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RESEARCH ARTICLE

# The effects of green finance on enterprises' green innovation under the "dual carbon" goal: an exploratory study based on fsQCA

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## Abstract

With increasing environmental degradation, green finance and green innovation have attracted the attention of policymakers and industries. However, the impact of green finance on corporate green innovation is still unexplored. Based on signal theory, this study analyzes the mixed effect of green finance on green innovation in enterprises. We use data from 31 provinces (333 cities in total) in China in 2021 and use a fuzzy set qualitative comparative analysis method. Green finance factors include green credit, green bond, green investment, green insurance, and green subsidy. Our research findings are as follows: Firstly, green innovation in businesses is not a product of a single antecedent situation but rather the interaction of several antecedent conditions. Green insurance and green subsidy are the core prerequisites for high green innovation in enterprises, and green credit plays an auxiliary role. Secondly, when there is a lack of green insurance, green bonds and green subsidies play a key role, leading to a high level of green innovation in businesses. Thirdly, the impact of various antecedents on the level of green innovation performance in enterprises is asymmetric. Policymakers should fully leverage the effect of green subsidy signals and minimize the risks of green innovation by expanding financing channels. Our findings enrich the literature on green innovation and finance and provide beneficial practical insights for green innovation in enterprises.

**Keywords** Green finance · Green innovation · Chinese enterprises · Signal theory · FsQCA

## Introduction

In recent years, environmental protection and governance issues have received widespread attention from decision-makers. China has been the world's greatest emitter of carbon dioxide each year since 2005, according to the World Resources Institute (Jiang et al. 2022). China's carbon dioxide emissions in 2022 were 11,480 million tons, making it undoubtedly the largest source of carbon emissions overall. Meanwhile, China has set two carbon goals, namely becoming carbon neutral by 2060 and attaining the carbon peak by 2030. It is challenging to maintain the high pollution, high energy consumption, and high investment economic development model (Kamal et al. 2021). Green innovation has become an efficient means of addressing environmental crises (Berrone et al. 2013). The term "green innovation" describes technical advancements that can better the environment by reducing pollution and energy use (Braun & Wield 1994; Usman & Hammar 2021). Compared with traditional creation, the characteristics of green creation in enterprises are long cycles, modest returns, and significant risks. Due to these traits, it is challenging for enterprises to get endogenous funding to carry out green innovation initiatives (Aboelmaged & Hashem 2019; Zameer & Yasmeen 2022). With the increasing implementation of the "dual carbon" policy, the development of green creation needs to rely on a large amount of funds (Zhang & Guo 2023). The knowledge asymmetry between investment and financing agents is reduced in a favourable financial environment, which finally results in the provision of loans to environmental firms at extremely cheap rates (Usman & Balsalobre-Lorente 2022). As of the end of 2021, China's green credit balance was 15.9 trillion yuan and green bonds worth over 600 billion yuan were issued. Green finance is closely related to the economy, society, and ecological

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environment and has a guiding role in the allocation of socio-economic resources (Musah et al. 2022). Therefore, green finance is indispensable for eliminating environmental toxins and achieving ecological environment governance objectives.

Researchers have started looking into the connection between green innovation and green financing. According to Jiang et al. (2022), green funds can promote the progress of green technologies by easing corporate funding restrictions. From the perspective of enterprise innovation, green innovation has grown to play a significant role in propelling businesses to strengthen their competitive advantages (Chen et al. 2006; Xie et al. 2019). Financial development can assist businesses in financing green projects by expanding available financing channels. By introducing funds into low-carbon and green industries, enterprises' green innovation has been encouraged (Disatnik & Steinhart 2015). Green finance helps enterprises accelerate energy efficiency, cut emissions, and support environmental transformation. In particular, green finance guides internal funds and social funds in the financial system to flow from the pollution field to the green field (Guild 2020; Li et al. 2018). In addition, green finance enhances the ability of financial institutions to monitor the recipients of funding (Mohsin et al. 2021). When using financial resources, the incentive mechanism for resource allocation can be changed to encourage green innovation in enterprises (Jahanger et al. 2022). However, most scholars focus on examining the policy effects of a single indicator, such as green credit and green bonds. There are few surveys linking the comprehensive indicators of green finance with corporate green creation.

Tracing back to existing research, the issue of how to successfully mix green innovation with funds is still in the exploratory stage, and relevant theoretical research is also relatively lacking (Yu et al. 2021). QCA can explore the impact of multiple antecedent interactions on results, thereby revealing the differential causal pathways of results (Chen & Miller 2015; Fiss 2011). As a result, we are compelled to use fsQCA to examine the connection between green finance and firms' green innovation. This study selects five representative antecedents to construct a research framework that affects green innovation in enterprises, using data from 31 provinces (333 cities in total) in China as case samples. Specifically, it responds to the following queries: Does single green finance constitute a necessary condition for enhancing green innovation in enterprises? What conditions are more important for improving green innovation in enterprises? What are the internal connections between various types of green finance? Our research makes contributions in three aspects. Firstly, we offer empirical proof that promoting green finance can help Chinese businesses adopt greener innovation. Secondly, we reveal the interactive process of green finance affecting green innovation, providing theoretical references and practical inspiration for policymakers. Thirdly, we introduce fsQCA, which helps to broaden the selection of methods in the investigation of green innovation.

The rest of this article is organized as follows: the "Literature Review and model construction" section elaborates on the literature review and model construction, "Design of research" explains the research design, "Results" conducts the data analysis, "Discussion" discusses results, and "Conclusions and policy implications" summarizes the research.

## Literature review and model construction

### *Signal theory*

American economist Spence (2002) proposed signal theory to explain how organizations reduce information asymmetry between information advantages and information disadvantages through signal transmission. The signal theory believes that the magnitude of the signal effect depends on factors such as the degree of information asymmetry between the two parties and the quality of the signal. According to the content of signal transmission, it can be divided into quality signals and intention signals (Choi & Kim 2023; Stiglitz 2000). The former indicates unobservable ability characteristics within the organization, while the latter indicates organizational behaviour or behavioural intention. Enterprises have their own technological advantages, expected returns, and potential risks, but they are unwilling to provide the market with all of this information. In order to hide the potential risks of research and development projects, companies often try to minimize information disclosure (Park 2023). From the perspective of external investors, screening high-quality innovative enterprises requires a significant investment of time and capital costs. The role of green finance in the signalling mechanism of enterprise innovation mainly lies in reducing the degree of information asymmetry (Lin & Xie 2023). Based on signal theory, green finance can transmit positive signals about the true quality of internal enterprises to the outside world, affecting the acquisition of external innovation resources. We focus on analyzing how various indicators of green finance play a signalling role in influencing enterprises' green creation.

