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Green technology upgrade path for food supply chain enterprises: insights from grounded theory and fuzzy-set qualitative comparative analysis (fsQCA)

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This study explores the green technology upgrade path for food supply chain enterprises using grounded theory and fuzzy-set qualitative comparative analysis (fsQCA). It identifies six key elements of food supply chain resilience: network centrality, network connectivity, network heterogeneity, resource bricolage, entrepreneurs' attention to new food technologies, and their alertness to such technologies. A theoretical model is constructed, and a questionnaire is designed based on these findings. The fsQCA reveals that configurational thinking exists among the key drivers of technology upgrades, with network centrality as a core element. Entrepreneurs' attention to external new food technologies significantly impacts technological transformation, and network centrality is a necessary condition for upgrades. The study finds that the interaction of network connectivity, resource bricolage, and entrepreneurial attention generates a multiplicative effect, accelerating technological upgrading. The results highlight the importance of network centrality and the dynamic evolution of factors influencing green technological upgrades. The findings offer new perspectives for future research and enterprise strategies, emphasizing the need for active construction of cooperative networks, intensified entrepreneur training, optimized resource assembly strategies, and sufficient financial support. Future research could explore how digital transformation influences these upgrade paths. Additionally, studying the impact of international cooperation and trade policies on green technology upgrades in food supply chains would be valuable.

KEYWORDS

green technology upgrade, configurational analysis, food supply chain enterprises, grounded theory, fsQCA

1 Introduction

In the era of globalization, food supply chain enterprises face mounting pressure due to concerns on food safety and environmental sustainability. Such pressure is driving them to upgrade with green technologies and optimize operations to enhance food safety and sustainable production. In China, government's innovation has expanded supply chain upgrade into warehouse management and order processing for a stronger global position.

However, they are facing challenges such as Financial limitations, lack of food-specific tech resources, and complex implementation pose challenges. Integrating resources and aligning technologies with existing processes require careful planning. The network environment and entrepreneurs' insights also significantly affect upgrade decisions.

Existing research on food supply chain innovation and sustainability has gaps as it mainly focuses on single factors, ignoring the complex interactions. However the green technology upgrade in this context is a complex process involving multiple elements.

To fill this gap, this study uses grounded theory to investigate real cases, identify key factors and relationships, and build a theoretical framework, then employs the fsQCA to investigate how these factors combine to influence the upgrade path, aiming to reveal the hidden mechanisms and offer new perspectives for future research and enterprise strategies.

2 Literature review

Global environmental issues are increasingly severe nowadays. The green technological upgrading of food supply chain enterprises has become crucial in sustainable food development. The fundamental difference between green technological upgrading and traditional upgrading in the food context lies in the dual externality characteristics. Compared with traditional upgrading, green upgrading in the food supply chain can not only internalize the negative environmental impacts related to food production, processing, and distribution, but also possess relatively strong positive externalities such as promoting sustainable food consumption patterns and enhancing food safety. Based on the connotation of green technological upgrading in the food supply chain, scholars have begun to study the driving factors, influencing mechanisms and other issues regarding green technological upgrading.

Social networks can help improve how well food supply chain businesses change and upgrade. This happens because social networks make these businesses better at changing (Coleman, 1988). Wang and Sun (2021) think that being central in a network and having structural holes are good for making green technology better in the food supply chain.

In the food industry, when different innovative groups work together, they form a network that looks like a "core-periphery" shape. The groups that are more central in this network are like the center of a wheel. They have a higher position and more respect in the network (She et al., 2018). These central groups can bring in better resources and partners. This helps them spend less money and time looking for information and working together on new technology in the food supply chain (Zhang and Tan, 2014).

Groups that are close to each other in the food industry, like those in the same company, can share information and knowledge easily. This makes it less confusing when they work together and lowers the cost of sharing information (Wang et al., 2016).

Ronald Burt came up with the idea of "structural holes" in a network. Imagine in a food supply chain network, there are two buyers who do not talk to each other directly, but they both talk to the same person in the middle. This middle person connects the two buyers, but they do not talk to each other directly. That's a structural hole (Burt, 1992). Burt says that members in the food supply chain network can get the information they need by using these structural holes.

Also, scholars usually think that when a food company really needs new important skills or is in danger of not surviving, the people who make decisions (like entrepreneurs) will not just do nothing. Instead, they will definitely try to find new ways and pay more attention to studying how to make their food company more innovative.

Many scholars think of attention as a way our minds work. They say that attention can control what managers in the food supply chain think about. Macmillan even thinks about attention as a whole process. In this process, decision - makers in the food supply chain deal with information and react to things outside the company. This includes steps like getting information, spreading it, and changing it into a useful form (D'Aveni and Macmillan, 1990).

Based on all this research, a scholar named Ocasio created the Attention - based View of the firm (ABV). The main idea is that when the top managers in a food company decide where to pay attention, it can change the company's decisions. Where entrepreneurs focus their attention can directly change which way the company will go in the future in the food supply chain (Ocasio, 1997).

At the same time, Napshin carried out some investigations into enterprise technological innovation in the food industry. Empirical research has indicated that the breadth and depth of entrepreneurs' attention can promote, to a certain extent, the transformation of new technologies in food enterprises and their strategic development (Napshin, 2009). Chen and Tang (2012) proposed that the degree of attention paid by a company's senior management team to external technological innovation in the food supply chain determines how much the company invests in innovative technologies. Chesbrough (2003) pointed out that during the innovation process in the food supply chain, a company is always open. The valuable development resources for the company come not only from within but also, to a large extent, from outside. Based on the above research, Dittrich and Duysters (2007) stressed that when food enterprises develop new technologies, they should also pay attention to external resources. This is helpful not only for reducing the cost of technological upgrading in the food supply chain but also for enabling them to find more effective ways to upgrade. Su and Lin (2011) thought that managers in the food supply chain should be good at using their own social networks to help get external resources during the process of enterprise technological transformation.

Overall, the existing research has given logical and theoretical backing to this paper, which takes network characteristics, external resources, and entrepreneur characteristics as the "antecedents" and "consequences" of the green technological upgrading of food supply chain enterprises, respectively. However, some deficiencies still exist:

1. Generally, the existing research does not have enough discussion and empirical analysis regarding the technological upgrading dimension from the perspective of network characteristics in the food supply chain. It's very important to figure out the role of network characteristics in the technological upgrading of food supply chain enterprises and to promote green technological upgrading.
2. The existing research has not explored enough how different factors in the food supply chain acquire various complementary resources needed for innovation and how these factors interact. The "synergistic" process involving multiple factors is still a mystery that needs more research. Exploring how multiple factors work together is helpful for effectively coordinating and managing the results of value formation in the food supply chain.

3. Current research mainly looks at the positive effects of individual factors on outcome variables in the food supply chain. There's a lack of study on the negative effects of mutual influences, and relevant empirical research is even scarcer. So, this paper uses fuzzy-set qualitative comparative analysis to explore the multiple conditional configurations that affect green technological upgrading and their complex interaction mechanisms in the food supply chain. This research helps to make clear how the upgrading technology of food supply chain enterprises realizes its value and what role green technology plays in these enterprises.

3 Research design

3.1 Research methods

Grounded theory, which was proposed by Glaser and Strauss in 1967, is a way of doing qualitative research. It combines practical research (empirical research) with theoretical research. This helps to get rid of the differences that usually exist between traditional qualitative and quantitative research methods.

