**
		(1.92)			(1.97)
Network cohesion*EID				0.005***	0.005***
				(2.70)	(3.27)
Constant	−0.284	−0.058	−0.115	0.638	0.525
	(-0.73)	(-0.14)	(-0.28)	(1.28)	(1.10)
Observations	2392	2392	2392	2392	2392
Log likelihood	−3414.68	−3412.829	−3428.95	−3425.369	−3386.411
LR test	404.48***	408.18***	375.94***	383.10***	461.02***
Voung	80.59***	81.53***	78.58***	78.96***	77.81***

Note: (a) Dependent variable: green innovation; (b) *p < 0.1, **p < 0.05, ***p < 0.01.

innovation community from the perspective of supply chain network resources.

Second, we find that the interaction between network power and cohesion has a negative effect on green innovation output. Our finding is contrary to that of Bellamy et al. (2014), who confirm that knowledge and information can facilitate firm innovation. We further expect that the reason for this is that the phenomenon of information overload generated by firms reduces the efficiency of knowledge search, which

Table 9
Negative binomial regression model: impact of supply chain network structure on green invention innovation.

Variables	(1)	(2)	(3)	(4)	(5)
Control variables					
R&D	0.124***	0.119***	0.126***	0.120***	0.121***
	(4.88)	(5.03)	(5.31)	(5.37)	(5.46)
ROA	1.120***	1.018***	1.291***	1.160***	1.187***
	(6.00)	(5.83)	(7.01)	(6.67)	(6.90)
Q	−0.339***	−0.322***	−0.374***	−0.347***	−0.350***
	(-8.36)	(-8.24)	(-9.57)	(-9.11)	(-9.20)
Age	0.744***	0.461***	0.129	0.056	0.036
	(4.69)	(2.94)	(0.72)	(0.33)	(0.21)
Lev	0.128	0.079	−0.042	−0.038	−0.021
	(1.33)	(0.90)	(-0.52)	(-0.49)	(-0.27)
LGI	0.162***	0.240***	0.079**	0.145***	0.145***
	(4.33)	(6.42)	(1.96)	(3.65)	(3.68)
HHI	3.297***	1.221**	0.079**	1.620***	1.728***
	(7.42)	(2.34)	(1.96)	(3.46)	(3.60)
Main effects					
Network power		0.032***		0.023***	0.070***
		(7.26)		(6.01)	(4.68)
Network cohesion			0.079**	0.100***	0.164***
			(1.96)	(8.74)	(7.77)
Network power*Network cohesion					−0.002***
					(-3.45)
Constant	−3.313***	−3.785***	−3.907***	−4.330***	−5.812***
	(-6.15)	(-7.23)	(-7.27)	(-8.25)	(-8.53)
Observations	2392	2392	2392	2392	2392
Log likelihood	−3725.006	−3690.359	−3678.058	−3654.742	−3648.532
LR test	288.170***	357.460***	382.070***	428.700***	441.120***

Note: (a) Dependent variable: green invention innovation; (b) *p < 0.1, **p < 0.05, ***p < 0.01.

Table 10
Negative binomial regression model: moderating effect of EID.

Variables	(6)	(7)	(8)	(9)	(10)
Control variables					
R&D	0.120***	0.119***	0.122***	0.120***	0.118***
	(5.36)	(5.32)	(5.39)	(5.34)	(5.45)
ROA	0.921***	0.893***	1.030***	1.034***	0.980***
	(5.70)	(5.54)	(6.02)	(6.05)	(6.05)
Q	−0.244***	−0.238***	−0.288***	−0.283***	−0.262***
	(-6.34)	(-6.22)	(-7.38)	(-7.22)	(-6.85)
Age	0.344**	0.347**	0.118	0.119	0.056
	(2.14)	(2.19)	(0.65)	(0.65)	(0.32)
Lev	−0.0002	0.0003	−0.085	−0.076	−0.058
	(-0.00)	(0.01)	(-1.23)	(-1.09)	(-0.87)
LGI	0.163***	0.161***	0.063*	0.053	0.110***
	(4.41)	(4.36)	(1.66)	(1.38)	(2.85)
HHI	0.413	0.259	2.387***	2.376***	0.822*
	(0.88)	(0.55)	(6.32)	(6.32)	(1.81)
Independent variables					
Network power	0.024***	0.015***			0.011**
	(6.43)	(2.74)			(2.11)
Network cohesion			0.085***	0.068***	0.051***
			(7.37)	(3.74)	(2.77)
Moderating variable					
EID	0.164***	0.113***	0.147***	0.069	−0.006
	(10.98)	(3.71)	(9.63)	(1.08)	(-0.09)
Moderate effects					
Network power*EID		0.001*			0.001*
		(1.89)			(1.96)
Network cohesion*EID				0.003	0.003
				(1.24)	(1.49)
Constant	−3.627***	−3.316***	−3.794***	−3.325***	−3.247***
	(-6.90)	(-6.08)	(-6.94)	(-4.97)	(-4.97)
Observations	2392	2392	2392	2392	2392
Log likelihood	−3628.2773	−3626.4072	−3629.7981	−3629.045	−3607.2058
LR test	481.630***	485.370***	478.580***	480.090***	523.770***

