RESEARCH ARTICLE

The drivers of collaborative innovation of the comprehensive utilization technologies of coal fly ash in China: a network analysis

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Abstract

Coal consumption brings a lot of coal fly ash (CFA). It requires interdisciplinary efforts in research, policy, and practice to improve the utilization of CFA. Although there have been a lot of achievements in technological innovation, the utilization of CFA is still difficult to match its output. So, it is urgent to explore how to guide its effective innovation. This paper uses social network analysis to discuss the characteristics of the collaborative innovation network of CFA comprehensive utilization technology in China. Then, this paper uses regression analysis to explore the differences in innovation performance under different research and development (R&D) backgrounds. The results show that (1) based on the network-level indicators, the collaborative innovation scale has an obvious trend of expanding. Partnerships increased from 20 to 574. Meanwhile, the network shows obvious scale-free and "small-world" characteristics, indicating that innovation resources are concentrated in a few organizations. (2) Based on the node-level indicators, the major contributor has shifted from universities and research institutions to enterprises. Enterprises account for the highest proportion (73%) and have the highest centrality (8.3). The betweenness centrality of the universities is 265, and only 14% of the organizations are universities which means universities play an important role in connecting different organizations in the network, but their participation in the collaborative innovation is insufficient. (3) Based on the collaborative relationship-level indicators, the cooperation is lack of depth. Only a small number of organizations, especially enterprises, have stable partners, showing the characteristic of "low cooperation width and high cooperation depth," which means fewer partners but more frequently collaborative innovation. (4) Based on the innovation performance, the innovation performance under the category of cooperative R&D, especially industry-academy cooperation, is better than that of independent R&D. But, industry-academy cooperation only occupied 43% of collaborative relationships in the network. Finally, this paper puts forward suggestions for governments from five aspects: decentralization, defining roles of enterprise and university, encouraging collaboration, changing the idea of the patent application, and promoting deeper cooperation.

Keywords Coal fly ash · Social network analysis · Complex network theory · Collaborative innovation network · Network evolution

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Introduction

Although there is a rapid emergence of various new energy sources, including nuclear energy, wind energy, and solar energy, fossil fuel are still the major energy source to account for 80% of the world's energy supply (Ju et al. 2021). As a type of fossil fuels, coal has always been playing an important role in energy supply throughout human history, to provide nearly 38% of the world's electricity, today (Wang et al. 2020). With growing energy demand and the high cost of alternative energy sources, coal will still be an important source of energy supply in the world, especially in developing countries such as China, Vietnam, and India,

due to abundant supply and low cost, relatively. According to the prediction, coal consumption will continue to grow 3.4% in the next 20 years, even though many coal-fired power plants have been or will be decommissioned (Hemalatha and Ramaswamy 2017). However, facilitating significant economic growth, coal consumption has also resulted in serious environmental issues, including waste management. Coal fly ash (CFA) is the most common solid waste in the coal combustion process (Żyrkowski et al. 2016), accounting for 5–20 wt% of raw coal (Yao et al. 2015). According to statistics, the total annual output of global CFA is about 1200 Mt, yet its average comprehensive utilization rate is only about 60% (Yang et al. 2021). The utilization rate in Europe is 47%, 39% in America (Wang 2008), and 70% in China.

In recent years, circular economy (Geissdoerfer et al. 2017), sustainable development (Chen et al. 2021; Hou et al. 2020), sustainable social development (Luna-Nemecio et al. 2020), zero-waste city (Awasthi et al. 2021), renewable energy (Smirnova et al. 2021), and low-carbon development (Tenaw and Hawitibo 2021; Zhang et al. 2021) have been well promoted in various industries. In the past, waste was considered as a cost and landfill was a typical management method. But with the shortage of resources, people are now realizing the potential value of waste (Awasthi et al. 2021). The key to sustainable development for the coal industry is to rationally increase the comprehensive utilization rate of the solid waste generated from coal consumption. As a kind of coal-based solid waste, CFA should be treated as a kind of resource, to be recycled and reused. Applying the circular economy concept to the utilization of CFA, a lot of attempts have been made in academia and industry to transform CFA from waste to resource (Zeng et al. 2020), to greatly benefit the related enterprises.

In terms of physical properties, CFA is a fine particle with an average particle size of less than 20 microns, a low specific gravity (about $0.54 \sim 0.86$ g/cm^3), and a large specific surface area ($300 \sim 500$ m^2/kg). CFA particles are composed of many kinds of spheres and porous unburned carbon. In terms of chemical properties, the pH of CFA ranges from 1.2 to 12.5. CFA is mainly composed of SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, and other metal oxides. There are also some trace elements in CFA, such as Cd, Cs, Pb, Cr, and Hg(Wang et al. 2021b). The unique physical and chemical properties of CFA make it used widely. At present, CFA is mainly used in the production of low value-added industrial products, such as construction, roads, ceramics, fillers, and agricultural soil amendments (Hemalatha and Ramaswamy 2017; Lin et al. 2020; Teixeira et al. 2016; Yao et al. 2015, 2014). However, due to the low added value of these applications, their products are limited by the small market radius and cannot match the large-scale production of CFA. In recent years, high value-added applications of CFA have emerged, such as the extraction of alumina, rare

metals, molecular sieves, and catalyst carriers (Cao et al. 2021; Dong et al. 2020; Wang et al. 2021b). But these technologies are still in their infancy and require further innovation before they can be widely used (Gollakota et al. 2019). The remaining CFA is treated as waste to be discharged into slag yard or landfill site to significantly affect the health of living organisms (León-Mejía et al. 2018); pose severe environmental risks to soil, atmosphere, agriculture, and ecology (Liu et al. 2020; Pandey and Singh 2010; Zhang et al. 2017); and lead to the waste of recyclable resources (Yao et al. 2015). Disposal costs of CFA will keep rising as the availability of landfill space dwindles continuously. The increasing global coal consumption has driven people to improve existing technologies constantly or develop new technologies (Hemalatha and Ramaswamy 2017). Therefore, it is of great importance to promoting effective innovation of the utilization technology of CFA to improve resource utilization efficiency and realize the efficient and sustainable development of the coal industry (Gollakota et al. 2019).

Innovation can provide a steady stream of power to promote the industry's sustainable development. One of the main indicators to measure innovation is patent (Hagedoorn and Cloodt 2003), in which comprehensive information of technology is documented in detail (Han and Park 2006). Along with the development of industry, the complexity and uncertainty of technological innovation increase gradually to make it quite challenging for an organization to achieve further innovation entirely by relying on its resources (Fischer and Görg 2002; Guan et al. 2005; Powell and Smith-Doerr 1996), which requires comprehensive cooperation and collaboration between organizations. Cooperation can promote the exchange of knowledge and information between related organizations to reduce the cost of innovation and improve the efficiency of innovation (Burg et al. 2014; De Noni et al. 2018). Therefore, the cooperation between different organizations in academia and industry has become an important mechanism to improve the ability of innovation and the competitiveness of the industry (Chang 2017; Yin et al. 2020). The direct output of this innovation model is the collaborative patent, which refers to the patent applied by two or more applicants, jointly (Belderbos et al. 2014). Based on collaborative patent data, an inter-organization collaborative innovation network can be constructed. Its development law can be revealed by analyzing its structure and evolution characteristics to further guide inter-organization collaborative innovation. It has been an important tool for analyzing collaborative innovation in a large number of studies (Guan and Liu 2016; Lei et al. 2013). It is worth noting that due to the different characteristics of different industries, their patent collaboration networks often differ in structure (Basole 2016; Dominguez Lacasa and Shubbak 2018; Yin et al. 2020). So, it is necessary to make a targeted analysis for the industry studied.