### The impact of green finance on enterprise green innovation

Due to green finance, the issue of corporate innovation is now one of the environment rather than society as a whole (Aleksandrov et al. 2013). The New Schumpeter Growth Theory contends that over time, financial development contributes to economic and technical advancement. Developed

financial systems promote corporate innovation by providing flexible funding sources and diversifying innovation activity risks (Fan et al. 2021). To meet its "dual carbon" goals on time, China must rely on green innovation, which is impossible without sustained and stable financial support. Financial institutions develop green financial tools as a significant external funding channel, such as green bonds, green insurance, and green credit (Guild 2020). As an important factor affecting green creation in businesses, green financial products can inspire social capital to invest in green industries and increase their research and development investment. Green finance, as a catalyst for the green economy, is becoming increasingly important in promoting green economic transformation and promoting enterprise innovation (Hou et al. 2023). Zhang et al. (2021) claim that green finance improves environmental productivity by decreasing pollution emissions and boosting clean output, promoting green innovation. In the meantime, the rise of green finance has made investors aware of the importance of managing environmental disasters and the environmental risks brought about by extreme weather (Wang et al. 2021). Green finance is sometimes referred to as "environmental finance" (Zeng et al. 2022), used to describe investment and financing activities that have a positive impact on the environment and promote sustainable development. Khan et al. (2022) argue that the "green development goal" is the essential difference between traditional finance and green finance. The green financial system can provide support for innovative green projects that are challenging to fund within the standard financial system. Whether green finance can help businesses achieve green creation and broad economic upgrading is still a crucial issue.

Existing research concentrates on the linear association between single green finance and firms' green innovation, laying the foundation for further exploration of the configuration effect of green finance on businesses' green innovation. Li et al. (2018) theoretically argue that green credit will boost clean production. Based on global evidence, Flammer (2021) demonstrated that the issuance of green bonds and the development of the stock market have promoted green creation in enterprises. Ning et al. (2023) used empirical research techniques to study the effect of environmental liability insurance on corporate green creation from the perspective of green governance. Their research found that purchasing environmental liability insurance can greatly promote businesses' utilization of green creation. The innovation of financial tools provides environmentally responsible entities with more means to address the challenges of environmental climate change (Lee & Lee 2022). Financial instruments such as green bonds, green funds, and green insurance are all part of green finance. Green financial instruments can attract investors with different risk preferences to invest, thereby stimulating enterprises' green innovation motivation (Tang & Zhang 2020). In addition, by giving direct funding, local governments may encourage businesses' passion for green innovation. Green finance relies on innovative services such as green investment and tax incentives. Under regulatory policies, the allocation of green financial resources reflects the green essence (Jia & Li 2023; Yang et al. 2023). In the light of certain research, government subsidies can significantly lower capital risks associated with technological innovation and enhance enterprises' capacity for green technology innovation (Aleksandrov et al. 2013). According to Peng and Liu (2018), government green subsidies provide funding sources for enterprise research and development, helping enterprises reduce green innovation risks. Moreover, green subsidies can solve financial difficulties and reduce social pollution control costs.

All dimensions of green finance may promote green innovation (D'Orazio & Valente 2019), but there are considerable distinctions in their effectiveness. The driving factors for green innovation are not unique and independent. The conditions that lead to high-level green creation in enterprises may not be the same as those that lead to low-level green creation in enterprises. In the meantime, most literature mainly explores the net effects of potential factors, neglecting the integration analysis of multi-level elements of enterprises' green innovation. In consideration of the above limitations, we introduce the fsQCA approach and investigate how green investing, green insurance, green bonds, and green subsidies affect enterprise green creation. Additionally, we find a combined model to boost the effectiveness of green innovation in Chinese businesses.

## Model construction

### Green credit with enterprise green innovation

Green credit refers to banks offering preferential interest rates to environmental protection businesses while imposing punitive interest rates on polluting businesses during lending (Lin & Pan 2023). Green credit is aimed at adjusting social capital flow and promoting green transformation. As the most important green financial tool, green credit is a key source of funding for enterprises to engage in green innovation. Specifically, banks can provide preferential interest rate loans to green enterprises through green credit to support their research and development activities. Based on data from American companies, Goetz (2019) confirms that green credit may lower an enterprise's long-term debt financing costs, thereby promoting their green technology research and development.

According to signal theory, green credit releases signals to the outside world to reduce capital costs and improve investment efficiency (He et al. 2019a, b). Through differentiated monetary and financial policies, green credit promotes

capital inflows into efficient, energy-saving, and low-polluting green projects. The signal mechanism of green credit will promote the optimization of economic structure and improve the quality of economic growth (Dong et al. 2020). In addition, punitive measures for green credit will weaken loan support for polluting industries, driving them to phase out outdated production capacity. Therefore, green credit encourages enterprises to improve and innovate production technology, thereby enhancing the level of green innovation.

#### Green investment with enterprise green innovation

Green investment is proposed in the context of a sustainable development strategy. Internal green investment aims to lower environmental expenses while enhancing environmental performance (Eyraud et al. 2013; Liao & Shi 2018). Enterprises' use of green innovation is directly impacted by green investment. On the one hand, eco-investing guides and leverages social and economic resources towards green industries like clean production, clean energy, ecological environment, and energy conservation and protection. Green finance can inspire green innovation by increasing the company's environmental investment. On the other hand, eco-investing is conducive to reducing pollution emissions of the whole society and improving resource utilization efficiency (Pavlyk 2020). Green investment promotes green technology research and development by suppressing the flow of capital to high-pollution and high-energy-consuming enterprises, thereby achieving green innovation.

