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Research article

A novel evolution model to investigate the collaborative innovation mechanism of green intelligent building materials enterprises for construction 5.0

Chengli Hu[1,*], Ping Liu[2], Hongtao Yang[3], Shi Yin[4,*] and Kifayat Ullah[5,*]

[1] School of Economics and Management, Harbin Engineering University, Harbin 150000, China
[2] School of Economics and Management, Taishan University, Tai'an 271000, China
[3] School of Business Administration, Huaqiao University, Quanzhou 362021, China
[4] College of Economics and Management, Hebei Agricultural University, Baoding 071001, China
[5] Department of Mathematics, Lahore Campus, Riphah International University, Lahore 54000, Pakistan

* **Correspondence:** Email: A13651614177@163.com, shyshi0314@163.com, kifayat.khan.dr@gmail.com.

Abstract: Green intelligent building materials is an effective way for building materials industry to reduce carbon. However, a small amount of research and development (R&D, unstable R&D investment and imperfect collaborative innovation mode hinder the development of green intelligent building materials industry. However, few scholars study the development mechanism of green intelligent building materials industry from the perspective of industrial chain considering the above obstacles. In this study, the game models under market mechanism and government regulation were constructed to analyze the income distribution mechanism for the development mechanism of green intelligent building materials industry. Finally, the questionnaire method was used to discuss the game strategy of collaborative innovation behavior among agents. The results are as follows. In the game strategy selection of collaborative innovation behavior among green intelligent building materials, factors such as database marketing maturity, information flow and technology volume generated by collaborative innovation, technical benefit coefficient, social benefit coefficient and profit and loss barrier factors are conducive to the collaborative innovation behavior of green intelligent building materials. When the market mechanism fails, the incentive effect of cost subsidy adopted by the government is more efficient and fast, and the driving force of achievement reward is more lasting.

The combination of the two incentives is the best. Moderate supervision and punishment lower than the free rider income can not ensure fair competition among green intelligent building materials enterprises. The punishment above the threshold can effectively restrain the negative impact of free rider income and prospect profit and loss. This study not only theoretically expands the development theory of digital industry from the perspective of industrial chain by considering the maturity factor of database, but also provides policy guidance for the development of green intelligent building materials industry in practice.

Keywords: green building materials; intelligent building materials; building materials industry; collaborative innovation; green innovation
Mathematics Subject Classification: 90B70, 91A80

1. Introduction

Digital circular economy is becoming a new engine of high-quality development in China. Construction industry is one of the important economic industries in China. Building materials are an important part of the production and construction of the construction industry. Accelerating the exploration, development and application of green building materials technology is a new path to realize the digital transformation of intelligent manufacturing [1]. This requires starting with construction product design, raw material production, architectural design and transformation. This will not only help protect the ecological environment, reduce air pollution, reduce enterprise production costs and reduce building materials waste, but also accelerate the improvement of innovative technology [2]. This is the leading direction of the whole development of China's construction industry. According to the Research Report on China's building energy consumption (2020), the total terminal carbon emission of the national construction industry in 2018 was 4.997 billion tons, accounting for 50.6% of the total national carbon emission. The carbon emission in the production stage of building materials alone reached 2.77 billion tons, accounting for 28% of the total carbon emission in China [3].

The architectural design concept is green, and the application of each architectural design technology highlights intelligence. The two constitute a complete architectural system. From a deep perspective, green building is the prerequisite and basic condition before the implementation of building. Under the premise of the establishment of green building achievements, green building is also an important goal of intelligent building [4]. The two are complementary and integrated. The creation of intelligent building aims to achieve green building and achieve the effect of saving resources and protecting the environment [5]. For example, construction companies should maximize the use of water and air resources, reduce the waste of energy and create safe and comfortable space. Unlike ordinary buildings, intelligent buildings pursue more efficiency, safety and applicability. Especially in the construction of residential buildings, the consumption of energy and light sources should be taken into account [6]. This should be based on meeting the residential needs of users and combined with the performance of the house itself. This should make full use of natural conditions, such as natural light and atmosphere, and appropriately adjust the indoor temperature to reduce energy consumption [7]. Intelligent buildings should also reasonably arrange construction work and time. In the case of unmanned operation, it is necessary to adjust the indoor temperature and humidity.

Combined with the strategy of sustainable development concept, it is necessary to take the realization of green building as the main goal. This puts forward high requirements for green intelligent building material manufacturers.

At present, green intelligent building materials still face some problems to be solved in the process of innovation research. R&D support for advanced thermal insulation and other green materials is insufficient [8]. Most of the existing R&D projects focus on the improvement of product application performance. There is less R&D of green building materials based on the goal of carbon peak and carbon neutralization. For example, as an important green low-carbon material, aerogel gel has the advantages of light weight, porous and low thermal conductivity. It is the only known material with the best thermal insulation and lower thermal conductivity than air. There is a lack of stable guarantee for R&D investment in green intelligent building materials. At present, a number of strategic scientific and technological innovation platforms such as the State Key Laboratory of green building materials mostly rely on state-owned enterprises [9]. The investment of R&D funds for platform scientific and technological innovation basically depends on the independent investment of supporting units. It is difficult to ensure continuous high profits to support the high investment of R&D platform. It is difficult for basic R&D investment to benefit in the short term. Enterprises also face the pressure of maintaining and increasing the value of assets. This leads to unstable investment in strategic scientific and technological innovation platforms. There is a lack of collaborative innovation mode of green intelligent building materials. In order to promote the coordination of various elements in scientific and technological innovation, government departments put forward policies to support leading enterprises to form innovation consortia [10,11]. At present, Shandong, Jiangsu and other provinces have taken the lead in establishing innovation consortia to carry out collaborative innovation in the fields of inorganic functional materials, laser equipment, biomedicine and so on. At the national level, the innovation consortium in the field of green intelligent building materials has not been established, and the atmosphere of collaborative innovation has not been formed. The R&D of disruptive low-carbon technology and equipment in the field of green intelligent building materials is lack, and the industrialization of achievement transformation is slow. Therefore, collaborative innovation of green intelligent building materials is very key. This not only improves the stable guarantee degree of scientific and technological R&D investment of green intelligent building materials through collaborative innovation, but also has important support for the active R&D of green intelligent building materials based on the goal of carbon peaking and carbon neutralization [12].