China is the largest consumer of coal in the world, accounting for 50% of global coal consumption, in which nearly 80% is used for thermal power generation (Wang et al. 2021a), leading up to 450 Mt CFA produced every year (Yang et al. 2021). CFA has become the largest amount of industrial solid waste in China. A lot of practices in the comprehensive utilization of CFA have been implemented to elevate the comprehensive utilization rate of CFA to more than 70% (Yao et al. 2014). Among them, a large amount of CFA is used by low value-added industries such as building materials and road engineering, while only about 5% is used for high value-added applications (Wang et al. 2021a). However, these applications are insufficient to fully utilize the CFA produced in China. Thus, there is an urgent need to explore more and more CFA utilization applications through technological innovation in the industry.

The purpose of this paper is to summarize the experience and analyze the problems in the technological innovation of the CFA comprehensive utilization in China, to provide some reference to other developing countries. In this study, China's collaborative innovation network of CFA comprehensive utilization technology is constructed. And, the structure and evolution characteristics are analyzed, the roles of different innovation organizations in the network are diagnosed, and the collaborative features are portrayed. Then, the innovation performance under different categories is explored. Last, theoretical guidance and policy suggestions for promoting the innovation level of CFA comprehensive utilization technology in China are concluded.

At present, little researches has focused on how to guide the innovation of CFA comprehensive utilization technology from the perspective of innovative collaboration networks, and this study can fill this gap. This paper discusses the role of different backgrounds of organizations in the innovation activities of CFA comprehensive utilization technology. Specifically, this paper answers the following questions: What is the structure and evolution of the collaborative innovation network of CFA comprehensive utilization technology in China? Which group is the core driver? What are the characteristics of collaboration in the network? Under what category does innovation perform best? How to promote further innovation in the industry? The results can provide a new idea for improving the innovation efficiency of CFA comprehensive utilization technology and promoting the sustainable development of coal industry.

Research data and methods

Data source

The direct output of technological innovation is patent, which contains many technical research details and economic intelligence of an industry (Campbell 1983). Using data analysis to classify and integrate the collected patents, researchers can obtain valuable information (Kyebambe et al. 2017). Patent information on patentee cooperation can reveal the evolution law and existing problems of collaborative innovation networks and help researchers understand the status of different patentees in technological innovation, so as to provide decision-making suggestions for innovation management.

Based on the IncoPat Global Patent Database,[1] this study collected the patents related to the CFA comprehensive utilization technology in China to systematically analyze the characteristics and evolution rules of the collaborative innovation network of CFA comprehensive utilization technology. This paper set the keywords as "coal fly ash" or "comprehensive utilization of coal fly ash" or "resourcelization utilization of coal fly ash". To exclude the influence of COVID-19, this paper sets the publication timeframe of patents from January 1, 1960, to December 31, 2019. In the search process, we chose a simple clan merge and screen out pending patents. Next, we removed patents with blank entries, duplicate patents, and international collaboration patents. In the end, a total of 6078 patents were obtained. Microsoft Excel was then used to encode the participating organizations of these patents and classify them according to their organizational characteristics (including enterprises, universities, research institutions, and cooperation).

Social network analysis

Patent data provide basic information on the collaborative innovation of different organizations. The cooperations between different organizations form a complex collaborative network, in which patentees at different positions with various organizations hold different innovation resources. How to interpret the roles and functions of different organizations in the collaboration innovation network is important to understand the generation and diffusion of innovation. To do so, social network analysis (SNA) is used.

SNA is an important method to quantify network structure (Li et al. 2019; Wang et al. 2021c; Yin et al. 2020), which can map the relationships among the participants in the network, thus helping to identify the most influential network nodes. In this study, the SNA method was adopted to analyze the collaborative innovation of China's CFA comprehensive utilization technology. The collaborative innovation network is represented as an undirected graph, where each node represents an organization. The line between the two nodes indicates that they jointly participate in the research and development (R&D) of a patent. By analyzing

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[1] https://www.incopat.com/

the cooperation network, the structure characteristics and evolution rules of the collaborative innovation network of the CFA comprehensive utilization technology can be revealed, the key organizations in this field can be discovered, and the relations among the organizations in the network can be explored.

Network structure analysis

(1) Network density Network density is the most basic measure of network structure, reflecting the connectivity degree of each node in the network. The greater the density of a network is, the more closely connected the participants in the network are. The network density is calculated by dividing the number of existing relationships in the network (the number of edges) by the maximum possible number of correlation coefficients in the network (the number of edges) (Kong et al. 2019). In the weighted network, no matter how many connections exist between the same node pair, it is regarded as a valid connection in the calculation process. The specific formula is as follows:

$$D = \frac{2E}{N * (N - 1)} \tag{1}$$

where E represents the number of edges in the network and N represents the number of nodes in the network.

(2) Clustering coefficient The network clustering coefficient (average clustering coefficient) represents the average clustering degree of nodes in a network. The larger the average clustering coefficient is, the more obvious the clustering phenomenon in the network is. In the undirected graph, its calculation formula is as follows:

$$CC = \frac{1}{N} \sum_{i=1}^{N} CC_i \tag{2}$$

$$CC_i = \frac{2 * E_i}{N_i * (N_i - 1)} \tag{3}$$

where CC represents the network clustering coefficient, CC_i represents the clustering coefficient of node i, N_i represents the number of neighbors of node i (the number of nodes connected to node i), E_i represents the number of connections between neighbors of node I, and N represents the number of nodes in the network.

(3) Degree distribution of the network The degree distribution is a concept in graph theory and complex network theory. In the graph structure, the number of edges connected to a node is the degree centrality of the node. The probability (P (k)) distribution of the degree centrality is the degree distribution of the network. By analyzing the

network's degree distribution, the topology of the collaborative innovation network can be understood. According to the different degree distribution, the network can be divided into regular networks, random networks, scale-free networks, small-world networks, and exponential networks (Wang, G. et al. 2021).

$$P(k) = \frac{N_k}{N} \tag{4}$$

where N_k represents the number of nodes of degree k in the network and N represents the number of nodes in the network.

(4) Modularity The module reflects the structure of the subnet in the network. A group can be considered a community (module) in a network if internal nodes are closely related to each other but not to external nodes. Modularity is a measure of whether community division in a network is reasonable. The higher the modularization is, the closer the internal connection of the divided community is, and the more sparse the relationship between the communities is, indicating that the division of the community is more reasonable (Newman 2006; Newman and Girvan 2004).

(5) Average path length In a network, the minimum number of edges between any two nodes is the path length of these two nodes, and the average value of the path length of all node pairs in the network is the average path length, which is an important feature of a complex network (Mao and Zhang 2017). It measures the information transmission efficiency of the network. Its calculation formula is as follows:

$$L = \frac{2}{N * (N - 1)} \sum_{i>j} d_{ij} \tag{5}$$

where L represents the average path length of the network, N is the number of nodes in the network, and d_{ij} is the least number of edges between node i and node j.

Node degree analysis

(1) Degree centrality Degree centrality measures the number of relationships (the number of neighbors) a node has, defined as the number of connections to that node. The higher the degree centrality of a node is, the more nodes directly connected with this node are, reflecting the dominant position of this node in the network. Degree centrality can be expressed as:

$$C(N_i) = \sum_j x_{ij}, i \neq j \tag{6}$$

where, in an undirected graph network, x_{ij} denotes whether there is a connection between node i and node j. If there is a connection between node i and node j, then $x_{ij} = 1$, else $x_{ij} = 0$.