There are three main types of grounded theory:

- Classical grounded theory (Glaser and Strauss, 1967): This type follows a more traditional approach.
- Procedural grounded theory (Strauss and Corbin, 1998): It has a set of procedures for doing the research.
- Constructivist grounded theory (Charmaz, 2006): This type takes into account the idea that knowledge is constructed by people.

These different types show different ways of understanding the world (epistemologies), which are positivist, interpretivist, and constructivist, respectively. These differences show up in the way the research is done, especially in the coding process.

For this study. Because grounded theory works well for research that is exploring new areas and where there is not much existing theory. For example, when we are looking at the key elements that make the food supply chain able to recover from problems (resilience), there might not be a lot of theory already. Grounded theory builds theory from the ground up. It starts with specific situations in food supply chain management.

This method involves collecting and analyzing data in a systematic way. Theory is formed through a process of coding that is done over and over again. In this study, procedural grounded theory is used to find the key elements of technological upgrading in food supply chain enterprises. The software NVivo20 is used for coding.

The coding process has three steps:

1. Open coding: This step takes concepts out of the raw data that are related to the food supply chain and sorts them into different groups.
2. Axial coding: Here, we look deeper into the meanings of the categories and the logical relationships between them within the context of the food supply chain.
3. Selective coding: This step focuses on finding the most important category (the core category) and then building a story that shows how the core category and the main categories are related in the food supply chain.

Finally, a test for theoretical saturation is done. This makes sure that the theoretical model we create for the food supply chain is strong and scientifically valid.

3.2 Data collection

This study used a sampling theory approach. From food supply chain enterprises that often work on technological developments, 27 employees were chosen. The people who were interviewed had to have at least a bachelor's degree and at least 1e year of experience in a related field. The interviews were semi-structured and in-depth. Each interview was done one-on-one and lasted more than 60 min. The interviews mainly focused on three things: why technological upgrading is necessary in the food supply chain, what the current situation is, and what the important elements are. The questions asked during the interviews could be changed flexibly. This was done so that the interviewees could express themselves freely. It also made sure that the data collected were real and valid. This is presented in Table 1.

4 Data analysis

The interview recordings were transcribed verbatim into textual data, and qualitative analysis software NVivo20 was used to assist in the coding process to ensure that the coding was standardized, normalized, and systematic.

4.1 Open coding

Open coding is the process of analyzing and organizing raw data to turn it into a structured form of expression. During this process, to prevent mistakes that might happen when only one person handles the data, the most original responses from the interviewees are used as labels to discover new concepts. In this study, the core topic is "food supply chain enterprises achieving technological upgrading." All the data collected from the interviews were analyzed through open coding. This led to the identification of 29 original statements. After that, the data were further processed. Manual coding methods were mainly used, and consistency analysis software was also helpful. Statements that were repetitive, logically unclear, or initial concepts that occurred less than two times were removed. However, the original data's integrity was kept intact. Then, the remaining statements were grouped into different categories. In the end, there were 13 categories. For each of these 13 categories, 2–3 original data statements along with their corresponding initial concepts were chosen. These selections are presented in Table 2.

4.2 Axial coding

The main goal of axial coding is to link different categories and create a closely connected web of relationships. At the heart of axial coding is a detailed review of the open coding that was done before.

TABLE 1 Interview outline.

Interview theme	Interview questions
The Necessity of Food Technology Upgrades	Why does your company believe that food technology upgrades are necessary? What prompted your company to consider food technology upgrades? What significant - long - term impact do food technology upgrades have on the company? What existing problems does your company hope to solve through food technology upgrades?
	At which stage is your company currently in the process of food technology upgrades?
	What kinds of disruptions has your company encountered during the food technology upgrade process? What are the specific circumstances of these disruptions? Why did these situations arise?
Current Stage of Food Technology Upgrades	What kinds of disruptions has your company encountered during the food technology upgrade process? What are the specific circumstances of these disruptions? Why did these situations arise?
	How is the progress of the food technology upgrade projects?
Impact of Factors on Food Technology Upgrades	Based on your experience, what factors do you think influence food technology upgrades?
	What kind of impact do you think these factors will have on food technology upgrades?
	Among these factors, which ones do you consider to be key factors? Why?

This is done to figure out the main categories that tie in with the central aims of this part of the study, as well as the subcategories that help explain the main categories well. After making clear the logical connections between the initial categories, this paper moved on to the axial coding stage. During this stage, the 29 initial categories were reorganized and summed up. As a result, 13 subcategories were identified. Then, further standardization work was carried out. Through this, six main categories were found: network centrality, network connectivity, network heterogeneity, resource bricolage, awareness of new food technologies, and the continued attention to new food technologies. These six main categories are shown in Table 3.

4.3 Selective coding

Selective coding entails further condensing and integrating the outcomes of axial coding in order to pinpoint the core category. In the scope of this study, it was determined that network centrality, network connectivity, and network heterogeneity are all specific expressions during the technological upgrading process of food supply chain enterprises. Consequently, these three aspects are jointly named network characteristics. Resources play an essential role in the green technological upgrading process within the food supply chain. Throughout the research, it was noticed that enterprises reach their objectives by making use of both external and internal resources. This practice is referred to as resource bricolage. Finally, it was revealed that being alert to new food technologies and maintaining persistent attention to new food technologies are crucial aspects that entrepreneurs concentrate on during the technological upgrading process. These two aspects are collectively called entrepreneur attention. This is presented in Table 4.

In summary, network characteristics, resource bricolage, and entrepreneur attention are critical factors in the green technological upgrading path of supply chain enterprises. This paper focuses on whether these causal variables are necessary conditions and how they interact to trigger green technological upgrading, as illustrated in Figure 1.

4.4 Reliability and validity analysis

This study focuses on senior managers and ordinary employees of food supply chain enterprises and uses a questionnaire survey to collect data from 15 food supply chain-related companies in China, covering food logistics, food processing, and food retail sectors. Based on configurational theory, a framework of factors influencing the green technology upgrade path is constructed. The questionnaire includes 35 items divided into two parts: an introductory section and variable measurement scales, categorized into network connectivity, resources, and entrepreneurs' attention, scored on a seven-point Likert scale. After data collection, 359 questionnaires were recovered, and 327 were deemed valid (91% response rate).

Reliability and validity tests (Table 5) show that the Cronbach's α values for network characteristics, resource bricolage, entrepreneur attention, and outcome variables all exceed 0.8, indicating high reliability. Factor analysis reveals that the KMO values $\geq$0.755, the composite reliability (CR) > 0.80, and the average variance extracted (AVE) meets the 0.5 criterion, confirming satisfactory reliability and validity.

TABLE 2 Open coding concepts and categories.