According to signal theory, green investment by enterprises releases signals to reduce greenhouse gas and air pollutant emissions. Enterprises that obtain green investment have a higher number of patent applications, valid patents, and patent citations. Green investment increases the scale of enterprise research and development expenditure and talent introduction expenditure, which enhances the motivation for enterprise green technology creation (Musah et al. 2022). At the same time, the institutions participating in green investment will also directly transfer their good reputation, management experience, and resources to the invested enterprises, increasing their green innovation resource advantages. In addition, the Environmental Protection Department reviews the environmental credit records of listed companies. It publishes the list of polluting enterprises so that investors can find green investment projects more accurately and quickly. Green investment signals reduce transaction costs between companies and investors, and companies can focus more on green innovation activities.

#### Green insurance with enterprise green innovation

Environmental liability insurance is commonly known as green insurance. Green insurance refers to the financial support and risk management provided by the insurance industry, involving aspects such as green industry operation, social governance, environmental resource protection, and green living consumption (Lyu et al. 2022; Ning et al. 2023). Green insurance is divided into the liability side and the asset side. The former speaks to the services and insurance products offered by insurance institutions around green, low-carbon, and sustainable development, while the latter involves investing insurance funds in the environmental sector. Green insurance is an institutional arrangement that disperses, protects, and compensates for the operational risks of the insured. Corporate innovation is a high-risk investment frequently affected by unreliable supplementary capital markets and financial constraints caused by fees (Bai et al. 2018). Green insurance not only performs the fundamental duties of insurance but also has a special function of fostering green innovation and restructuring the industrial sector.

According to signal theory, a sound insurance product system releases signals to the market to relax financing constraints and reduce agency costs, which is conducive to promoting green creation for businesses (Hsu et al. 2021; Yin et al. 2022). Enterprises delegate their environmental responsibilities to insurance companies by obtaining green insurance. Green insurance lowers compensation losses and operational risks caused by environmental pollution, prompting banks to relax loan conditions and loosen corporate financing constraints. A solid business environment and green innovation investment are also necessary for supporting green innovation (Ferreira et al. 2014; Manso 2011). Green insurance purchases help to improve managers' tolerance for green innovation risks and encourage CEOs to carry out green creation boldly. Purchasing green insurance also aids in creating a setting for green innovation where decisions are made that are generally stable. Finally, green insurance reduces the agency costs of management through incentive effects and stimulates the importance of green innovation for enterprises.

#### Green bond with enterprise green innovation

The green bond is an emerging debt financing tool with both "green" and "financial" characteristics and an essential step towards creating a sustainable financial system (Li et al. 2023; Zerbib 2019). As a direct channel to ease financing constraints, green bonds are the main force of green finance to achieve optimum resource allocation. Green bonds mainly reduce climate pollution by funding projects harmless to ecosystems, such as solar energy, clean water, and clean cars (He et al. 2019a, b). Green bond mainly reflects the ability of listed companies to raise funds through bond issuance. By increasing the number of green bonds, institutions can increase the environmental premium and reduce their financing costs by issuing bonds to clean R&D enterprises.

According to signal theory, issuing green bonds by enterprises can send two positive signals. Firstly, green bonds release signals to external investors that the company is actively fulfilling its green social responsibility. Secondly, green bonds convey a top-down transformation signal to internal members and also clarify the strategic intention of the group to comply with the trend of green development. Guiding enterprises to implement green innovation through green bonds can improve the overall market competitiveness and financial performance (Zhang & Guo 2023). At the same time, restraining polluting enterprises from issuing bonds for financing will encourage them to put green innovation activities into effect. Therefore, green bonds help businesses develop sustainably and serve as a major impetus for them to perform better in terms of environmental governance and green innovation.

### Green subsidy with enterprise green innovation

Green subsidies are financial support provided by government departments to help enterprises prevent and control environmental pollution (Květoň & Horák, 2018). The government supports the development of corresponding enterprises and ecological environment protection by establishing green subsidies. Under increasingly strict environmental regulations, green creation for firms requires higher costs compared to general creation. If long-term high investment fails to make a profit, the enterprise will stop green innovation due to insufficient funds. The role of government green subsidies on corporate innovation has been extensively discussed by both domestic and foreign experts, although the results are inconsistent. Some scholars believe that government subsidy funds provide resource support for green innovation, which is conducive to easing corporate finance restrictions and stimulating the generation of green innovation. Contrarily, some academics additionally mention that the role of government green subsidy in enterprises' green innovation is not significant (Balasubramanian & Lee 2008). Green subsidies can help promote growth and decline period enterprises, but this effect is not significant for mature enterprises.

According to signal theory, managers will interpret positive signals from government green subsidy policies, thereby increasing R&D investment in green innovation (Aerts & Schmidt 2008). The positive signals released by government research and development subsidies can help enterprises access external innovation resources and effectively promote innovation. In order to enhance enterprise readiness for green innovation and offset their green development costs, the government generally adopts incentive measures to promote green business behaviour of enterprises (Bellucci et al. 2019). Government green subsidies can help enterprises raise funds and reduce the cost of green innovation, stimulating their enthusiasm for implementing green innovation activities. Especially for high-polluting enterprises in their growth period, government green subsidies provide timely assistance for their green creation and play a crucial role.

In summary, it is challenging for a single green finance indicator to cover all the funding requirements of an enterprise's green innovation process. As an organic system, green finance consists of green credit, green investment, green insurance, green bonds, and green subsidies. These antecedents not only have complementary substitutability but also have synergistic connections in the process of improving the green innovation performance of businesses. For the sake of deeply exploring the causal complex mechanism of green finance on businesses' green innovation, we construct a conceptual model based on a configuration perspective. Figure 1 illustrates the conceptual model.