(2) Betweenness centrality Betweenness centrality reflects one node's potential ability to control the exchange of information and resources between other nodes. Specifically, the exchange of information and resources between two non-adjacent members of a network depends on those members on the path between them. Those members control the connection between two non-adjacent members. So, a node with a high betweenness centrality indicates that it has a great impact on the information transmission in the network. Freeman (Freeman 1977) pointed out that the intermediate member has "greater interpersonal influence" on the members at both ends of the path. Its calculation formula is given as follows:

$$CB(N_i) = \sum_{j<k} \frac{d_{j,k}(N_i)}{d_{j,k}} \tag{7}$$

where $d_{j,k}$ denotes the total number of paths between nodes j and k and $d_{j,k}(N_i)$ denotes the number of paths through node i between node j and node k.

(3) Eigenvector centrality The importance of a node is related not only to itself, but also to its neighbors. The eigenvector centrality takes the importance of a node's neighbor nodes into account. The basic thought of it is that the centrality of a node is a function of the centrality of its neighbor nodes. That is, nodes connected to a small number of influential nodes may have more centrality than nodes connected to a large number of ordinary nodes. Its calculation formula is as follows:

$$EC(i) = x_i = c \sum_{j=1}^{n} a_{ij} x_j \tag{8}$$

where k is the proportionality coefficient, a_{ij} is the element in the graph network adjacency matrix A (if there is a connection between node i and node j, it is 1; otherwise, it is 0), x_j is the degree centrality of node j, and x_i is the reassigned centrality of node i. When we iterate the above formula many times, we can get the matrix form as follows:

$$Ax = \lambda x \tag{9}$$

In this case, the eigenvector x's value corresponds to each node's eigenvector centrality.

Cooperative relationship level analysis

The cooperation depth (CD) is used to reflect the characteristics of collaboration between organizations. The cooperation depth (CD) of an organization is determined by the number of its cooperation partners (NCP) and the total number of times it participates in the collaboration (NC). NCP is regarded as its cooperation width. The number of cooperation partners (NCP) of an organization reflects the breadth of collaboration. It can be represented by its degree centrality in the network. The number of times an organization participates in cooperation (NC) reflects the cooperation positivity of an organization.

$$CD = \frac{NC}{NCP} \tag{10}$$

Analysis of innovation performance: from the perspective of patent quality

Different types of collaborative innovation among organizations affect innovation performance (Belderbos et al. 2014; Wu et al. 2019). Therefore, to make efficient innovation policies, it is necessary to analyze the performance of technological innovation under different types of collaboration innovation. Since patent is the direct output of an industry's innovation, patent quality is the most important expression of an industry's innovation ability. In previous studies, due to different research purposes, patent quality has been expressed with diverse emphases, such as legal quality, commercial quality, technical quality, and text quality (Mann and Underweiser 2012; Potterie and B. 2011; Squicciarini et al. 2013). Among them, technical quality, demonstrating the novelty, creativity, and practicability of the patented technology, can better reflect the technical level of a patent. In this section, the technical quality of a patent is the research object.

Proxy variables of technical quality of patent

To study technical quality of a patent, it is of great importance to find appropriate proxy variables. At present, selecting proxy variables of the technical quality of patents is mostly started from structured data of patent documents. Among them, forward citation of a patent, the number of times that a patent is cited by subsequent patents to indicate the newer patent is technically built on the cited patent, is widely used in many studies because patents that receive many citations from later patents tend to be more important for technological progress (Fisch et al. 2017; Harhoff et al. 2003). However, the critical issue is that it requires a longer time to build up forward citation of a patent. To compare patents with the same quality, the longer the time

Figure 1. The number of patents of CFA comprehensive utilization in China
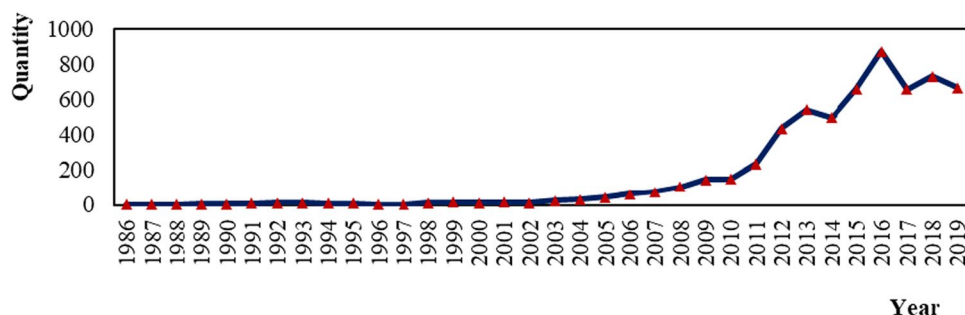
of publication is, the higher the forward citation of patents is. Consequently, the technical quality of patents with a short time of publication is easily underestimated.

To resolve this issue, this paper chooses the number of claims as to the proxy variable of the technical quality of a patent to eliminate the influence of time. Meanwhile, since this variable can only be determined after the examination of the patent examiner, it can reflect the technical quality of a patent more objectively. Claims specify the "parts" of patented technology, which reflect the technological importance and economic value of a patent (Zeebroeck and Bruno 2011). Generally speaking, the larger the number of claims, the larger the scope of technology can be protected by law, meaning more innovations the technology covers (Tong and Frame 1994; Wittfoth 2019).

Independent variables

This paper introduces the variable "Category" to discuss the quality differences of technological innovation of CFA comprehensive utilization under different R&D backgrounds. By integrating with Wu's study (Wu, Lanfen et al. 2019), inventors' categories are divided into (1) independent R&D of the enterprise; (2) independent R&D of the university; (3) independent R&D of the research institution; (4) industry-academy cooperation, including enterprise and university and enterprise and research institution; (5) enterprise cooperation; and (6) academic cooperation, including university and university, research institution and research institution, and university and research institution.

A model for innovation performance analysis

According to proxy and independent variables of the technical quality of a patent, this paper designs a simple econometric equation:

$$PQ_i = \beta * Background_i + PI_i + \mu_t + \varepsilon_i \tag{11}$$

where subscript i represents the individual patent and β represents the estimation coefficient.

This paper introduces the number of the patent inventor as a control variable to control its effect on the technical quality of a patent. The dummy variable μ_t is set to eliminate the effect of time on the technical quality of a patent and ε_i is set to control the individual effect.

Results and analysis

Descriptive statistical analysis

According to the retrieved patents of CFA comprehensive utilization technology in China, the development of CFA comprehensive utilization technology in China can be divided into three stages. (1) The early stage (1986–2003): During this period, the number of patents of CFA comprehensive utilization technology is very small and remains stable. (2) Medium-speed growth stage (from 2003 to 2010): During this period, the number of patents of CFA comprehensive utilization technology increases at a low growth rate. (3) Rapid growth stage (from 2011 to 2019): During this period, the number of patents of the CFA comprehensive utilization increased rapidly and presented a certain fluctuation, as shown in Fig. 1. These three stages have distinct development characteristics, so it is necessary to discuss the characteristics of innovation in each stage separately.