Category	Concept	Original data statements
Food industry technology	Technology search	Through learning abroad, the company realizes that there is a certain connection between German food processing technology and our core technology.
	Entrepreneurial opportunity recognition	By undertaking foreign food projects, the CEO of a domestic company saw the problem with the technology used in domestic food production, namely a serious lack of intellectual property rights, and took immediate action.
Food entrepreneurship technology perception	New technology Judgment	The company dispatches some employees abroad every year to learn advanced food information technology.
	Technology upgrade perception	We took the lead in signing an agreement with a foreign food energy production and supply chain company, changing the food energy production market in our country.
Technology attention	Technology attention	Our company has been concentrating on the research and development of food numerical control products for more than 10 years.
	Patent protection	We have established a protection system including core food patents and competitive patents.
Continuous technological Innovation	Expanding international markets	Transport food produced domestically to foreign countries for sale.
	Continuous New technology focus	Although already at the core of food competition, the company will still continue to focus on the development of new product technologies in the future and always adhere to the path of innovative development.
Knowledge Connection	Establishing national labs	Establish a national engineering laboratory for high-end food CNC machine tool control group technology.
	University-industry cooperation	We have maintained close cooperation with universities for a long time to jointly develop the latest food technologies.
Resource Connection	Enterprise collaborative innovation	The company forms long-term stable partnerships with other enterprises, enhancing overall strength.
	Collaboration with government	Our company constantly monitors current political changes to obtain the latest resource information.
	Enterprise collaborative innovation upgrade	The company forms long-term stable partnerships with other enterprises, enhancing overall strength.
Cooperation Density	Parallel advancement	Different food projects are advanced in parallel.
	collective brainstorming	Group brainstorming sessions.
Network centrality strength	Perceiving business environment changes	When the basic food business reaches a bottleneck, a thorough transformation is needed; otherwise, once the business environment changes, the company will face difficulties.
	Network position	The more important the network position, the more it reflects the company's networking capabilities. Position determines the power a company possesses and often leads to success; companies with many sources of information have strong networking capabilities.
	Cooperation experience	Cooperation experience is also a type of networking capability; having cooperation experience gives dominance during the process of cooperation.
Resource integration	Creative utilization of existing technology	Combine core food products with other products to enter new industries.
	Supply chain integration	The company integrates the upstream food supply chain by acquiring other enterprises.
Mimetic innovation	Reverse engineering	The company spends millions every year on purchasing new food products and learns through reverse engineering.
	Forward engineering	When new food technologies emerge, the company studies their principles and develops similar but functionally simpler products in a short period of time.
Resource transplantation	Production line transformation	Transform the existing food production line into one suitable for cooperative products.
	Workforce patchwork	We often calculate in this way: If the funds required to purchase imported food machinery are converted into production time, how many workers can be hired with this amount of money to achieve the same production efficiency?
	Experience patchwork	Corresponding capabilities for food technology transformation and upgrading.
Building partnerships	Exchange learning	Our company often sends relevant personnel to participate in food technology exchange conferences and continuously establishes new partnership relationships.
	Building network partnerships	Look for companies related to food products for cooperation and establish an international cooperation network.
Differential management	Talent attraction	Consider adopting a more flexible approach to attract food talents from research institutions across the country and even abroad.
	Diversified human resource construction	In the process of food information exchange, we tend to organize people with different educational backgrounds and even different ages to come together and generate ideological collisions.

The model fit index χ^2 is 1044.134, which meets the critical value. The degrees of freedom (df) for the model is 474, and the χ^2/df ratio is 2.203, falling within the acceptable range of (1, 3). The Comparative Fit Index (CFI) is 0.944, which is greater than 0.9. The Tucker-Lewis Index (TLI) is 0.938, also greater than 0.9, both meeting the recommended critical values. The Root Mean Square Error of Approximation (RMSEA) is 0.061, and the Standardized Root Mean Square Residual (SRMR) is 0.034, both of which are less than 0.08, indicating that they meet the recommended critical values. The specific details are shown in Table 6.

4.5 Dependent variable

The main emphasis of this study lies in the key factors that affect the path of technological upgrading in the food supply chain industry. As such, the dependent variable is the preference for the technological upgrading path. This focuses on the main factors that influence food supply chain enterprises when they select a green technological upgrading path, taking into account the impact of the current macro-environment. By clarifying the conditional variables and the dependent variable, this paper carries out a descriptive statistical analysis of these variables. The specific details are presented in Table 7.

5 Configurational analysis

Qualitative Comparative Analysis (QCA) is a research method that combines qualitative and quantitative approaches, initially proposed by the American sociologist Charles Ragin. Its fundamental idea is based on set theory and Boolean algebra, examining how the interactions among multiple causal conditions collectively lead to changes in the outcome being explained (Xu et al., 2020). Fuzzy-set Qualitative Comparative Analysis (fsQCA) emphasizes the membership scores of variables, with values ranging from 0 to 1 (Ragin, 2008).

5.1 Variable measurement

5.1.1 Social network characteristics

The number of connections in a social network is positively related to the strength of social capital. That is, the wider an individual's social network is, the stronger their social capital will be. For individuals, having stronger social capital improves their ability to get resources. From a corporate viewpoint, the capacity of social capital lies in setting up external connections to obtain scarce resources. In this study, social networks are analyzed from three aspects: network centrality, network heterogeneity, and network connectivity.

5.1.1.1 Network centrality

Network centrality gauges the interconnected transactions between a food supply chain enterprise and other entities, reflecting how embedded and central the enterprise is within the social network (Cross and Parker, 2004). Centrality can be shown in three ways: degree centrality, closeness centrality, and betweenness centrality. Degree centrality measures an actor's ability to carry out transactions within the network. A node that has many connections has a high degree centrality (Freeman, 1979). For example, in a food supply chain, if a company has a lot of direct connections with other companies like suppliers, distributors, or retailers, it has a high degree centrality. Closeness centrality looks at how independent an enterprise is. It shows how much an enterprise depends on others for transactions. If a company can complete many of its transactions without having to rely too much on other intermediaries, it has a high closeness centrality. Betweenness centrality examines the intermediary role of an actor. It means that important information and resources pass through the node. For instance, if a particular company in the food supply chain is often the go - to for passing on market trends or new product ideas between different parties, it has a high betweenness centrality. In this study, degree centrality is mainly used to analyze the connections between food supply chain enterprises and external resources.

5.1.1.2 Network connection strength

Xu (2021) proposes that every connection that has an impact on technological innovation within a social network represents a kind of linkage. This linkage is formed through the interactions among various elements, giving rise to a cooperative innovation relationship. Jie et al. (2021) point out that network connections are the ties that are established through formal or informal agreements, the flow of information, and social relationships among enterprises. These connections play a crucial role in facilitating cooperation among enterprises. They also help enterprises maximize their economic benefits and mitigate risks while incurring minimal costs. Stronger network connections encourage mutual trust, coordination, and knowledge sharing among enterprises. Moreover, they provide support for technological innovation, which is beneficial for the transformation and upgrading of enterprises (Li and Yang, 2018).

5.1.1.3 Network heterogeneity

Network heterogeneity refers to the degree of diversity in the industries with which a food supply chain enterprise is connected. When a food supply chain enterprise collaborates with other types of enterprises, such as internet companies, the heterogeneity of its network increases (Miao, 2018). Aldrich and Zimmer (1986) define network heterogeneity as the non-redundant information that can be accessed within a social network. Diversifying social networks brings several benefits to enterprises. It expands their opportunities and enhances their ability to integrate and transform resources. Heterogeneous knowledge and resources can inspire innovative thinking and lead to improvements in financial performance, innovation capabilities, and research and development (R&D) performance.

However, network heterogeneity also has some drawbacks. It can introduce communication barriers and bring about differing perspectives among different enterprises. These factors may potentially impede technological upgrading and transformation processes.

This study focuses on examining the appropriate level of network heterogeneity required by food supply chain enterprises during the processes of technological upgrading and transformation. The aim is to explore how inter-organizational network heterogeneity affects these crucial processes and draw relevant conclusions based on the analysis.

5.1.2 Resource patching

The idea of "patching" means the immediate steps that enterprises take to grab new development chances or deal with new problems by using the resources they have at a particular moment during their

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TABLE 3 Axial coding results.

Main category	Subcategory
Network centrality	Cooperation density, Network centrality strength
Network connectivity	Knowledge connection, Resource connection
Network heterogeneity	Building partnerships, Differential management
Resource ingenuity	Resource integration, Mimetic innovation, Resource transplantation
Alertness to new technologies	Resource integration, Mimetic innovation, Resource transplantation
Persistence in new technology attention	Technology attention, Continuous technological innovation

TABLE 4 Selective coding results.