## Design of research

### Selection of research methods

From a configuration perspective, the article's approach to problem analysis is the QCA. QCA takes a holistic perspective to conduct case-level comparative analysis (Ragin 2009), with every situation being viewed as a "configuration" of conditional variables. Unlike traditional analysis techniques, QCA analysis seeks to identify the causal relationship between conditional configurations and results by

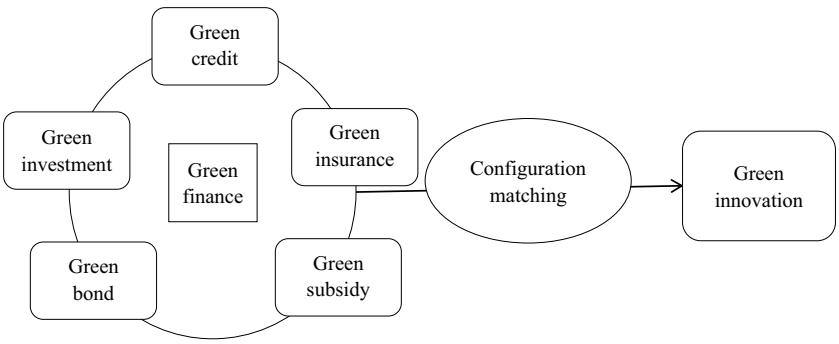


**Fig. 1** Conceptual model

comparing different situations. Besides, QCA can determine which variables and configurations are necessary or adequate conditions for the results. Clear set qualitative comparative analysis (csQCA), multivalued set qualitative comparative analysis (mvQCA), and fuzzy set qualitative comparative analysis (fsQCA) are the three subtypes of QCA. FsQCA can address difficulties relating to degree changes or partial membership, while csQCA and mvQCA are exclusively appropriate for handling category concerns. As a result, fsQCA has become increasingly popular in recent years in pertinent empirical research (Du & Kim 2021; Kraus et al. 2018).

Firstly, according to QCA analysis, there are several concurrent causal links as a result of the interdependence and various combinations of the antecedent conditions (Ragin 2009). FsQCA can solve the problem of accomplishing the same goal via multiple paths, which helps to gain knowledge about the differentiated green innovation driving mechanism in Chinese firms. Secondly, the benefits of qualitative and quantitative analysis are combined by the QCA approach, allowing for both large-scale case analysis and overall conditional configuration analysis at the case level (Schneider & Wagemann 2012). Thirdly, the conclusions drawn based on fsQCA have high accuracy and strong reliability (Zhang & Du 2019). The fsQCA method has significant advantages in exploring the linkage matching and complementary substitution effects of different antecedent conditions. Therefore, we adopt the fsQCA method in this study.

## Cases and data sources

This study follows the principle of selecting QCA case samples, using 31 provinces (333 cities in total) in mainland China as case samples, with data selected in 2021. Green finance is categorized into five dimensions based on the connotation and service types: green bond, green credit, green insurance, green subsidy, and green investment. Authorities like the People's Bank of China, the Bureau of Statistics, and a number of statistical yearbooks, including national and provincial statistical yearbooks, environmental status reports, and other specialized statistical yearbooks, provide the data for these conditional variables. The green patent information is provided by the Chinese Intellectual Property Office. The World Intellectual Property Organization (WIPO) unveiled the "International Patent Classification Green List" search engine. In order to find and count how many green patents there are, we manually search patents pertaining to environmentally friendly technology in accordance with the division of green patent search entries. Finally, in order to ensure the validity of the data, we eliminated cases of missing data.

## Variable measurement

### Result

The outcome variable is green innovation. Most scholars use the number of green patent applications or green patent authorizations to measure green innovation (Chen et al. 2022; Zhao & Wang 2022). Patent applications require companies to have strong research and development capabilities in green technology. As the primary form of green innovation achievements for enterprises, the technical threshold for patent application is very high. Therefore, the number of patents in a company better reflects a strong capacity for green creation. On the other hand, the patent application situation cannot be fabricated, and compared to other measures, its data sources are more impartial and accurate (Zhang et al. 2022). Based on this, we gauge an enterprise's capacity for green creation using the number of green patent applications filed yearly. Specifically, to get the total number of green patent applications, the number of green utility model patent applications and the total number of green invention patent applications are added together.

### Antecedents

The conditional variables are green investment, green insurance, green bonds, green credit, and green subsidy.

Firstly, green credit. In December 2019, the Central People's Bank of China revised the green credit statistical system based on the "Green Credit Industry Guidance Catalogue". The People's Bank of China system divides green credit into six categories based on its purpose: clean production, clean energy, ecological environment, infrastructure green upgrading, green services, and energy conservation and environmental protection industries. The credit for environmental protection projects comprehensively covers the requirements of the green credit statistical system (He et al. 2019a, b). Therefore, we measure green credit by the ratio of credit for environmental protection projects to overall credit.

Secondly, green investment and green insurance. We measure green investment by the ratio of investment in environmental pollution control to GDP. Meanwhile, the promotion degree of environmental pollution liability insurance is used to measure green insurance, that is, the proportion of environmental pollution liability insurance income to total premium income.

Thirdly, green bonds and green subsidies. Based on the regional data obtained from the above data collection process, the degree of green bond development is used to measure green bonds. The ratio of the issuance of green bonds to the overall issuance of all bonds is the degree of green bond development. Finally, to accurately measure the impact of green subsidies on green innovation in

enterprises, this study obtains green subsidy data by manually selecting detailed government subsidy items. Specifically, we measure green subsidy by the ratio of budgetary spending on environmental protection to overall budgetary spending. Table 1 displays each variable's particular circumstance.

### Calibration of variables

Before the qualitative comparative analysis of the fuzzy set, all variables need to be calibrated. Specifically, each circumstance and outcome is handled as a separate set, and each instance receives a score indicating its membership in a particular set (Schneider & Wagemann 2012). Calibration means that according to theoretical understanding and empirical evidence, researchers calibrate variables into sets. Following calibration, the set's membership falls between 0 and 1. In the fsQCA software, the calibrate function is used to calibrate, and the calibration threshold is determined by the percentile (Fiss 2011; Ragin 2009). The information in this piece is based on statistical data, which has high reliability and wide applicability but lacks external basis and theoretical standards for calibration. Therefore, drawing on the research of Ragin (2009) and Fan et al. (2017), this study uses the direct method for calibration. The thresholds for complete membership and complete non-membership are set at 95% and 5% of the case data, respectively, and 50% as the crossover point. In the calibration process, some sample data is equivalent to 0.5, which needs to be avoided (Greckhamer 2016). The existence of the maximum ambiguity point will cause cases to be challenging to categorize and not include in the analysis, thus reducing the final sample size. Therefore, we correct the true value of 0.5 to 0.501 according to the established practice (Du & Kim 2021). Table 2 displays all conditional and outcome variables' calibration anchor points.