Regarding the R&D background distribution of CFA comprehensive utilization technology, independent R&D patents of universities and research institutions account for a high proportion in stage I, which indicates that organizations with rich knowledge backgrounds mainly promote innovation in the initial stage of CFA comprehensive utilization technology, as shown in Fig. 2. In addition, most of the technological innovations in China is achieved through independent R&D, along with gradually decreasing contribution of cooperation in three stages. Nonetheless, since more and more researchers have recognized the role of collaboration in the innovation process (Huang et al. 2021; Jiao et al. 2021; Maietta et al. 2017), it is necessary to further analyze the characteristics of collaborative innovation of CFA comprehensive utilization technology.
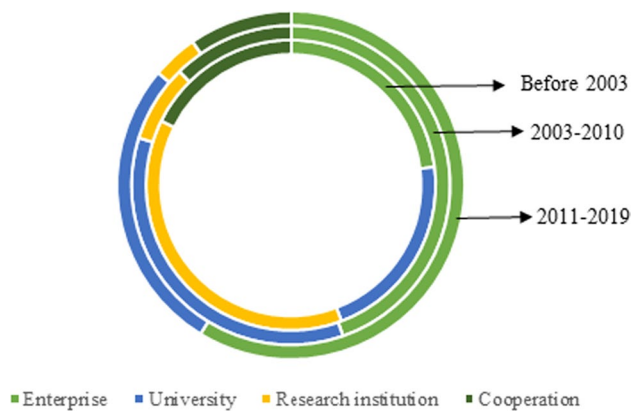
Figure 2. Innovation category of comprehensive utilization technology of CFA

Table 1 The proportion of different inventors

	Before 2003	2003–2010	2011–2019	Total
Enterprise	44%	66%	83%	81%
University	20%	23%	11%	12%
Research institution	36%	11%	6%	7%

In addition, along with the development of the industry, the contribution of enterprises gradually increases, while the contribution of universities and research institutions gradually decreases, indicating that enterprises are playing an increasingly important leading role in the innovation process of the CFA comprehensive utilization technology, as shown in Table 1. It means that the innovation process has progressively changed from theory-oriented (research institutions and universities) to market-oriented (enterprises), which reflects the importance of practical application in technological innovation diffusion.

Collaborative innovation network of CFA comprehensive utilization technology

This section gives the empirical results of analysis on the collaborative innovation network of CFA comprehensive utilization technology. The research is divided into three levels: network level, node level, and relationship level.

Network level: network characteristics of collaborative innovation network

The collaborative innovation network is an important carrier of technical cooperation. Analyzing the characteristics of a collaborative innovation network from the network level is helpful to comprehend its evolution law, to promote further development of collaborative innovation in the future. Fig. 3

shows the collaborative innovation network of CFA comprehensive utilization technology. The nodes of the network represent different R&D organizations. The size of the node represents the number of partners of the R&D organization. The larger the node is, the more partners the organization has. A line between two nodes represents a collaborative relationship between these two organizations. The thickness of the line represents the number of times of cooperation between these two organizations. The more times of cooperation between two organizations, the thicker the line will be.

As shown in Fig. 3, the collaborative innovation network shows diverse characteristics at different stages. (1) Stage 1 (before 2003): The collaboration in the network is mostly pair collaboration, which means the scale of collaborative innovation is small. Universities and research institutions are dominant in this stage. Cooperation is more in the form of industry-academy cooperation. (2) Stage 2 (2003–2010): The number of organizations participating in the collaboration increases to a certain extent. Some larger nodes in the network indicate that some organizations have a certain influence, such as universities and research institutions, mostly, to demonstrate that in this stage, universities and research institutions still have greater power. In addition, there appeared some pair groups that cooperated more frequently. (3) Stage 3 (2011–2019): The number of nodes participating in the collaboration increases substantially. There are a large number of larger nodes, among which enterprises account for the largest proportion. The collaborative innovation of CFA comprehensive utilization technology has changed from universities and research institutions to enterprises. Compared with the previous two stages, a larger scale of cooperation has been formed between organizations, as the emergence of a larger collaborative group indicates the aggregation of innovation resources and the expansion of influential core nodes. The appearance of thicker lines indicates that some organizations have formed a more stable cooperative relationship than the previous two stages.

With the development of the collaborative innovation of CFA comprehensive utilization technology, the importance of enterprises in collaborative innovation increases gradually, indicating that the innovation is changing progressively from theory-oriented to market-oriented. Furthermore, the main indicators of the collaborative innovation network at different stages are shown in Table 2, which can reflect the evolution characteristics and structural characteristics of the collaborative innovation network.

Network density is the most basic measure to represent the connectivity between each node of the network and reflect the cohesion of the network. Network density of the collaborative innovation network of CFA comprehensive utilization technology shows a trend of gradual decline, mainly because the number of nodes increases much faster than the rate of cooperative relationship. In general, the

Figure 3. Collaborative innovation network of CFA comprehensive utilization technology at each stage. Note: The color of each node represents the corresponding category of these organizations (purple represents enterprise, green represents scientific research institution, and orange represents university)
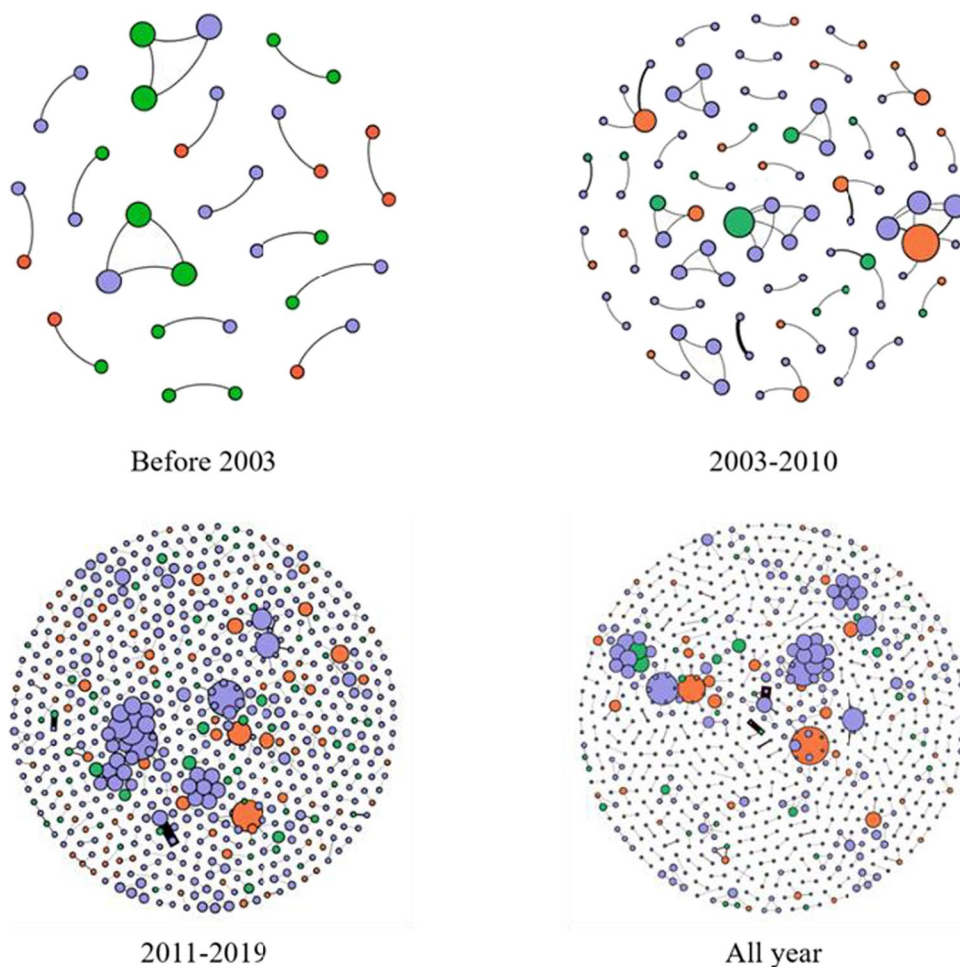