Core category	Main category
Network characteristics	Network centrality, Network connectivity, Network heterogeneity
Resource bricolage	Resource bricolage
Entrepreneurial attention	Alertness to new technologies, Persistence in new technology attention

growth. Companies that do not have many resources often have to make the best of what they have to handle changes in the business world.

The traditional resource-based view mainly focuses on the connection between a company's different internal resources and its competitive edge. But it looks at this relationship in a static way. So, it cannot explain why companies that have similar resources can perform differently. This view does not take into account how actively managers choose and put together resources. In real life, resource patching is like a "resource bricolage" activity. It does not say that heterogeneous resources aren't valuable. Instead, it pays more attention to how resources are put together. When there are limitations, those who are doing the "bricolage" can use physical resources, human resources, skills, market resources, institutional resources, and network resources in creative ways.

Resource patching can be split into two kinds: means-oriented resource patching and social network-oriented resource patching. To sum it up, resource patching is a dynamic and adaptable plan. It allows companies to use their available resources in new and creative ways. This helps them get better at dealing with changes in the environment and taking advantage of new opportunities.

5.1.3 Entrepreneurs' attention to new technologies

The attention-based view suggests that how entrepreneurs or teams distribute their attention has a significant impact on the future decisions and actions of a firm (Yuan et al., 2022). For food supply chain enterprises, effectively allocating attention in both the market and technological areas is essential for achieving technological path upgrading. However, numerous entrepreneurs in the food supply chain industry tend to pay more attention to the market and less to technology (Barney, 1991). This inclination often results in a tendency to follow existing trends rather than being innovative. This study examines relevant literature and analyzes this issue from two aspects: the sensitivity to new technologies and the continued focus on new technologies.

5.1.3.1 Alertness to new technologies

Alertness, which is a mental state in which individuals react to particular, unforeseeable situations, is classified by Shao (2006) as a special type of attention from the perspective of cognitive psychology. In the technological context, alertness means being sensitive to and aware of current or future technological advancements. Entrepreneurs who have a high level of alertness employ "environmental scanning" to observe the external environment and keep looking for useful technological information. According to the new attention-based view of the firm, when entrepreneurs pay attention to new technologies, they involve themselves in screening and evaluating these technologies. Most food supply chain enterprises do not have strong core technological innovation capabilities. As a result, entrepreneurs depend on their industry knowledge to assess new technologies and determine the appropriate courses of action.

5.1.3.2 Persistence of attention to new technologies

The persistence of attention to new technologies means the length of time and the degree of consistency with which an entrepreneur focuses on emerging technologies (Aldrich and Fiol, 1994). In the case of food supply chain enterprises, managers need to not only pay attention to new technologies but also keep this focus over a period of time. Many Chinese food supply chain enterprises face the problem of not following through well enough. This means they need to change from simply depending on existing technologies to finding the key factors that can drive their upgrading and transformation. To achieve this, they need to put more effort into research and development.

In the fast-changing environment of the food supply chain, it is extremely important for managers to keep their attention on technology for the development of the enterprise. Managers should be sensitive to new technologies, evaluate whether these technologies are in line with the company's goals, and invest at the appropriate time to secure a competitive position in the market.

5.2 Variable calibration

The fuzzy-set qualitative comparative analysis (fsQCA) method is employed to construct configurations. The initial step in this process is the calibration of variables. The QCA method utilizes a set-theoretic approach. In this approach, each variable is regarded as a complete set. For each case, there is a corresponding membership score within both the conditions and the outcomes (Ragin, 2008). As a result, the calibration process entails transforming the data into a 0–1 fuzzy set to enable the analysis. Regarding the sample data in this study, the values at the 75% percentile, 50% percentile, and 25% percentile obtained from the descriptive statistical analysis are utilized as the full membership point, crossover point, and full non-membership point, respectively. Subsequently, the fsQCA 3.0 software is used to assign membership scores to the data. Moreover, during the calibration of the samples, if the value of the crossover point is precisely 0.5, it cannot be incorporated into the truth table. To address this, the value is adjusted to 0.499 (Schneider and Wagner, 2012), as demonstrated in Table 8. When it comes to the calibration of non-outcome variables, the process is analogous but carried out in the opposite direction. For the non-set

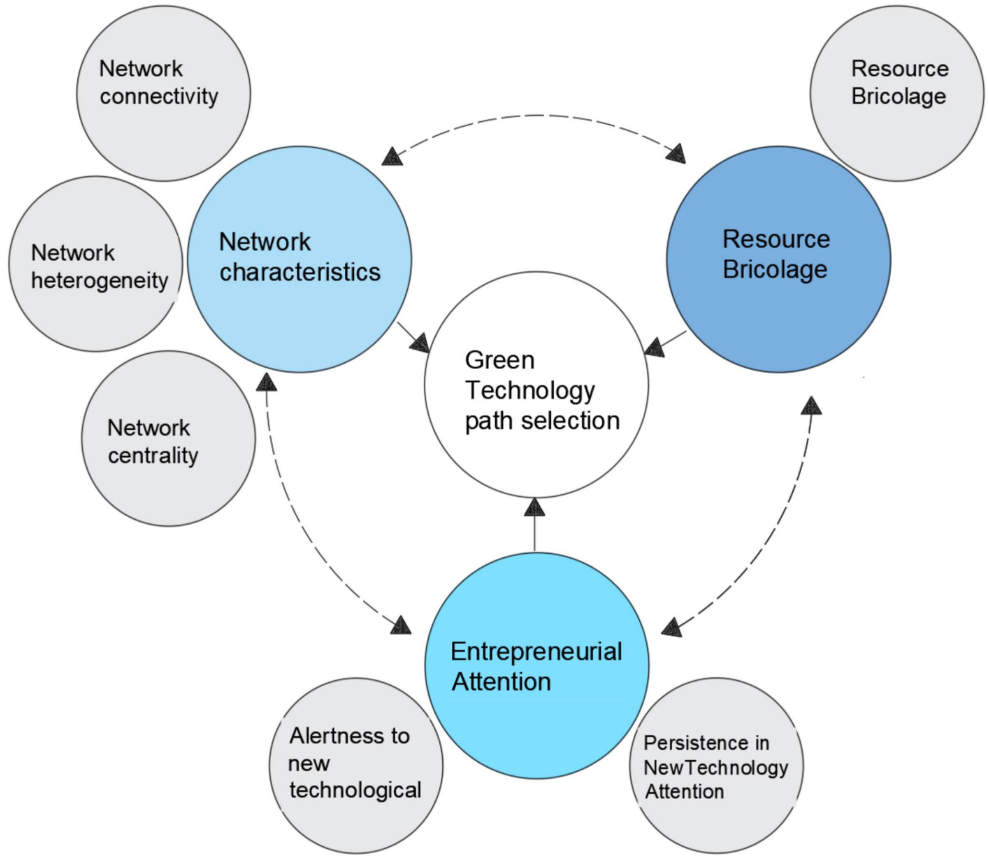

FIGURE 1
Matching model of key driving elements of supply chain enterprise green technology upgrading.

TABLE 5 Reliability and validity test.