**Table 2** Calibration threshold of each variable

| Variables | | Calibration | | |
|---|---|---|---|---|
| | | Fully in | Crossover point | Fully out |
| Outcome | Green innovation | 3.3712 | 1.987 | 0.9104 |
| Antecedents | Green credit | 8.803 | 5.319 | 1.5712 |
| | Green investment | 2.3184 | 1.303 | 0.3968 |
| | Green insurance | 3.9094 | 2.344 | 0.7248 |
| | Green bond | 1.4746 | 0.77 | 0.2278 |
| | Green subsidy | 1.7468 | 0.717 | 0.1866 |

## Results

### Necessity conditions analysis

Referring to existing research practices, this study tests whether a single condition of green finance is a necessary factor for green creation in firms (Schneider & Wagemann 2012). The key indicator for measuring necessary conditions is consistency. If the consistency coefficient of a single factor is higher than 0.9, then this factor is a necessary factor for the result (Zhang et al. 2020). The necessity test results of the antecedent variables obtained by applying fsQCA software are shown in Table 3. From the outcomes, we can see that the maximum consistency coefficient of the antecedent conditions is 0.762163, which is lower than 0.9. Therefore, whether the enterprise has a high level of creation and the requirements for green finance cannot be limited to one (Greckhamer et al. 2018). The results of the necessity analysis also reflect the complexity of businesses' green innovation, which means that firms' green innovation is generated by the synergy of multiple conditions of green investment, green insurance, green bonds, green credit, and green subsidies. It is essential to put antecedents together and study how green finance affects green innovation from the perspective of configuration.

**Table 1** Variables and measurements

| Variable type | Variable name | Measurement |
|---|---|---|
| Outcome | Green innovation | The number of green patent applications |
| Antecedents | Green credit | The proportion of credit for environmental protection projects to total credit |
| | Green investment | The ratio of investment in environmental pollution control to GDP |
| | Green insurance | The ratio of environmental pollution liability insurance income to total premium income |
| | Green bond | The ratio of issuance of green bonds to the overall issuance of all bonds |
| | Green subsidy | The ratio of budgetary spending on environmental protection to overall budgetary spending |

**Table 3** Necessity analysis of single condition

| Antecedent conditions | High green innovation | | Not high green innovation | |
|---|---|---|---|---|
| | Consistency | Coverage | Consistency | Coverage |
| Green credit | 0.727405 | 0.715376 | 0.608577 | 0.611287 |
| ~Green credit | 0.604752 | 0.602025 | 0.716637 | 0.728633 |
| Green investment | 0.709862 | 0.709044 | 0.608874 | 0.621153 |
| ~Green investment | 0.620716 | 0.608432 | 0.714795 | 0.715603 |
| Green insurance | 0.731896 | 0.707665 | 0.614705 | 0.607038 |
| ~Green insurance | 0.593583 | 0.601339 | 0.703972 | 0.728393 |
| Green bond | 0.708272 | 0.713900 | 0.605861 | 0.623710 |
| ~Green bond | 0.626677 | 0.608881 | 0.722087 | 0.716556 |
| Green subsidy | 0.699415 | 0.742220 | 0.570005 | 0.617801 |
| ~Green subsidy | 0.639843 | 0.592988 | 0.762163 | 0.721426 |

## Analysis of the antecedent configuration's sufficiency

Sufficiency analysis is mainly to analyze the sufficiency of configurations created by various antecedent conditions, which is the core of the QCA method. Following the operation principle of fsQCA, we use the truth table for evaluation and set the thresholds. The consistency level for assessing sufficiency should not be less than 0.75, according to Schneider and Wagemann (2012). Some scholars suggested that the consistency level for assessing sufficiency should be increased to 0.8 (Du & Kim 2021). We finally adopted 0.8 as the sufficiency threshold. The truth table for all logically possible configurations is $2^k$ rows (Fiss 2011). In this study, there are 32 ($2^5$) rows. We set the raw consistency threshold at 0.8 (Schneider et al. 2010). Based on the size of the survey sample, we set the frequency threshold of cases where enterprises participate in green creation to 1 (Nijssen & Ordanini 2020; Schneider & Wagemann 2012). At the same time, following the research suggestion of Zhang and Du (2019), the PRI threshold was set to 0.70. After conducting standard analysis on running data, simple solutions, moderate solutions, and complex solutions are gained. The simple answer contains all logical residuals, but its rationality is not evaluated. The moderate solution only includes logical residuals that are consistent with the theoretical framework and empirical data. Besides, there are no logical rests in the complex solution. According to the QCA analysis results presented by Ragin (2009) and Fiss (2011), the antecedent condition that only exists in the moderate solution is the auxiliary condition. The core condition is the prerequisite that exists simultaneously in both the moderate answer and the simple answer. The final analysis outcomes are shown in Table 4. In Tables 4 and 5, "●" and "⊗" represent, respectively, the presence and non-existence of the core prerequisite. "●" and "⊗" represent the presence and non-existence of the

**Table 4** Precondition configuration for regional green innovation

| Antecedent conditions | High green innovation | | | | Not high green innovation | |
|---|---|---|---|---|---|---|
| | H1 | H2 | H3 | H4 | L1 | L2 |
| Green credit | ● | ● | ⊗ | ● | | ⊗ |
| Green investment | | ⊗ | ⊗ | ● | ● | ● |
| Green insurance | ● | ● | ⊗ | ⊗ | • | ⊗ |
| Green bond | ⊗ | | ● | ● | ⊗ | |
| Green subsidy | ● | ● | ● | ● | ⊗ | ⊗ |
| Raw coverage | 0.387 | 0.376 | 0.315 | 0.317 | 0.316 | 0.332 |
| Unique coverage | 0.039 | 0.021 | 0.013 | 0.009 | 0.023 | 0.039 |
| Consistency | 0.885 | 0.900 | 0.915 | 0.919 | 0.887 | 0.878 |
| Overall solution coverage | 0.448 | | | | 0.355 | |
| Overall solution consistency | 0.878 | | | | 0.869 | |

**Table 5** Robustness test

| Antecedent conditions | Adjust the consistency threshold | | | Change the calibration threshold | | | |
|---|---|---|---|---|---|---|---|
| | H2’ | H3’ | H4’ | H1’’ | H2’’ | H3’’ | H4’’ |
| Green credit | ● | ⊗ | ● | ● | ● | ⊗ | ● |
| Green investment | ⊗ | ⊗ | ● | | ⊗ | ⊗ | ● |
| Green insurance | ● | ⊗ | ⊗ | ● | ● | ⊗ | ⊗ |
| Green bond | | ● | ● | ⊗ | | | ● |
| Green subsidy | ● | ● | ● | ● | ● | ● | ● |
| Raw coverage | 0.376 | 0.315 | 0.317 | 0.334 | 0.320 | 0.330 | 0.264 |
| Unique coverage | 0.070 | 0.013 | 0.017 | 0.041 | 0.020 | 0.062 | 0.011 |
| Consistency | 0.900 | 0.915 | 0.919 | 0.835 | 0.853 | 0.821 | 0.875 |
| Overall solution coverage | 0.409 | | | 0.446 | | | |
| Overall solution consistency | 0.894 | | | 0.804 | | | |

auxiliary prerequisite, respectively. In addition, a space can signify the existence or absence of a situation.