Note: (a) Dependent variable: green invention innovation; (b) *p < 0.1, **p < 0.05, ***p < 0.01.

has a negative impact on green innovation output. This evidence suggests that, while it is good for firms to focus on acquiring green knowledge and information, acquiring excessive green knowledge and information can be a liability for green innovation. John and Yang (2016) propose information overload as a hindrance to new product development. Compared to this study, we accidently find that information overload phenomenon also has an inhibitory effect on green innovation output. Thus, our study may be the first to confirm the

Table 11
Replacing empirical sample: impact of supply chain network structure on green innovation.

Variables	(1)	(2)	(3)	(4)	(5)
Control variables					
R&D	0.136***	0.127***	0.134***	0.126***	0.126***
	(4.42)	(4.49)	(4.63)	(4.64)	(4.68)
ROA	1.050***	0.974***	1.198***	1.082***	1.098***
	(5.41)	(5.28)	(6.23)	(5.88)	(6.02)
Q	−0.442***	−0.406***	−0.465***	−0.428***	−0.433***
	(-8.83)	(-8.38)	(-9.68)	(-9.07)	(-9.18)
Age	0.628***	0.334**	0.035	−0.064	−0.104
	(3.84)	(2.07)	(0.19)	(-0.36)	(-0.58)
Lev	0.060	0.032	−0.101	−0.085	−0.075
	(0.58)	(0.34)	(-1.13)	(-0.99)	(-0.86)
LGI	0.147***	0.218***	0.082**	0.141***	0.140***
	(3.91)	(5.86)	(2.06)	(3.55)	(3.57)
HHI	2.558***	0.537	2.436***	0.983**	0.996**
	(5.90)	(1.07)	(6.14)	(2.12)	(2.12)
Main effects					
Network power		0.029***		0.021***	0.057***
		(6.90)		(5.74)	(4.09)
Network cohesion			0.102***	0.089***	0.138***
			(9.10)	(7.74)	(6.70)
Network power*Network cohesion					−0.001***
					(-2.79)
Constant	−1.784***	−2.139***	−2.267	−2.538***	−3.591***
	(-3.19)	(-3.98)	(-4.05)	(-4.70)	(-5.45)
Observations	1747	1747	1747	1747	1747
Log likelihood	−3855.740	−3823.914	−3816.965	−3795.773	−3791.777
LR test	233.780***	297.430***	311.330***	353.720***	361.710***

Note: (a) Dependent variable: green innovation; (b) *p < 0.1, **p < 0.05, ***p < 0.01.

Table 12
Replacing empirical sample: moderating effect of EID.

Variables	(6)	(7)	(8)	(9)	(10)
Control variables					
R&D	0.128***	0.128***	0.130***	0.127***	0.123***
	(4.63)	(4.64)	(4.62)	(4.52)	(4.63)
ROA	0.850***	0.821***	0.963***	0.963***	0.904***
	(4.90)	(4.75)	(5.26)	(5.28)	(5.20)
Q	−0.325***	−0.322***	−0.383***	−0.374***	−0.342***
	(-6.77)	(-6.70)	(-7.90)	(-7.68)	(-7.18)
Age	0.216	0.233	0.007	0.024	−0.051
	(1.31)	(1.43)	(0.04)	(0.13)	(-0.28)
Lev	−0.047	−0.046	−0.139*	−0.130*	−0.105
	(-0.60)	(-0.59)	(-1.73)	(-1.65)	(-1.37)
LGI	0.155***	0.150***	0.062	0.045	0.099**
	(4.12)	(4.00)	(1.62)	(1.12)	(2.52)
HHI	−0.018	−0.131	1.945***	1.944***	0.411
	(-0.04)	(-0.28)	(5.10)	(5.14)	(0.92)
Independent variables					
Network power	0.023***	0.016***			0.012**
	(6.40)	(2.78)			(2.16)
Network cohesion			0.081***	0.055***	0.037*
			(7.00)	(2.94)	(1.94)
Moderating variable					
EID	0.129***	0.087***	0.111***	0.004	−0.063
	(8.60)	(2.95)	(7.21)	(0.07)	(-0.99)
Moderate effects					
Network power*EID		0.001*			0.001*
		(1.66)			(1.70)
Network cohesion*EID				0.004*	0.005**
				(1.81)	(2.12)
Constant	−1.962***	−1.711***	−2.101***	−1.416**	−1.316**
	(-3.66)	(-3.09)	(-3.71)	(-2.06)	(-1.99)
Observations	1747	1747	1747	1747	1747
Log likelihood	−3786.073	−3784.65	−3790.145	−3788.521	−3766.806
LR test	373.120***	375.950***	364.970***	368.220***	411.650***

Note: (a) Dependent variable: green innovation; (b) *p < 0.1, **p < 0.05, ***p < 0.01.

knowledge overload phenomenon in green innovation output in the supply chain network environment.