Study variables		Cronbach's α	KMO	Combined reliability (CR)	AVE
Network characteristic	Source network connection strength (NS)	0.879	0.866	0.881	0.597
	Network centrality(NC)	0.862	0.797	0.862	0.610
	Network heterogeneity(NH)	0.911	0.892	0.912	0.674
Resource bricolage	Resource bricolage (RB)	0.955	0.943	0.956	0.729
Entrepreneurial attention	Attention to new technologies(AT)	0.910	0.755	0.910	0.771
	Persistence towards new technologies(PT)	0.915	0.847	0.916	0.733
Green technology upgrade(GTU)		0.935	0.856	0.936	0.786

calculations, the 75th percentile, 50th percentile, and 25th percentile values from the sample data are used as the full non-membership point, crossover point, and full membership point, respectively.

5.3 Empirical analysis

5.3.1 Necessary condition analysis

In line with the fuzzy-set qualitative comparative analysis (fsQCA) research paradigm put forward by Xu et al. (2020), this study establishes the following parameter settings: the case frequency threshold is set at 1, the consistency threshold is fixed at 0.9, and the PRI (proportional reduction in inconsistency) consistency threshold is determined to be 0.7. Lee (2014) has pointed out that fsQCA is applicable for analyzing samples of different sizes, specifically small samples (fewer than 10 or 15 cases), medium samples (ranging from 15 to 50 cases), and large samples (exceeding 100 cases). In the context of medium sample analysis, it is ideal to have 4–7 causal conditions. In this study, 36 Chinese industries are examined, which falls within the scope of a medium sample. Accordingly, six causal conditions are selected, thereby meeting the requirements for medium sample analysis. Before commencing the fsQCA analysis, it is crucial to assess the necessity of individual conditions. According to Rihoux and Ragin (2009), a

TABLE 6 Results of the confirmatory factor analysis.

Indicators of fit	Critical value (Recommended value)	Model indicators	Whether in conformity with
χ^2	The smaller the better	1044.134	
df	The bigger the better	474	
χ^2/df	$1 < \chi^2/df < 3$	2.203	Accord with
CFI	>0.9	0.944	Accord with
TLI	>0.9	0.938	Accord with
RMSEA	<0.08	0.061	Accord with
SRMR	<0.08	0.034	Accord with

condition with a consistency score of 0.9 or higher is regarded as a necessary condition.

To determine the necessary conditions for green technology path selection in the supply food chain sector, fsQCA software is utilized, with the consistency threshold set at 0.9. In the case of high green technology path selection, the analysis reveals that network centrality has a consistency score of 0.94. This indicates that network centrality is a necessary condition for high green technology path selection. However, for the other variables, their consistency scores are below 0.9, suggesting that they are not individually necessary conditions. This finding implies that the technological upgrading of supply chain enterprises is influenced by multiple causal conditions, thereby highlighting the significance and practicality of the fsQCA method. Similarly, for non-high green technology path selection, the persistence of entrepreneurs' attention to new technologies has a consistency score greater than 0.9. This indicates that it is a necessary condition for non-high green technology path selection.

To ensure the robustness of the results, a test is conducted on the core conditions in the absence of individual variables. The final outcomes of the necessary condition analysis are presented in Table 9.

5.3.2 Conditional configuration analysis

Core conditions are of utmost importance as they represent the key variables that are vital for achieving a particular outcome. These are the fundamental elements that have a significant impact on the result. On the other hand, peripheral conditions play a more supportive role. They are not as crucial as core conditions but still contribute to the overall outcome. Importantly, peripheral conditions only appear in the intermediate solution.

Before carrying out configurational analysis using fsQCA, a three-step procedure is adhered to:

Step 1: Constructing the Truth Table.

In this step, values are assigned to the outcomes based on specific consistency and PRI consistency thresholds. The original consistency threshold is set at 0.8, and the PRI consistency threshold is set at 0.75. Configurations that meet both of these thresholds are assigned a value of "1." This indicates that they are considered valid and relevant combinations for the analysis. Configurations that do not meet these thresholds are assigned a value of "0," signifying that they do not satisfy the required levels of consistency and PRI consistency.

Step 2: Refining the Truth Table.

This step involves further refining the truth table to ensure its accuracy and reliability. It may include tasks such as checking for any inconsistencies or ambiguities in the data, removing any redundant or irrelevant configurations, and making any necessary adjustments to the values assigned in the previous step.

Step 3: Analyzing the Truth Table.

The final step is to analyze the refined truth table. This involves examining the patterns and relationships within the data to identify the causal conditions and their combinations that lead to the desired outcomes. By analyzing the truth table, researchers can gain insights into the complex relationships between different variables and how they contribute to the overall outcome.

Refining the truth table entails determining the frequency thresholds, consistency thresholds, and dealing with logical remainders. In this study, no logical remainders emerged. However, to ensure comprehensive consideration, reasonable assumptions were made to evaluate their potential impact.

When analyzing the truth table using fsQCA 3.0 software, three solution sets are obtained: the complex solution, the parsimonious solution, and the intermediate solution. The intermediate solution is preferred in this study as it incorporates logical remainders that are supported by either empirical evidence or theory. This solution strikes a balance between complexity and simplicity, guaranteeing that the results are in line with real-world situations.

Regarding the representation of the results, this study adheres to the approach proposed by Ragin and Fiss. In this approach, "●" is used to signify the presence of a causal condition within a configuration. Conversely, "○" indicates the absence of a causal condition. A large circle is employed to denote a core condition, emphasizing its crucial role in the outcome. A small circle is used for a peripheral condition, which plays a secondary or supporting role. A blank space is reserved for conditions that do not have an impact on the outcome.

Table 9 presents the combinations of influencing factors for supply food chain enterprises during the process of technological upgrades. Based on the data, the overall consistency of the samples is calculated to be 0.948. This value exceeds the fsQCA requirement of 0.8, indicating a high level of reliability in the results. The overall coverage of the samples is 0.774, which implies that the combination of the four factors can account for 77.4% of the total sample. This demonstrates the strong explanatory power of the identified factors. The specific details of these results are further elaborated in Table 10.

According to the analysis, four configurations (H1, H2, H3, H4) lead to high green technology path transformation, with a solution consistency of 0.948 and coverage of 0.774, indicating they are sufficient conditions. For the non high green technology upgrade path, two configurations have a consistency of 0.947 and coverage of 0.705, also sufficient conditions.

> *H1*: PTfz * ATfz * RBfz * ~ NHfz * NCfz → GTU.

For the specific analysis of H1: The entrepreneur's attention to new food technologies, which is marked by a high degree of persistence, implies that the entrepreneur is committed to making a long-term and continuous investment in technology. This sustained focus on technological advancement indicates that the entrepreneur recognizes the importance of staying updated with the latest developments in the field.

Moreover, a high level of alertness to new food technologies means that the company is well-equipped to promptly detect and respond to emerging trends in the industry. This agility is crucial as it allows the company to stay ahead of the competition and adapt to

TABLE 7 Descriptive statistical analysis.

Statistical indicators	Pre-cause conditions						Outcome variable
	Network characteristics			Resource bricolage	Entrepreneurial attention		
	Source network connection strength(NS)	Network centrality (NC)	Network heterogeneity (NH)	Resource bricolage (RB)	Attention to new technologies (AT)	Persistence towards new technologies (PT)	Green technology upgrade (GTU)
Mean	4.966	4.758	4.766	5.031	5.167	5.028	4.927
Standard deviation	1.190	1.160	1.180	1.140	1.300	1.280	1.290
Maxima	7.000	7.000	7.000	7.000	7.000	7.000	7.000
Minima	1.000	1.000	1.000	1.000	1.000	1.000	1.000

TABLE 8 Calibration of each variable.