This study discovers four paths that may bring about high-level green innovation. The total solution consistency is 0.878, indicating that among all enterprise cases that satisfy the above conditions, 87.8% of enterprises present high-level green creation results. The total solution’s coverage is 0.448, indicating the above four types of conditional configurations may explicate 44.8% of the sample’s high-level green innovation cases in the sample. We further discover two paths that might not result in high levels of green innovation. According to the consistency of the overall solution (0.869), the obtained configuration path can effectively cover the example situation and has a coverage rate of 0.355. Table 4 shows that the consistency level of individual or overall solutions for each configuration is 0.8 higher than the acceptable minimum standard. Therefore, the conditional allocation of this study can be considered as a sufficient combination of factors for high-level or non-high-level green innovation in a company. The five conditions of green investment, green insurance, green credit, green bond, and green subsidy are not sufficient conditions for green innovation of companies in themselves. However, the combination of these six conditions has reached sufficiency.

In configuration H1 (Green insurance * ~ Green bond * Green credit * Green subsidy) and configuration H2 (~ Green investment * Green insurance * Green credit * Green subsidy), green subsidy and green insurance are the core prerequisites leading to high green innovation in enterprises. Green credit plays a supporting role. When green insurance is absent, green bonds and green subsidy play a key part in the configuration of H3 (~ Green investment * ~ Green insurance * Green bond * Green subsidy * ~ Green credit) and H4 (Green credit * Green investment * ~ Green insurance * Green bond * Green subsidy), leading to a high level of green innovation among businesses. In the H4 configuration, green investment plays a core role, while a supporting role is played by green credit. In the non-high-level green innovation implementation configuration L1 (Green investment * Green insurance * ~ Green bond * ~ Green subsidy) and configuration L2 (Green investment * ~ Green insurance * ~ Green credit * ~ Green subsidy), the absence of green subsidy and the existence of green investment are the core factors. In the former configuration, green insurance exists as an auxiliary antecedent, and the lack of green bonds exists as a core antecedent. As opposed to the former configuration, in the latter configuration, when green bonds exist or do not exist, the deficiencies of both green credit and green insurance play a central role.

### Robustness test

We conducted robustness testing based on the experience of previous scholars using the fsQCA method in their research. Zhang and Du (2019) proposed that calibration standards can be adjusted, and original consistency thresholds can be raised to verify robustness. Table 5 displays the check outcomes. Firstly, the initial consistency threshold is raised from 0.8 to 0.9, resulting in three configurations. The number of conditional configurations has been simplified and included in the original conditional configuration. Meanwhile, the essential explanation has not changed. The overall consistency level increases from 0.878 to 0.894, and the overall solution coverage decreases from 0.448 to 0.409. Compared with the results with a consistency threshold of 0.80, the test results show relatively small changes. Secondly, this study further changes the calibration thresholds of the five conditional variables. We adjust the complete membership threshold, intersection threshold, and complete non-membership threshold from 95%, 50%, and 5% to 90%, 50%, and 10%. The results show that except for minor changes in the analysis data, there is no significant change in the conditional configuration analysis results. The overall consistency level decreases from 0.869 to 0.804, and the overall solution coverage increases from 0.355 to 0.446. It is evident that our research findings are still solid.

## Discussion

Signal theory is based on the assumption of reducing information asymmetry between information advantages and information disadvantages. At the same time, there are also issues with the quality of signals (Connelly et al. 2010). There are differences in the degree of information asymmetry and signal quality in areas with different intensities of green finance implementation. Therefore, the impact of various indicators of the green finance on green creation of enterprises varies. Using a theoretical examination and comparison of the antecedent configurations of green innovation, this study proposes the following three propositions.

Firstly, green insurance and green subsidies can jointly motivate Chinese enterprises to implement green innovation activities. We name this situation as insurance-subsidy driven (H1, H2). From the perspective of signal quality, in areas with better implementation of green insurance, the signal quality released by government green subsidies is higher. However, only the two conditions of green insurance and green subsidy are insufficient to improve the green innovation of firms. Green credit exists as an auxiliary condition, expanding the possibility of green innovation. In configuration H1, regardless of green investment, when green bonds are insufficient, green innovation of enterprises can still be promoted, because the signal mechanism linking green insurance, green subsidies, and green credit has raised sufficient innovation funds for enterprises. Green insurance and green subsidies are core conditions, while green credit is an auxiliary condition. The consistency of configuration H1 is 0.885, with a 0.387 original coverage rate and a 0.039 unique coverage rate. It implies that this path can interpret 38.7% of high-level green innovation cases, of which 3.9% can only be interpreted by this path (as shown in Fig. 2).

In areas with poor credit and insurance environments, the signals released by government green subsidies are distorted. Low-quality signals increase the degree of information asymmetry between enterprises and external resource owners. Therefore, the acquisition of external innovation resources by enterprises is hindered, which inhibits their innovation. Compared to configurations H1 and H2, configuration L2 lacks green credit, green insurance, and green subsidy. Even if enterprises can raise enough green investment, they are unwilling to implement low-carbon environmental protection projects, and their green innovation performance is not high. In configuration H2, if a company lacks green investment, regardless of how green bonds are, the company can still complete a large amount of green innovation. At this point, green insurance and green subsidies are high, and green credit serves as an auxiliary condition for enterprises. Configuration H2 has a consistency of 0.900, with an original coverage rate of 0.376 and a unique coverage rate of 0.021. As shown in Fig. 3, this path covers cases from 10 provinces in China, including Jiangsu and Guangdong. In the process of transitioning to a green economy, with the development of green creation, enterprises are full of uncertainty. Insurance companies can create customized green insurance goods and services for innovating enterprises, aiding them in efficiently addressing innovation risks in green technology research and development.