Before 2003

2003-2010

2011-2019

All year

Table 2 The characteristic indicators of collaborative innovation networks

	Before 2003	2003–2010	2011–2019	All year
Nodes	34	96	632	732
Enterprise	41%	69%	75%	73%
University	21%	19%	14%	14%
Research institution	38%	13%	11%	13%
Edges	20	67	574	654
Enterprise cooperation	10%	38%	55%	51%
Academic cooperation	25%	9%	8%	8%
Industry-academy cooperation	65%	53%	37%	41%
Network density	0.036	0.015	0.003	0.002
Average degree	1.176	1.396	1.816	1.787
Communities	16	39	202	233
Modularity	0.92	0.95	0.97	0.97
Average clustering coefficient	1	0.78	0.716	0.696
Average path length	1	1.212	3.317	3.837

network density of the collaborative innovation network of CFA comprehensive utilization technology is 0.002, which is lower than that of other research fields, including carbon capture and storage technology (0.016) (Yin et al. 2020), green building (0.0067) (Wang, G. et al., 2021), solar photovoltaic (0.029) (Dominguez Lacasa and Shubbak 2018), and autonomous vehicles (0.005) (Li et al. 2019), but higher than that of wind power (0.001) (Liu et al. 2021).
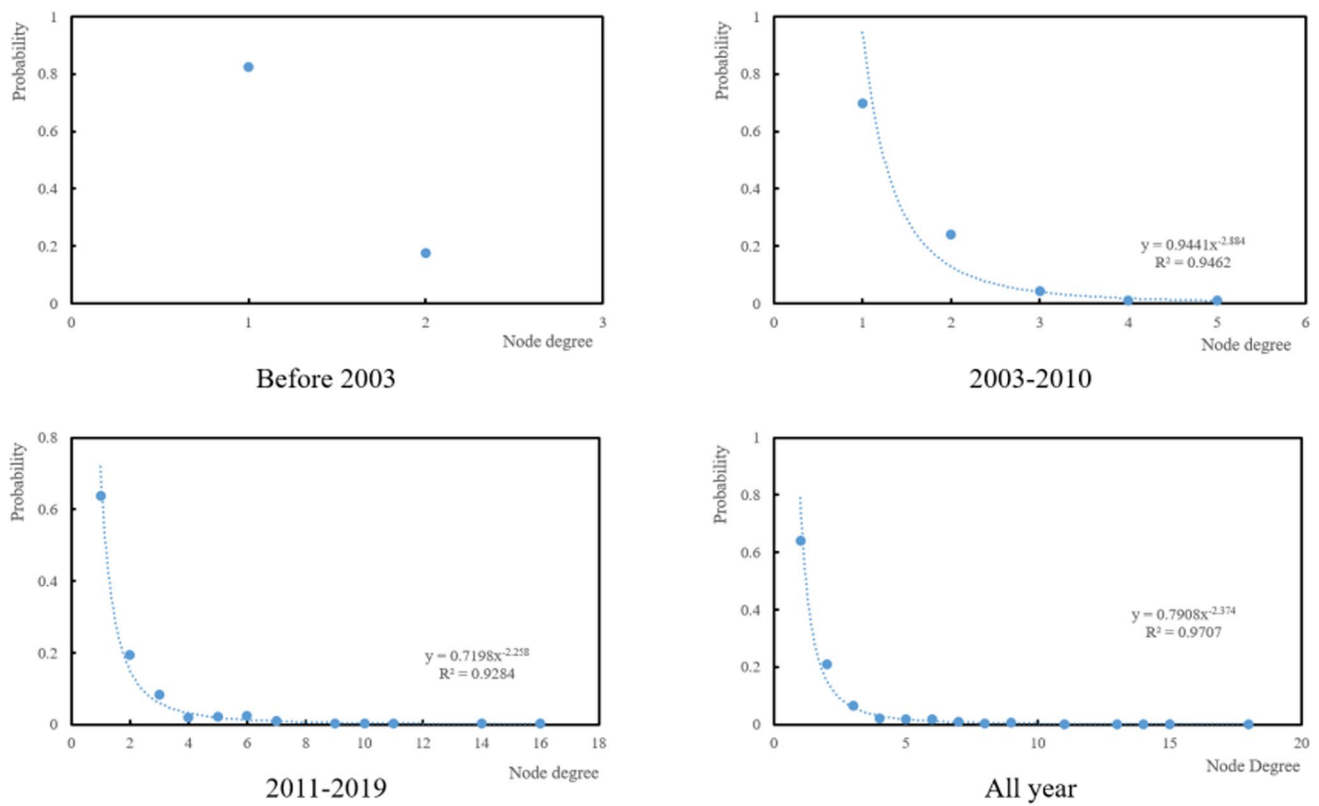
Figure 4. Degree distribution of the network at each stage

The average degree represents the average cooperation scale of a node. From stage 1 to stage 3, the average degree of the innovation collaboration network of CFA comprehensive utilization technology increases gradually. In addition, the average degree of the three stages is lower than 2 to indicate that in the evolution process of the innovation collaboration network, the cooperation scale is small at each stage, but mostly based on "one-on-one" cooperation. However, along with the development of stages, the proportion of "one-on-one" cooperation decreases gradually, and some higher degree nodes slowly emerge in the network, as shown in Fig. 3. It indicates that the cooperation scale is expanding. Moreover, the number of communities expands gradually and maintains a very high degree of modularity, meaning that more and more collaborative groups appear in the network.

The average clustering coefficient, average path length, and degree distribution are three most reliable indicators to measure network topology. The average clustering coefficient reflects the clustering degree of a network and indicates the average coupling degree of the "cluster" formed by nodes and their surrounding nodes. As the average clustering coefficient of the collaborative innovation network is greater than 0.7, there is a strong aggregation. With the development of the industry, the average clustering coefficient

declines gradually, indicating that the degree of aggregation is reduced. The average path length increases from 1 to 3.317 to imply that although the scale of collaborative innovation of this network is constantly expanding, it has a low cost of information transmission due to short average path length (< 5). High clustering coefficient (> 0.7) and short average path length (< 5) make the network show obvious characteristics of a "small-world" network, which has a faster efficiency of information transmission (Watts and Strogatz 1998). The small-world network effect is more obvious in stage 1 and stage 2.