Study variable name			Critical value		
			Fully subordinate	Cross point	Not subordinate at all
Pre-cause conditions	Network characteristics	Source network connection strength (NS)	5.800	5.000	4.000
		Network centrality (NC)	5.750	5.000	4.000
		Network heterogeneity (NH)	5.600	4.800	4.000
	Resource bricolage (RB)	Resource bricolage (RB)	6.000	5.000	4.375
	Entrepreneur attention	Attention to new technologies (AT)	6.000	5.330	4.330
		Persistence towards new technologies (PT)	6.000	5.000	4.000
Outcome variable		Green technology upgrade (GTU)	6.000	5.000	4.000

changing market demands. Overall, this shows that the entrepreneur's attention has a significant impact on the technological upgrade path of food supply chain enterprises.

When it comes to resource patching, the existing resources within the company play a vital role in determining the degree of technological upgrading. These resources serve as the foundation upon which the company can build and implement new technologies.

Among the various network characteristics, network centrality emerges as a core condition. This means that the company's position at the center of the network gives it greater access to information, resources, and opportunities for collaboration. On the other hand, low network heterogeneity indicates the presence of a unified and coordinated technology platform and system. This uniformity allows for more efficient communication and collaboration within the network, facilitating technological upgrades.

Interestingly, network connection strength is found to be less significant. This suggests that the degree of technological upgrading is more influenced by internal connections within the company rather than the strength of connections with external entities. Internal connections, such as those between different departments or teams within the company, are crucial for the successful implementation and integration of new technologies.

The decision to pursue a particular technological upgrade path in the food supply chain is primarily determined by two factors: the entrepreneur's attention to new food technologies and the availability of internal resources. When entrepreneurs discover new food technologies, they first conduct an assessment of their company's resource levels. Based on this assessment, they decide whether to adopt a dependent or innovative technological path.

For latecomers in the industry, who often face limited resources and intense external pressures, they tend to utilize all available resources to upgrade their technological paths. This strategic move enables them to compete effectively in a resource-scarce and highly competitive market. By leveraging their existing resources and making strategic investments in new technologies, latecomers can enhance their competitiveness and position themselves more favorably in the market.

> *H2*: PTfz * ATfz * ~ NHfz * NCfz * NSfz → GTU.

In the detailed examination of Hypothesis 2 (H2), the entrepreneur's attention to new food technologies, characterized by both high persistence and high alertness, has a substantial impact on the technological upgrade path of food supply chain enterprises. This implies that when entrepreneurs remain consistently focused on new technologies and are highly attuned to emerging trends, it significantly shapes the direction and nature of technological advancements within their enterprises. Low network heterogeneity, in conjunction with high network centrality and network connection strength, serves as a set of core conditions. This combination indicates that when a food supply chain enterprise embarks on a technological upgrade, the entrepreneur is acutely aware of external technological changes. They closely monitor these changes and actively leverage their connections with other enterprises to foster and accelerate their own technological progress. This collaborative approach enables the enterprise to tap into a broader

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TABLE 9 Analysis of the necessity condition results.

Pre-cause conditions		Outcome variable	
		High green technology upgrade path selection	Non high green technology upgrade path selection
Network characteristics	NS	0.830	0.600
	~NS	0.550	0.840
	NC	0.940	0.780
	~NC	0.500	0.700
	NH	0.830	0.600
	~NH	0.560	0.840
Resource bricolage	RP	0.860	0.610
	~RP	0.580	0.880
Entrepreneur attention	AT	0.870	0.590
	~AT	0.490	0.810
	PT	0.840	0.580
	~PT	0.610	0.930

The symbol "~" represents the logical operation "not" or "negation".

pool of knowledge, resources, and expertise, facilitating more rapid and effective technological advancements. Interestingly, resource patching emerges as an insignificant factor in this context. This suggests that in such combinations, the size or composition of internal resources does not play a major role in determining the technological upgrade path. Instead, these enterprises primarily follow a path-dependent approach, building upon existing technologies and knowledge bases to drive their technological evolution. Within this particular combination, the technological path upgrade of food supply chain enterprises hinges on two crucial factors: the entrepreneur's attention to new food technologies and the degree of connection with other enterprises. The entrepreneur's persistent attention to new technologies acts as a driving force, guiding the overall technological strategy of the enterprise. Meanwhile, the degree of connection with other enterprises serves as a key element of this attention. It provides the enterprise with access to external resources, ideas, and collaborative opportunities that can enhance its technological capabilities. However, it is important to note that low network heterogeneity poses a limitation. While a cohesive network can facilitate collaboration and knowledge sharing, it also restricts the spread of new information. This lack of diversity in information sources can hinder the enterprise's ability to detect and respond to emerging high-tech trends, ultimately impeding technological upgrading.

To address this limitation, if an enterprise aims to maintain the entrepreneur's sensitivity to new food technologies while also possessing sufficient resources, it should consider expanding its network beyond the existing "circle of friends." By doing so, the enterprise can introduce new perspectives, ideas, and resources, injecting fresh vitality into its technological development efforts. This expansion can not only promote technological path upgrades but also contribute to sustainable economic development, enabling the enterprise to remain competitive in an ever-evolving market environment.

> *H3*: PTfz * RBfz * NHfz * NCfz * NSfz → GTU.

In the detailed examination of Hypothesis 3 (H3), the entrepreneur's attention to new food technologies is marked by a high degree of persistence. This implies that the entrepreneur remains consistently focused and committed to exploring and incorporating new external food technologies into the enterprise's operations. However, interestingly, the alertness to new food technologies is considered an irrelevant condition within this context. This suggests that while the entrepreneur's long-term attention is crucial, their immediate responsiveness to every new technological development might not play a significant role in the overall process.

The degree of resource patching is found to be high. This indicates that the enterprise actively engages in gathering and integrating various resources from its surroundings to support its technological initiatives. In terms of network characteristics, network centrality and network connection strength emerge as core conditions. Network centrality implies that the enterprise holds a central position within the network, enabling it to have better access to information, resources, and collaborative opportunities. High network connection strength further strengthens this position, facilitating seamless communication and cooperation with other entities in the network. On the other hand, network heterogeneity is regarded as a peripheral condition, suggesting that while diversity in the network might offer certain advantages, it is not a primary determinant in this particular scenario.

This configuration indicates that the entrepreneur's continuous attention to new external food technologies is at a high level. During the process of determining and following technological upgrade paths, the enterprise primarily relies on two key factors: the degree of connection with other enterprises and the amount of resources utilized. When an enterprise has abundant resources at its disposal and enjoys a high degree of connection with other external enterprises, it becomes relatively easier to achieve a technological upgrade path. This is because a rich resource base provides the necessary financial, technological, and human capital, while strong connections enable the exchange of knowledge, best practices, and collaborative efforts with peers.

This particular situation is predominantly observed in latecomer food supply chain enterprises. For instance, companies like Guangxi Zhongzhou Nanhai Shipbuilding Co., Ltd. and Liuzhou Jiangnan Foundry Co., Ltd. have consistently found themselves in a state of technological path dependence. These enterprises, to a significant extent, rely on resource factors to drive their technological upgrade and transformation processes. They combine new food technologies with their existing technological capabilities, leveraging the strengths of both to achieve incremental improvements. However, it is important to note that such food supply chain enterprises may not possess all the necessary conditions for a core technological upgrade path. They might lack certain advanced research and development capabilities, proprietary technologies, or a strong brand reputation that are typically associated with a more fundamental and independent technological upgrade.

Nevertheless, through the entrepreneur's unwavering attention to new food technologies and the strategic patching of surrounding resources, these enterprises are able to accumulate a certain amount of human and material resources. This accumulated resource base serves as a foundation for their technological upgrade efforts. When external environmental conditions change in a favorable way and the enterprise satisfies its own internal

TABLE 10 Analysis of the configuration results.