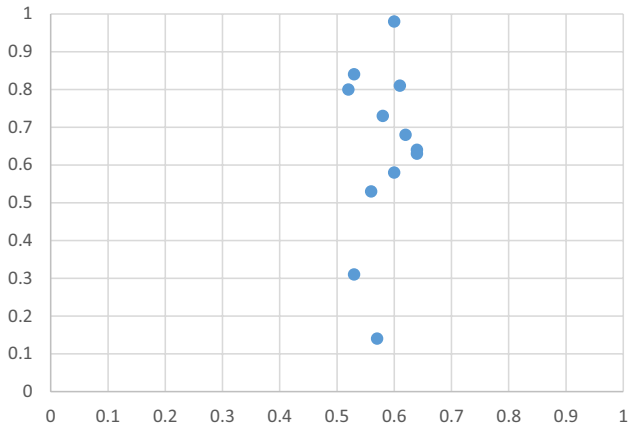


**Fig. 2** Cases covered by configuration H1

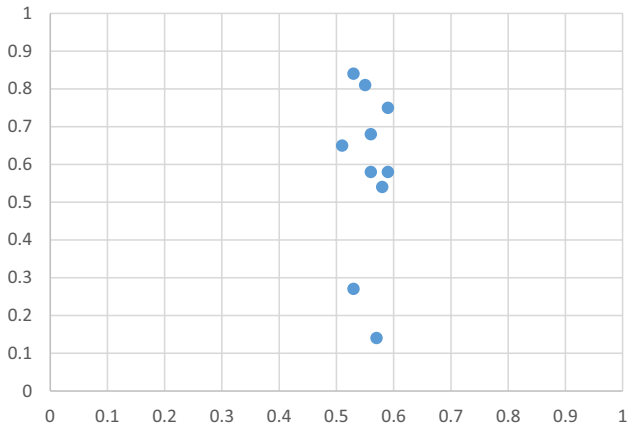


**Fig. 3** Cases covered by configuration H2

Secondly, green bonds and green subsidies are the core premise for enterprises to achieve high-level green innovation without purchasing green insurance. We name this situation bond-subsidy driven (H3, H4). The consistency values for H3 and H4 configurations are 0.915 and 0.919, respectively. These two values are higher than the overall consistency of 0.878 for high-level green creation samples. The signal quality of corporate green bonds is higher, which is more conducive to external investors making investment decisions and providing them with innovative resources. Green subsidies and green bonds play a central part in the process of green innovation of companies, and other conditions are irrelevant to high-level green innovation of businesses. In the case of firms configured with H3 (as shown in Fig. 4), a favourable environment for green bond issuance has grown to be a key driver in encouraging business innovation in Shandong, Sichuan, and five other provinces. The original coverage of this path is 0.315, and the unique coverage is 0.013. Compared with configurations H3 and H4, the case enterprises in configuration L1 purchased green insurance. However, a poor performance of green innovation was caused by a lack of green bonds and green subsidies.

Thirdly, the results of all the above configurations reflect that compared to other conditions, green subsidy is the most crucial factor in improving green innovation for Chinese enterprises. Green subsidies directly alleviate the pressure on research and development funds and release positive signals of the company's research and development prospects to the outside world. This signal can attract innovative resources such as external funds, talent, and technology to enter, thereby promoting enterprise innovation. The case covered by H4 is shown in Fig. 5. Investment institutions in Hunan Province pursue short-term high returns and may not be able to support the innovation activities of businesses in the long term. The original coverage of this path is 0.317, and the unique coverage is 0.009. To obtain long-term financial support, enterprises also need to consider funding support from other sources of investment. Government green subsidies provide funding sources for enterprise research and development, reducing the cost of social pollution control. In addition, green subsidies can help solve the financial difficulties of enterprises and reduce the risks of green innovation (Peng & Liu 2018). Therefore, the government should attach importance to financial support for enterprises.

## Conclusions and policy implications

### Research conclusions

On the basis of signal theory, this study discusses the "combined effect" of five green financial conditions, namely green insurance, green bond, green credit, green investment, and green subsidy, on enterprise green innovation. We collect