The degree distribution of the network at each stage is shown in Fig. 4. The degree probability distribution of stage 2 and stage 3 presents characteristics of power-law distribution, to indicate that the topology of the network is a scale-free network. It reflects that the collaborative innovation network has serious heterogeneity, and the degree of centrality (innovation resources) among nodes in the network is unevenly distributed. The degree of most nodes in the network is very low, implying that the cooperation in the network is more carried out in a small scope. With the passage of stages, a small number of high degree points in the network indicate that several dominant R&D organizations are occurring in the collaborative innovation, which attracts many partners. It suggests that only a few organizations have

Table 3 The top 15 organizations with a high centrality

Degree centrality			Betweenness centrality			Eigenvector centrality		
Code	Category	Centrality	Code	Category	Centrality	Code	Category	Centrality
36	University	18	86	University	1046	569	Enterprises	1
845	Enterprises	15	569	Enterprises	989	3087	Enterprises	0.87
569	Enterprises	14	36	University	788	2823	Enterprises	0.85
86	University	13	496	University	755	110	Enterprises	0.85
297	Enterprises	11	106	Enterprises	725	3076	Research institution	0.83
2823	Enterprises	9	1	Enterprises	685	3093	Research institution	0.83
110	Enterprises	9	1160	Enterprises	680	3096	Enterprises	0.83
1485	Enterprises	9	845	Enterprises	605	3101	Enterprises	0.78
3087	Enterprises	9	180	University	425	3104	Enterprises	0.78
3096	Enterprises	8	210	Research institution	420	3008	Enterprises	0.76
3093	Research institution	8	608	Enterprises	368	2903	Enterprises	0.71
3076	Research institution	8	2854	Enterprises	329	3099	Enterprises	0.68
31	Enterprises	7	823	Enterprises	293	3103	Enterprises	0.68
3008	Enterprises	7	356	Enterprises	288	3100	Enterprises	0.66
77	University	7	41	Research institution	255	2795	Enterprises	0.66

Table 4 Top 5/15 centrality within different organization categories

	Degree centrality	Betweenness centrality	Eigenvector centrality
Enterprise	3/10	2/9	4/13
University	2/3	3/4	0/0
Research institution	0/2	0/2	1/2

Table 5 The mean centrality of the top ten organizations in each category

	Degree Centrality	Betweenness centrality	Eigenvector centrality
Enterprise	8.7	369	0.75
Research institution	3.87	47	0.16
University	6.2	283	0.11

a large number of innovation resources, which makes the collaborative innovation network show an obvious "Matthew effect."

Node level: node analysis of collaborative innovation network

In a collaborative network, the role of a node depends on its location in the network. When placed at the core position of the network, a node will play an important role in the further development of the network. Therefore, the roles of different organizations in the collaborative innovation network of CFA comprehensive utilization technology can be easily identified from their positions in the network. The top 15 organizations with high degree centrality, betweenness centrality, and eigenvector centrality are listed in Table 3 and the top 5/15 organizations with a high centrality by category are shown in Table 4.

It can be seen from Table 3 and Table 4, enterprises play a dominant role position in the network in all three indicators, for example, Code 569 (Shanghai Construction Materials Engineering Co., LTD). The proportions of universities

and research institutions are lower than that of enterprises. Specifically, an organization with high centrality indicates that it has partnerships with many other institutions. Top five organizations with high degree centrality are enterprises and universities to demonstrate their strength to meet their own needs and acquire complementary knowledge. An organization with the shortest distance between the other two organizations has a strong ability to control the other organizations and plays a key role in coordinating the collaborative innovation activities of different organizations. For example, Code 86 (Tsinghua University) and Code 36 (Wuhan University of Technology) are both in the top five organizations with degree centrality and betweenness centrality to indicate that these two universities play a key coordinating role in coordinating the collaborative innovation of CFA comprehensive utilization technology. In addition, enterprises positioning at the absolute core positions are mainly involved in several large collaborative innovation groups in the network.

Generally, enterprises occupy a key position in the collaborative innovation network of CFA comprehensive utilization technology, as enterprises have the highest mean value in all three indexes, as shown in Table 5. Their

Table 6 The top 10 organizations in terms of number of collaboration (NC)

Code	Category	Name	NC
31	Enterprise	China Shenhua Energy Co. Ltd	54
2753	Enterprise	Shenhua Junneng Resources Comprehensive Development Co. Ltd	45
2756	Research institution	Beijing Low Carbon and Clean Energy Research Institute	27
36	University	Wuhan University of Technology	25
55	Enterprise	Shenhua Group Co. Ltd	25
297	Enterprise	China Petroleum and Chemical Corporation Limited	23
569	Enterprise	Shanghai Construction Materials Engineering Co., Ltd	21
845	Enterprise	State Grid Corporation of China	17
86	University	Tsinghua University	16
2823	Enterprise	Shanghai Pulian Ready Mixed Concrete Co., Ltd	9

Table 7 Top 10 organizations in cooperation depth

Code	Category	Name	NCP	NC	CD
55	Enterprise	Shenhua Group Co. Ltd	1	25	25
2753	Enterprise	Shenhua Junneng Resources Comprehensive Development Co. Ltd	2	45	22.5
2756	Research institution	Beijing Low Carbon and Clean Energy Research Institute	2	27	13.5
31	Enterprise	China Shenhua Energy Co. Ltd	7	54	7.7
366	Enterprise	Hunan Provincial Construction Engineering Group Corporation	1	7	7
2812	Enterprise	Fushun Research Institute of Petrochemical Industry, SINOPEC	1	7	7
2781	Research institution	Hunan Institute of Building Construction Technology	1	7	7
1897	Enterprise	Shenhua Zhunger energy co. LTD	1	5	5
2782	Enterprise	Research Institute of Petroleum Engineering Technology, China Petroleum & Chemical Corporation	1	5	5

collaborative characteristics are manifested by more partners and a larger scale of collaborative groups (Fig. 3). It shows that enterprises are good at acquiring the knowledge they need through cooperation. The higher betweenness centrality of universities means universities play the role of a bridge in the network. The lower eigenvector centrality of universities indicates that their partners have few partners other than universities, so the cooperation characteristics of universities are shown as more partners but smaller scale of cooperation groups (Fig. 3 Supplement material Fig. 2).

Interestingly, compared with universities and enterprises, research institutions play a less important role in the collaborative innovation network of CFA comprehensive utilization. It may because enterprises that regard scientific institutions as partners are more likely to launch service innovations than universities, but less likely to introduce breakthrough innovations (Giannopoulou et al. 2019). It causes enterprises to reduce technological collaborative innovation with scientific research institutions, making the position of scientific research institutions in this network not important.

Relationship level: relationship analysis of collaborative innovation network

The number of times an organization participates in cooperation (NC) reflects the cooperation activity of an organization. Regarding NC, enterprises are much higher than universities and research institutions to indicate that, enterprises attach importance to finding cooperation partners to make up for their defects in technology and knowledge, to meet the demand of the market and policy, as shown in Table 6.

In general, finding new partnerships is often costly. When making technological innovations, organizations often choose to cooperate with their familiar partners. So, a higher cooperation depth (CD) between two organizations is conducive to the development of collaboration again. Though the top 10 organizations with higher CD have few partners (the number of cooperation partners, NCP, is low), they have made a lot of cooperation with their partners to form a stable partnership to demonstrate a low cooperation width, except for Code 31 (China Shenhua Energy Co. Ltd.), as shown in Table 7. Supplement material Table S1 shows the cooperation depth of the top 10 organizations of degree