Pre-cause conditions	High green technology transformation				Non high green technology transformation	
	H1	H2	H3	H4	Nh1	Nh2
Network connection strength (NS)		●	●	●	○	○
Network centrality (NC)	●	●	●	●		●
Network heterogeneity (NH)	○	○	●	●	○	○
Resource bricolage (RB)	●		●	●	○	○
Alertness to new technologies (AT)	●	●		●	○	
Persistence for new technologies (PT)	●	●	●		○	○
Consistency	0.974	0.974	0.981	0.972	0.957	0.969
Coverage	0.448	0.434	0.683	0.669	0.651	0.557
Unique coverage	0.025	0.011	0.034	0.196	0.148	0.053
Concordance of solutions	0.948				0.947	
The coverage of the solution	0.774				0.705	

● Indicates the existence of the conditional variable, ○ Indicates the absence of the core condition, where the large circle represents the core condition, the small circle represents the edge condition, and the blank space indicates that the conditional variable is irrelevant.

requirements, it can then implement technological upgrade paths. For example, a shift in consumer preferences towards healthier or more sustainable food products might prompt the enterprise to invest in new production technologies or supply chain management systems that align with these trends. Similarly, if the enterprise has successfully integrated new resources and improved its operational efficiency, it may be better positioned to adopt more advanced technologies and move away from a path-dependent technological trajectory.

> *H4*: ATfz * RBfz * NHfz * NCfz * NSfz →GTU.

In the detailed examination of Hypothesis 4 (H4), the entrepreneur's attention to new food technologies within food supply chain enterprises is predominantly characterized by a high level of alertness. This implies that these entrepreneurs are extremely sensitive to new technological developments in the food industry and promptly begin to focus their attention on them. Such alertness is a crucial indicator of their awareness and responsiveness to emerging trends and innovations in the field. The persistence of attention also plays a significant role and should not be overlooked. It ensures that the entrepreneur's focus on new technologies is not just a momentary reaction but a sustained commitment over time. This continuous attention allows for a more in-depth exploration and understanding of new technologies, enabling the enterprise to make more informed decisions regarding their adoption and integration. The degree of resource patching is found to be high in this context. This indicates that the enterprise actively engages in gathering and integrating various resources from different sources. These resources could include technological know-how, financial capital, human expertise, and other assets that are essential for driving technological upgrades. When considering network connections, the centrality and connection strength of the food supply chain enterprise's network emerge as core conditions. A high degree of network centrality means that the enterprise occupies a central position within the network, facilitating easy access to information, resources, and collaborative opportunities. This central position enables the enterprise to stay updated on the latest industry developments and quickly respond to changes. High connection strength further strengthens this advantage by ensuring seamless communication and cooperation with other entities in the network. Conversely, network heterogeneity is regarded as a peripheral condition. This suggests that while diversity in the network can offer certain benefits, it is not a primary determinant of the enterprise's technological upgrade path. Instead, the focus is on the enterprise's ability to effectively utilize its central position and strong connections within the network.

Under this specific combination of factors, the entrepreneur demonstrates a certain level of technological attention towards the external environment. However, this attention is mainly manifested in their alertness to new food technologies. In other words, the food supply chain enterprise is highly sensitive to the emergence of new external food technologies. This sensitivity allows them to quickly identify and assess the potential impact of these new technologies on their operations.

From the perspective of resource utilization, the main driver behind the technological upgrade path of food supply chain enterprises is the effective utilization of external resources. When there is an ample supply of resources, combined with the entrepreneur's sensitivity to new food technologies, numerous opportunities for technological upgrade paths can be created. This means that in the face of changes in the external environment, such as shifts in consumer preferences, advancements in production techniques, or regulatory changes, the enterprise can rapidly adapt and upgrade its technological path. For example, if a new and more efficient production technology emerges in the market, the enterprise can quickly leverage its external resources, such as partnerships with technology providers or access to capital, to adopt this new technology and improve its overall competitiveness.

Based on the comprehensive comparative analysis of the statistical results, this paper proposes a configurational

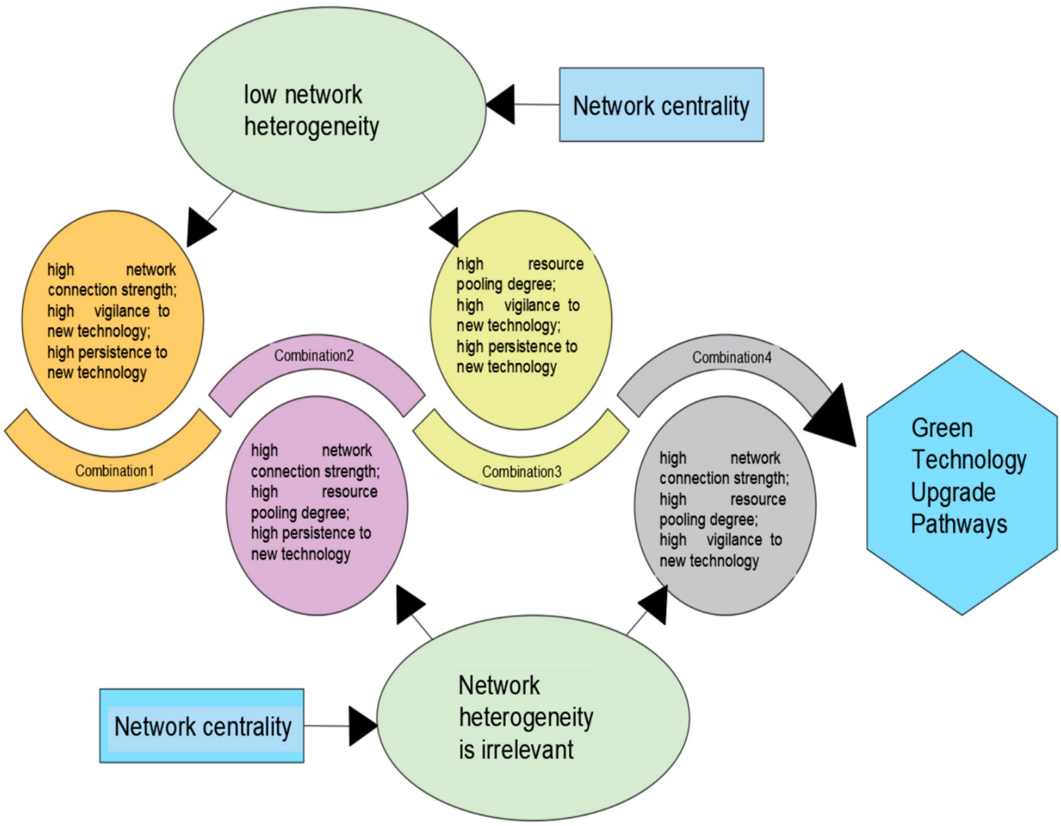

FIGURE 2
The configuration model of the key driving elements of green technology upgrading in supply chain enterprises.

model of key driving factors for the technological upgrade of food supply chain enterprises, as illustrated in Figure 2. This model provides a visual representation of the complex interplay between various factors and helps to clarify the relationships and mechanisms underlying the technological upgrade process.