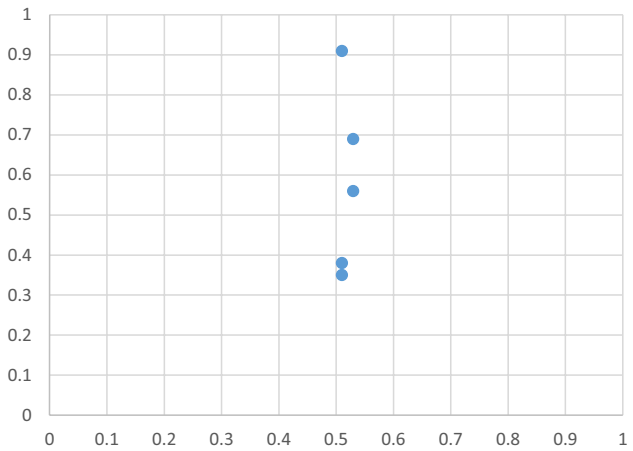


**Fig. 4** Cases covered by configuration H3

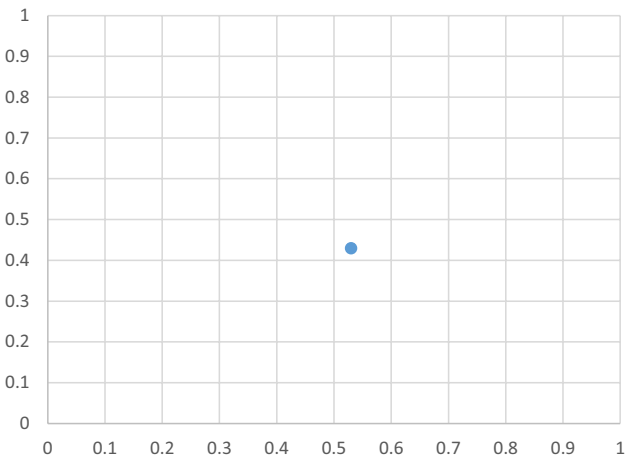


**Fig. 5** Cases covered by configuration H4

sample case data from 31 provinces (333 cities) in China and use fsQCA to investigate factor allocation in various scenarios. Firstly, firm green innovation is the result of multiple conditions, collaborative interaction, and joint action. The outcomes of necessity analysis indicate that none of the five antecedents under the green finance system can provide the necessary conditions for firms' green innovation alone. Secondly, the performance of green innovation in firms is influenced by multiple antecedents, and the impact of each antecedent on the performance of green innovation in businesses is asymmetric. The results of adequacy analysis indicate that various antecedent configurations can lead to both high-level and non-high-level green innovation. There are four driving paths for high-level green innovation in businesses, which can be summarized as two adaptation models, namely insurance-subsidy driven and bond-subsidy driven. Thirdly, green subsidy is the most crucial factor in enhancing green innovation among Chinese enterprises. In addition, green insurance and green subsidies are the core prerequisites for high green creation in enterprises, with green credit playing a supporting role. When there is a lack of green insurance, green bonds and green subsidies play a crucial role, leading to higher levels of green creation in enterprises.

## Implications

From both theoretical and practical perspectives, we offer the following recommendations for the implementation process of green creation in enterprises.

(1) The green subsidy is the core indicator for companies to achieve high-level green innovation, indicating that the government should increase funding to inspire companies to carry out green innovation activities. Policymakers should attach importance to providing financial support to enterprises and minimize the risks of green innovation by expanding financing channels. To effectively leverage the signal effect of green subsidies, enterprises should actively understand the government's green subsidy policies. By submitting real information on one's own technological innovation capabilities and research and development projects to the government, the possibility of obtaining green subsidies is increased. However, relying solely on government funding is far from enough.

(2) Green insurance can encourage businesses to cut carbon emissions and raise the bar for green innovation. At the same time, the favourable environment for the issuance of green bonds may stimulate businesses' interest in eco-friendly innovation. The insurance industry should fully leverage the advantages of green insurance to help attain the "dual carbon" goals, as well as continuously improve the risk protection capabilities of enterprises in response to green innovation. The comprehensive insurance services for green and low-carbon transformation are provided by green insurance. Green insurance positively influences social development, environmental protection, and the progress of social civilization.

(3) For businesses engaged in green technology research and development, relevant financial institutions should give priority to supporting their credit investment and financing activities. Fully leverage the role of green finance in fostering eco-friendly innovation and promoting superior economic development. The problems faced by enterprises in green credit, such as information asymmetry and inefficient credit allocation, need to be addressed. Banks can increase the threshold and cost for polluting enterprises to access credit resources. Promote green investment of enterprises to play its role in improving environmental governance. Although green investment occupies a certain amount of financial funds for enterprises, it can improve environmental quality to a certain extent.

(4) The government should fully utilize the guiding function of green finance in resource allocation and hasten the advancement of the green finance audit system. Establish a monitoring mechanism for green funds to strictly control the use of green funds, thereby reducing the risk of green innovation. On the one hand, the government should simplify the application procedure for environmentally friendly, green, and low-carbon industries. More social capital should be directed and encouraged to invest in the green economy. Priority should be given to green innovation projects in the approval process. In the meantime, credit penalties should be imposed on fake green companies and illegal green investments. On the other hand, the government should alleviate corporate financing constraints and ensure adequate financial support for business green innovation. Raising the environmental threshold for polluting enterprises to access green financial resources forces them to innovate green.

(5) The signal theory is applicable to the study of green finance on green innovation in enterprises. This study verifies the existence of a green finance signalling mechanism and provides more favourable evidence for government-guided research on enterprises achieving innovation through green finance. Creating a low-carbon economy and assisting companies in achieving energy saving and emission reduction through green financing are the goals of developing green finance. Enterprises can establish a positive external environment and advance their green transformation process by receiving financial support. To secure the long-term growth of green innovation activities, diversified

financing sources are obtained through risk management and resource allocation in green finance.

## Contributions

Our study adds to the body of literature in three different ways.

Firstly, we demonstrate through empirical research how green finance may encourage green innovation in Chinese businesses. This study obtains four high-level green innovation configuration paths and two non-high-level green innovation configuration paths. The experimental outcomes prove that various conditions of green finance interact with each other, forming diversified configurations. Drive green creation in enterprises by achieving the same goal through different routes. Our research findings will help managers discover potential ways to combine different conditions to achieve high-level green innovation performance.

Secondly, this study not only provides theoretical guidance and practical inspiration for decision-makers but also promotes the integration and development of green finance and innovation theory. The intricate interactive relationship between green finance and green innovation has been revealed. This study shifts the focus of the green innovation-driven model of firms from the impact of single-layer antecedent conditions to the linkage effect of multiple antecedent conditions. Meanwhile, we underline the need for the government to expand financial support for businesses, as doing so considerably improves the effectiveness of focused efforts to raise businesses' levels of green innovation.

Thirdly, this study introduces fsQCA, which helps to broaden the selection of methods in the study of green innovation. The majority of study to date has concentrated on the impact of single-level elements, lacking systematic and holistic analysis. To systematically integrate the five factors of green finance, we use the fsQCA approach. We provide a new perspective on the complex interaction and causal asymmetry among the various conditions behind green innovation in firms.

## Limitations and future research

There are still some shortcomings and room for improvement in this study. Firstly, due to limitations in data collection methods and personal experience knowledge, we only selected five antecedents. This study did not further explore other antecedents, and the cases did not cover all industries. Secondly, the universality of research conclusions needs to be improved. In the future, more comprehensive factors can be identified for more in-depth research. Thirdly, the sample cases are all from China. Enterprise samples from industrialized nations can be added to QCA to enhance our research findings further.

**Author contribution** SL was responsible for the definition of conceptualization and methodology and the use of software. CY analyzed and interpreted the data and was a major contributor to writing—original draft. DZ was responsible for the supervision and writing—reviewing. All authors read and approved the final manuscript.

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**Data availability** All materials and data which was generated or analyzed during this study were. included in this article.

## Declarations

**Ethics approval** Not applicable.

**Consent for publication** Not applicable.

**Competing interests** The authors declare no competing interests.

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