Table 8 Top 15 organization pairs with the most active cooperation

Partner 1	Partner 2	Cooperation type	Number
China Shenhua Energy Co. Ltd	Shenhua Junneng Resources Comprehensive Development Co. Ltd	Enterprise cooperation	41
Shenhua Group Co. Ltd	Beijing Low Carbon and Clean Energy Research Institute	Industry-academy cooperation	25
Hunan Provincial Construction Engineering Group Corporation	Hunan Institute of Building Construction Technology	Industry-academy cooperation	7
China Petroleum and Chemical Corporation Limited	Fushun Research Institute of Petrochemical Industry, SINOPEC	Enterprise cooperation	7
China Shenhua Energy Co. Ltd	Shenhua Zhunger Energy Co. LTD	Enterprise cooperation	5
China Academy of Building Research	Jianyan Building Materials Co., Ltd	Industry-academy cooperation	4
Huaneng Power International Co., Ltd	China Huaneng Group Clean Energy Technology Research Institute Co. Ltd	Enterprise cooperation	4
Jiangsu Ni High Technology Co., Ltd	Changzhou Building Research Institute Co. Ltd	Enterprise cooperation	4
Shenhua Junneng Resources Comprehensive Development Co. Ltd	Aerospace Propulsion Technology Research Institute	Industry-academy cooperation	4
China Shenhua Energy Co. Ltd	Aerospace Propulsion Technology Research Institute	Industry-academy cooperation	4
Nanjing University of Aeronautics and Astronautics	Inner Mongolia Changtai Resources Recycling and Recycling Technology Development Co. Ltd	Industry-academy cooperation	4
Inner Mongolia Changtai Resources Recycling and Recycling Technology Development Co. Ltd	Qinghai Institute of Salt Lakes, Chinese Academy of Sciences	Industry-academy cooperation	4
Nanjing University of Aeronautics and Astronautics	Qinghai Institute of Salt Lakes, Chinese Academy of Sciences	Academy cooperation	4
China Electric Power Research Institute	State Grid Corporation of China	Industry-academy cooperation	3
Wuhan Municipal Construction Group Co. Ltd	Wuhan University of Technology	Industry-academy cooperation	3

centrality. It can be seen that most organizations show the features of high NCP but low CD, which indicates that they have not formed a stable cooperative partnership. So, there is no organization with high-level cooperation width and high-level cooperation depth in the collaborative innovation of CFA comprehensive utilization technology, which means there is no organization that both have more cooperation partners and more collaborative innovation outputs at the same time.

Top 15 organization pairs with the most active cooperation in the network are shown in Table 8, where industry-academy cooperation accounts for a large proportion. However, the total amount of cooperation between the top 15 organization pairs only accounts for 18.8% of the total cooperation in the network, which indicates that the collaboration in the network is lacking depth.

Comparison of innovation performance under different R&D categories

There are great differences in the innovation performance under different R&D backgrounds, as shown in Table 9. When independent R&D of universities is selected as the control group, the coefficients of other categories are all positive except for the academic cooperation. In general, the innovation performance of cooperation is significantly higher than that of independent R&D. Among them, the innovation performance of industry-academy cooperation is the best (with a coefficient of 1.427) to demonstrate that the cooperation between industry, education, and research plays an important role in knowledge dissemination, which facilitates the comprehensive integration of the needs of

Table 9 Regression result

	Coefficient	P value	SE
Independent R&D of university	Control group		
Independent R&D of research institution	0.93	0.006	0.34
Independent R&D of enterprise	0.366	0	0.093
Academy-industry cooperation	1.427	0	0.398
Enterprise cooperation	1.172	0	0.292
Academic cooperation	-0.532	0.164	0.383
Inventor	0.008	0.59	0.015
Constant	5.54	0	0.285

enterprises with the research resources of universities and research institutions to further improve the practicability and novelty of the technology. Noticeably, the innovation performance of enterprise cooperation (with a coefficient of 1.172) is significantly higher than that of independent R&D of the enterprise (with a coefficient of 0.366).

Regarding independent R&D, poor innovation performance of enterprises and universities may be owing to that a single enterprise lacks sufficient and extensive knowledge to make technological innovation alone, while universities lack enough connection with practice. Furthermore, the quality of independent technological innovation by enterprises is higher than that by universities, which indicates that in the innovation of CFA comprehensive utilization technology, the market demand is crucial to technological innovation. It further illustrates the importance of industry-academy cooperation for universities to improve their innovation performance. The high performance of independent innovation by scientific research institutions might be that they have richer knowledge reserves compared with enterprises and are more focusing on research fields compared with universities, such as Beijing General Research Institute of Mining and Metallurgy, Chongqing Research Institute of Building Science, Guizhou Institute of Building Materials Science, and Hebei Institute of Coal Science. As a result, with enough knowledge and a deeper understanding of the development in related fields, innovative technology from research institutions is generally more applicable.

Discussion and policy implication

Decentralization: realize innovation flowers bloom together

The evolution of the collaborative innovation network of CFA comprehensive utilization technology shows a strong scale-free network characteristic, which is embodied in the condition of extremely uneven distribution of node degree centrality. Most nodes in the network have only some connections, while very few nodes have a large number of connections. In the collaborative innovation network, there are 232 communities within the communities of "all-year," divided by the community classification algorithm. Most of these communities have less than 5 members, only a few have more than 10 members, with a maximum of 45 members, as shown in Figure S1. In other words, only a few organizations in the collaborative innovation network have plenty of innovation resources to exhibit the "Matthew effect," which is getting stronger along with the development of technology (Fig. 4).

Hence, the future of collaborative innovation of CFA comprehensive utilization technology depends on these few nodes to a great extent, as it will reduce the cost of cooperation and improve the efficiency of technological innovation in the short term. Nevertheless, in the long run, this situation will limit the development of technology innovation, owing to limited knowledge mastered by an organization. If future technology innovation is all related to handful of organizations, serious problems of technological homogenization may occur (Han et al. 2018), and there may be a lack of diversified solutions for some core technical problems. At the same time, once the core node exits the collaborative innovation network, the collaborative innovation capability of the network will decline significantly or even collapse (Crucitti et al. 2003; Hao et al. 2020).

So, it is necessary to develop targeted policies to foster more core organizations in the collaborative innovation network, to weaken the power of monopolistic organizations without affecting the current innovation. The government needs to allocate innovation resources and increase investment to encourage organizations to strengthen collaborative innovation. The government should establish a cooperation platform to disseminate cooperation information and promote the widespread dissemination of technological innovation.

Define roles: play to the core role of the enterprise and the "bridge" role of universities

Furthermore, in the collaborative innovation network of CFA comprehensive utilization technology, the proportion of enterprises is gradually increasing, from 41% in the first stage to 75% in the third stage, which shows that this industry's development has steadily changed to market-oriented. In the early stage of industrial development, due to insufficient policy guidance and knowledge for enterprises, the innovation of CFA comprehensive utilization technology relied more on universities and research institutions. With further industry development, driven by market demand and policy requirements, more and more enterprises have invested in this business and seek cooperation to improve their technology. When analyzing the role of organizations in the network, the degree centrality and eigenvector centrality of enterprises are much higher than that of universities and research institutions, which indicates that the enterprise has more partners and its partners have more partners. Therefore, some large-scale communities of enterprises have been formed as the cores in the collaborative innovation network (Figure S2). However, regarding betweenness centrality, universities and research institutions account for a large proportion of the top 10 organizations to demonstrate the essential role in transmitting and coordinating technological innovation in the network (Han et al. 2018).

By comparing the mean values of the three centralities of the top ten organizations of each category, the mean value of

three centralities of enterprises is the highest, proving that the enterprise plays a more important role in the collaborative innovation network of CFA comprehensive utilization technology. The eigenvector centrality of universities is very low, indicating that their partners usually collaborate with universities, but less with other organizations (Figure S2). Meanwhile, the betweenness centrality of universities is 283. The eigenvector centrality and betweenness centrality of universities show that universities play a role of "bridge" in the collaborative innovation of CFA comprehensive utilization technology, and many organizations are connected only through universities. However, the universities only account for 14% in all organizations, which means universities' participation in the collaborative innovation network is insufficient.

So, the government should guide universities to become "bridges" in the collaborative innovation network and continue to play the main role of enterprises. The government should promote the knowledge flow between universities and enterprises. For example, the government should encourage enterprises to explore market demand actively. Meanwhile, the government can invite enterprises and universities to carry out academic forums regularly.