5.4 Robustness test

To ensure the accuracy of the final experimental results, this paper conducted a robustness test on the causal conditions that ultimately lead to high green technology upgrade paths. By organizing and analyzing the research data, the consistency threshold for PRI was adjusted from 75 to 80%, and the configurational results were analyzed again (Mendel and Korjani, 2018). As shown in the table below, the analysis of the table and the adjustment of the case frequency and PRI consistency threshold resulted in configurational outcomes consistent with those in the previous analysis, indicating that the results of this experiment have a certain level of robustness. See Table 11.

The robustness test, excluding logical remainders and adjusting the consistency threshold from 0.75 to 0.80, confirms that the core conditions of the four factor combinations remain unchanged. The number of configurations is consistent with the original analysis, indicating high robustness of the results.

6 Discussion

Through the analysis of the above fsQCA statistical research results, this paper has identified the main combination factors in the process of technological upgrade paths for food supply chain enterprises. In summary, this study found that there is a "configurational" effect among the key driving factors affecting the technological upgrade of food supply chain enterprises; secondly, it was found that network centrality plays a certain core role in the technological upgrade path; furthermore, during the process of technological upgrade, the influencing factors tend to strengthen continuously; finally, the key impact mechanisms leading to the technological upgrade path of food supply chain enterprises were identified.

Further analysis of the four combinations reveals that there is a sustained mechanism among network connectivity, resource bricolage, and the entrepreneur's attention. When network connectivity, entrepreneurs' external attention, and resource orchestration capabilities are combined, they can generate a multiplicative effect, significantly accelerating the speed and quality of corporate technological upgrading. Network connectivity provides the foundation for acquiring external resources and information. The high level of external attention from entrepreneurs ensures that these resources and information are correctly understood and applied. Strong resource orchestration capabilities guarantee that the company can achieve its technological innovation goals within limited time and cost constraints. Therefore,

TABLE 11 Results of the robustness test.

Pre-cause conditions	High green technology transformation			
	H1	H2	H3	H4
Network connection strength (Ns)		●	●	●
Network centrality (NC)	●	●	●	●
Network heterogeneity (NH)	○	○	●	●
Resource bricolage (RB)	●		●	●
Alertness to new technologies (AT)	●	●		●
Persistence for new technologies (PT)	●	●	●	
Consistency	0.970	0.971	0.973	0.969
Coverage	0.479	0.471	0.705	0.700
Unique coverage	0.023	0.015	0.018	0.014
Concordance of solutions	0.948			
The coverage of the solution	0.774			

the organic combination of these three factors is one of the key elements for the successful realization of technological upgrading in enterprises.

7 Conclusions and policy implications

7.1 Conclusion

7.1.1 Comprehensive characteristics of factors affecting the green technological upgrade path of food supply chain enterprises

The factors affecting the green technological upgrade path of food supply chain enterprises exhibit comprehensive characteristics. These factors do not operate in isolation; instead, they interact with each other, leading to diverse combinations and conditions that correspond to various states of green technological upgrades. Therefore, in contrast to traditional research approaches, the conclusions drawn from configurational thinking tend to emphasize holistic application, thereby further enriching the existing research methodologies in this field.

7.1.2 The important role of network centrality in the process of green technological upgrades in the food supply chain

Resource bricolage and the entrepreneur's attention are crucial antecedent conditions for green technological upgrades. In the current information era, numerous food supply chain enterprises are gradually enhancing their communication with the external environment during the process of green technological upgrades. They continuously integrate available resources, and entrepreneurs utilize their market sensitivity to help the enterprise seize opportunities and achieve green technological upgrades.

Furthermore, network centrality also plays a significant role in this regard. Enterprises with higher network centrality are often in a better position to access valuable information, cutting-edge food technologies, and reliable partners within the network. This can effectively promote the green technological upgrading process by reducing information asymmetry and facilitating knowledge sharing among different entities in the food supply chain.

7.1.3 Dynamic evolution in the process of green technological upgrades for food supply chain enterprises

The research findings indicate that the green technological upgrade path of food supply chain enterprises is a dynamic process propelled by key influencing factors. As these crucial factors continuously exert their driving forces, the green technological upgrade path of such enterprises transitions from an initially relatively smooth trajectory to a final stage of self-upgrading.

This evolutionary process, to a certain degree, enriches the traditional understanding of technological upgrade paths and underscores the unique characteristics and challenges inherent in green technological upgrades within the food supply chain context. For example, as environmental regulations become increasingly stringent and market demands for sustainable food products rise over time, food supply chain enterprises must continuously adapt and upgrade their green technologies in order to remain competitive and meet the growing expectations of stakeholders. Consequently, the dynamic evolution of the green technological upgrade path emerges as an essential aspect that merits in-depth exploration.

7.2 Policy implications

The four combinations of green technological upgrade paths mentioned above are all conducive to the green technological upgrades of food supply chain enterprises. To effectively promote such upgrades within enterprises, the following recommendations are proposed:

7.2.1 Actively construct cooperative networks

By forging extensive and close cooperative ties with various stakeholders in the food supply chain and other related fields, enterprises can enhance their network centrality. This empowers enterprises to gain better access to advanced green food technologies, relevant market information, and professional knowledge resources, thus facilitating the dissemination and application of green technologies within the food supply chain.

7.2.2 Intensify entrepreneur training programs

By providing comprehensive and in-depth training, entrepreneurs can significantly enhance their awareness and understanding of external environmental conditions. This is particularly relevant in relation to green food technology trends, environmental policies, and market demands for sustainable food products. Such enhanced understanding equips entrepreneurs to make more informed and strategic decisions regarding green food technology innovation and investment. Consequently, they are better able to lead their enterprises in the pursuit of green technological upgrades.

7.2.3 Optimize resource assembly strategies

Encourage and support enterprises to actively participate in cross-sector integration and innovation activities. By dismantling sectoral barriers and facilitating the sharing and complementary use of resources among different industries, enterprises can assemble a more diverse and efficient pool of resources for green food technological development. This encompasses not only tangible resources such as raw materials, equipment, and capital, but also intangible resources like technological patents, R&D capabilities, and managerial expertise.

7.2.4 Provide sufficient financial support

Governments and financial institutions ought to allocate special funds and provide preferential loan policies in order to support the research, development, and application of green technologies within food supply chain enterprises. Simultaneously, they should streamline the approval procedures associated with green technology projects, thereby reducing administrative burdens and time costs. Moreover, reasonable incentive mechanisms, such as tax incentives, subsidies, and awards, should be designed to encourage enterprises to actively invest in green technological upgrades and continuously enhance their green innovation performance.

8 Further research and limitations

8.1 Further research

This study has provided insights into the green technology upgrade path of food supply chain enterprises, yet further research is needed. This includes expanding sample scope to cover more diverse enterprises globally and across industries, especially SMEs; conducting longitudinal and dynamic analyses to track changes over time and monitor real-time activities; exploring additional factors like digital transformation, consumer behavior, and the role of policy and incentive mechanisms, including evaluating existing policies and designing optimal incentive structures to promote sustainable development in the food industry.

8.2 Limitations

This study on the green technology upgrade path of food supply chain enterprises has limitations. Sample limitations include potential lack of representativeness due to size and industry specificity. Methodological issues involve biases in grounded theory and fsQCA, and measurement challenges in capturing variables accurately. Contextual limitations relate to temporal boundaries and unobserved external factors. Future research could address these to deepen understanding.

Data availability statement

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

Author contributions

LL: Conceptualization, Methodology, Writing – original draft. YR: Methodology, Resources, Writing – original draft, Formal analysis, Visualization, Writing – review & editing. RD: Writing – original draft, Data curation, Investigation. CL: Funding acquisition, Writing – original draft, Investigation. SM: Writing – original draft, Data curation, Validation.

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Conflict of interest

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

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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