Finally, we find that EID positively moderates the relationship between supply chain networks and green innovation. This is mainly because environmental disclosure engenders environmental 'legitimacy' (Shi et al., 2021) and the satisfaction of supplier or customer expectations (Li et al., 2022), which reduce the risk of disruption of knowledge information, ensure continued access to resources (Bellamy et al., 2020), as well as expand the range of knowledge information sources. Moreover, the level of EID reflects a firm's ability to organise and compile information (Bellamy et al., 2020), and a firm's higher ability to organise information can effectively improve the efficiency of knowledge and information search, which promotes green innovation output. This finding extends the views of Li et al. (2022) and Bellamy et al. (2020) on EID, increases understanding by explaining why and how the external and internal forces of environmental disclosure affect firms' green innovation outputs and provides a basis for firms to use their own EID to improve their green innovation output.

5.2. Managerial implications

The results of our study also have important implications for the influence of supply network structure on green innovation activities in firms' innovation practices. First, managers should be aware of the importance of supply chain management, in which firms rely heavily on their partners in the supply chain network for survival. They should actively seek out partners, nurture the supply chain network structure and use this structural feature to cultivate organisational advantage because there are differences in green knowledge and information among firms, and organisational advantage can help them to access critical knowledge and information (Wen et al., 2020). Furthermore, in the face of a large and disparate amount of green knowledge and information, managers should identify which green knowledge and information are beneficial for them to filter and reduce the ineffective search process of firms, improve the utilisation of firm resources, and facilitate green innovation outputs.

Second, as an important channel for firms to connect with the outside world, managers should consider the important role of EID, take the initiative to disclose environmental information to reduce information asymmetry. Facing the government's environmental regulations as well as social and other forms of pressure, firms can use EID as a tool to gain rationality (Shi et al., 2021), which not only improves relations with the government and alleviates the concerns of stakeholders such as partners but also helps firms to gain a good reputation, build a good corporate image, seek more partners, and increase the source of green knowledge and information.

Finally, with severe environmental problems and the general increase in public awareness of environmental protection, firms that focus only on economic benefits without considering the ecological environment will be gradually eliminated from the market (Li et al., 2019). Wang et al. (2022a,b) believe that firms' environmental investment can ensure the effective implementation of sustainable development strategies, promote the formation of environmental management capacity. Managers must consider the constraints of the ecological environment while developing the company, and accept green innovation with a positive attitude. The demand for a huge green product market can bring potentially significant economic benefits to firms, which can, in turn, bring a good reputation to the firm, which is beneficial to its future development. It can also reduce the environmental degradation associated with the production process and realise a virtuous cycle of economy and environment.

6. Conclusions and limitations

This study examines the impact of supply chain network structure characteristics on green innovation from the social capital theory perspective and elaborates on how EID can improve the relationship between them. Specifically, this study collects the data of A-share listed firms in China and their suppliers and customers and constructs a supply chain network structure consisting of network power and cohesion. The location of the firm in the network and the cohesion of the supply chain network influences the firm's ability to acquire knowledge and information; therefore, we conclude that network power and cohesiveness have a facilitating effect on green innovation output. However, when firms face excessive and overly complex green knowledge and information, search efficiency will be reduced; hence, the interaction effect of network power and cohesion will inhibit green innovation output. In addition, we find that EID positively contributes to the effect of network power and cohesion on green innovation output. Our study is among the first to link supply chain network structure, green innovation output, and EID, thereby expanding the literature on supply chain networks, green innovation output, and EID.

Although this study explores the link between chain network structure, green innovation, and environmental disclosure, it still has some limitations worth noting. First, we use the supply chain networks of listed firms from China and construct them based on top five consumers and suppliers, so some non-listed firms, firms that do not disclose, or firms with other relationships (e.g., service relationships) may be missed. Therefore, future studies can adopt more primary data with all cooperative firms as the sample. Second, our sample range was from 2012 to 2019, and as the concept of green innovation was created later, it was possible that the number of green innovations of firms in the years before that time was smaller. Therefore, future studies can delay sampling backwards. Finally, we consider the voluntary type of EID, where firms choose the aspects that are beneficial to them to disclose; thus, future studies can consider the moderating role of other factors, such as mandatory laws and regulations, on the relationship between supply chain network structures and green innovation output.

Data availability

Data will be made available on request.

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