Encourage collaboration: establish an industry-university-research cooperation platform

Through regression analysis, the innovation performance of cooperative R&D is higher than that of independent R&D to prove the importance of integrating innovation resources within different organizations. The innovation performance of industry-academy cooperation is the highest, which indicates that the collaboration between enterprises, universities, and research institutions can exchange knowledge and information effectively, to form a mutually beneficial and win–win relationship (Belderbos et al. 2014; Yin and Li 2019). Nevertheless, it will not be enough to achieve high-quality development of CFA comprehensive utilization technology by only involving enterprises or universities or research institutions in it. The innovation performance of enterprise cooperation ranks second to reflect the advantages of technology complementarity and integration between enterprises (Tsay and Liu 2020). In independent R&D, the quality of the independent innovation of enterprises is higher than that of universities to show that the market-oriented innovation is very important in the innovation of CFA comprehensive utilization technology and further validate the importance of cooperation with enterprises for universities to improve their innovation performance.

So, the government should attach importance to the role of market in technological innovation and encourage industry-academy cooperation. Universities and scientific
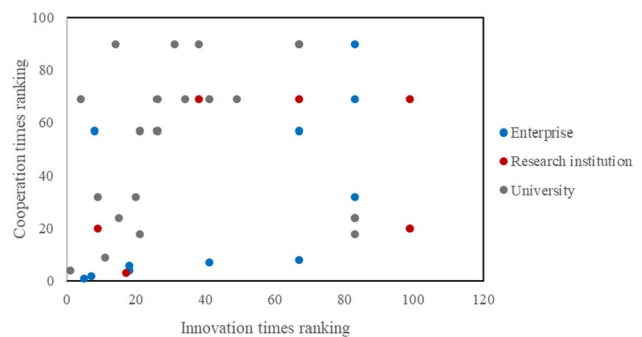

Figure 5. Top 100 organizations both in innovation times and cooperation times

research institutions have abundant knowledge but do not understand the market demand and lack sufficient funds to carry out the practice; enterprises have sufficient funds to carry out the practice, but understand the market demand but lack knowledge. Therefore, the government can realize the complementary advantages of different organizations by establishing industry-university-research cooperation platforms. Through the industry-university-research cooperation platform, research achievements and interests of different organizations are displayed, to promote the transfer of knowledge and technology complementarity and technology integration and reduce the cost of cooperation. In this way, universities and research institutions can realize technology transfer and transformation; enterprises can improve their innovation capacity.

Make the change: change performance measurement standards of university

It can be seen from Fig. 2, there are a large number of independent R&D organizations in the process of innovation of CFA comprehensive utilization technology. According to the regression results, it means that if the policy can promote their cooperation, the innovation performance of CFA comprehensive utilization technology will be improved significantly. As shown in Supplement material Table S2, the top 5 organizations with a higher number of innovations of different organizations are universities, which hold many patents. It is very different from the organizations in the top 5 number of collaboration (Table 6). As shown in Fig. 5, most universities have high innovation activity and low cooperation activity. If universities engage in industry-academy collaboration actively, there will be much room to improve their innovation performance.

So, the government should guide the universities to participate in collaborative innovation with enterprises. The current patent assessment on China's universities is still based on whether to apply for a patent. It leads to

the phenomenon of "applying for a patent for the sake of application." Therefore, universities should improve the requirements for patent rights in their scientific research performance assessment standards and reverse the situation of "focusing on the patent application, only, but neglecting technology transfer" for researchers. For example, universities should decrease the reward for patents that are authorized but not transformed, increase the reward for patents that are authorized and transformed, and include the criteria in the evaluation of professional titles.

Promote the cooperation depth: encourage the orderly advancement of collaborative innovation

Deep partnerships can reduce the collaboration cost to facilitate the transfer of knowledge and information to increase the efficiency of innovation. Some organizations in the collaborative innovation network of CFA comprehensive utilization technology have established some stable partners. And most of these organizations are enterprises. Although these enterprises have fewer partners, they have formed a close relationship with their partners for collaborative innovation, showing the characteristics of "low cooperation width and high cooperation depth," which means fewer partners and more frequently collaborative innovation. However, when analyzing those organizations with high cooperation width, the cooperation between them and their partners lacks depth. That is, there is no "high cooperation width and high cooperation depth" organization in the network at present. In addition, the total number of cooperation between the top 15 pairs of organizations only accounts for 18.8% of the total number of collaborations in the network, which also indicates that the cooperation in the network lacks depth.

Therefore, future policies should focus on promoting the depth of cooperation. The government should encourage collaborative organizations to upgrade and innovate the original collaborative innovation achievements step by step to realize the continuous improvement of technical quality.

Conclusions

The continuous innovation of CFA comprehensive utilization technology is an important way to solve the massive accumulation of CFA. There are three different types of organizations in the innovation of CFA comprehensive utilization technology: enterprises, universities, and research institutions. Different organization types play very different roles in technology development. Therefore, integrating the cooperation between these organizations will highly promote the quality of technological innovation and promptly facilitate further development of the industry. Here are the main findings:

(1) Based on the network-level indicators, the overall collaboration level of the collaborative innovation network of CFA comprehensive utilization technology is low. Over time, the scale of the collaborative innovation network is gradually expanding. Meanwhile, the network presents more and more distinct characteristics of a scale-free network, showing the obvious "Matthew effect," to imply that the collaborative innovation of CFA comprehensive utilization technology depends largely on a few organizations. In addition, the network also shows a certain degree of "small-world" network characteristic to demonstrate high efficiency of information transmission within the network. But over time, the characteristic of the "small-world" network is diminishing gradually.

(2) Based on the node-level indicators, the major contributors of the innovation of CFA comprehensive utilization technology in China have been changed from research institutions and universities to enterprises, which reflects the importance of practice needs and empirical experience in technological innovation. Throughout the development phase, enterprises account for the highest proportion and have the highest centrality, indicating that enterprises occupy the dominant position in the collaborative network. From the perspective of the betweenness centrality, universities play a "bridge" role. But, a large number of universities participate in independent innovation actively, and their participation in collaborative innovation is relatively low (accounted for 14% in all organizations). So, it is necessary to enhance the participation of universities in collaborative innovation.

(3) Based on the collaborative relationship-level indicators, on average, this collaborative innovation network lacks cooperation depth. Only a small number of organizations, especially enterprises, have some stable partners, showing the characteristic of "low cooperation width and high cooperation depth," which means fewer partners and more frequently collaborative innovation. At present, most organizations engage in collaborative innovation with their partners less than five times on average.

(4) Based on the innovation performance, the innovation performance of cooperative R&D is higher than that of independent R&D. The innovation performance of industry-academy cooperation is the highest, followed by enterprise cooperation. But, the industry-academy cooperation has not been paid enough attention (accounted for 41% in all collaborative relationships). In addition, the innovation performance

of patents developed independently by organizations is lower than that of collaborative patents. Moreover, the innovation performance of independent R&D of enterprises is higher than that of universities, which proves the importance of market-oriented innovation in technological innovation. If universities can be guided to aggressively participate in the collaboration innovation, innovation efficiency of the CFA comprehensive utilization technology will be greatly improved.

Lastly, in the discussion, this paper made suggestions on the future work of the government from various aspects, such as decentralization, defining roles of enterprise and university, encouraging collaboration, changing the idea of the patent application, and promoting deeper cooperation.

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Data availability The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

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Consent for publication Not applicable.

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