Collaborative innovation of green intelligent building materials is an important feature of the new round of scientific and technological revolution and industrial reform [13]. It is also an important way for the development of green intelligent building materials industry to form new momentum, new business forms and new models. Strengthening collaborative innovation among green intelligent building materials industries is a development model and industrial organization form to improve the productivity and competitiveness of green intelligent building materials industry [14]. This has become an inevitable requirement for the development of green intelligent building materials industry. With the further improvement of industrial integration platforms and carriers such as industrial Internet and cloud computing around the world, the breadth and depth of green intelligent integration will continue to expand [15]. Firstly, there will be more and more integration within the green intelligent building materials industry, such as the extension of the green intelligent new material industry chain to downstream applications. Upstream and downstream industries have achieved vertical integration and coordinated development. Secondly, there will be more and more industrial integration between green and intelligent building materials industries, such as the cross integration of information technology, construction technology, new energy technology and new material technology. This is accelerating the transformation of green intelligent building materials industry from single point technology and single product innovation to systematic and integrated innovation of multi technology and multi industry integration and interaction. New products of green intelligent building materials integrating advanced technologies in many fields will continue to emerge. In the green intelligent building materials industry, building a high-level collaborative innovation network can have a chain reaction to the green intelligent building materials industry [16]. This is conducive to overcoming key green intelligent building materials technology and producing spiral innovation effect. The high complexity and uncertainty of green intelligent building materials industry determine that the main body of green intelligent building materials has high requirements for the acquisition and integration of innovative resources. The main body of green intelligent building materials carries out collaborative innovation by establishing an innovation network with related industries. This can effectively integrate heterogeneous innovation resources and reduce R&D costs and risks [17]. Furthermore, it helps to trigger new technological trajectory and paradigm transformation and realize industrial breakthrough innovation. Therefore, this will help to enhance the innovation ability of green intelligent building materials in the building materials industry.

The research on the collaborative innovation problem among green intelligent building materials industries is supported by the collaborative theory. Synergy theory suggests that in complex and open systems, the subsystems produce “1 + 1 > 2” synergies through the interaction energy [18]. The coordinated development of green intelligent building materials industry is based on the potential difference of resource position. Heterogeneous green intelligent building materials innovation subjects to establish a synergistic relationship with their own resource differences. Lv et al. (2019) applied the collaborative theory to build an index system of the selection of supply chain collaborative product innovation partners based on innovation resources [19]. Guo et al. (2019) constructed the collaborative evolution model of e-commerce industry and big data industry based on Haken model, and believed that the coordinated development of the two is an important driving force for the rapid development of digital economy [20]. Maddikunta et al. (2021) established an industrial collaborative network through division of labor and cooperation and resource sharing [21]. Mojumder and Singh (2021) studied the green supply chain management model and synergistic effect evaluation model based on the whole industry chain from the perspective of internal and external cross-industry collaborative management [22]. Some scholars take the way of combining collaborative theory with game theory to analyze the evolution law of the subjects involved in the collaborative innovation process from a dynamic perspective. Wijesiri et al. (2021) established the game model of technology sharing and evolution of green intelligent building materials technology based on the characteristics of cross-regional and interdisciplinary cooperation of upstream and downstream building materials research units [23]. Wang et al. (2021) studied the cooperation between innovative members of enterprises, universities and research institutions in industrial collaborative innovation networks under government intervention [24]. Li et al. (2021) studied the optimal strategy selection of green behavior of construction and demolition waste recycling units considering remanufacturing capacity [25]. Jeihoonian et al. (2022) established a conference cluster supply chain configuration model considering the horizontal and vertical collaboration within the cluster [26]. Previous studies have shown that the collaborative innovation of upstream and downstream green intelligent building materials enterprises with inputs and products as the link between industries is an important force driving the overall technological progress of the industry. Because the innovation investment of green intelligent building materials has obvious positive externalities [27–30]. On the one hand, green building materials can maintain or even improve the whole ecological environment system and reduce excessive waste of energy and resources. The social benefits of green building materials far outweigh the private benefits of green building materials producers or consumers [28]. On the other hand, intelligent building materials producers bring direct positive externalities to consumers by actively developing and producing new intelligent building materials. This feature of intelligent technology can also enhance the positive externality of green building materials industry [29]. The free riding behavior and prospect profit and loss of supply chain members will seriously affect the willingness of enterprises to invest in innovation. This leads to simple cooperation among supply chain members. However, meeting the needs of personalized customization and sharing innovation risks among members will promote collaborative innovation among supply chain members [30]. Therefore, the process of game between members is dynamic, which is dynamically adjusted on the basis of the other party's strategy choice. It is necessary to establish an evolutionary game model. Different from the collaborative innovation among traditional industries, the green intelligent building materials industry is more guided by the government because of its strategic nature. Local governments can fully consider the social effects undertaken by enterprises in the process of technological innovation.

From the perspective of digital management, Guo et al. (2015) combined the three main lines of production flow, material flow and capital flow to develop a digital management platform for building materials equipment manufacturing enterprises, so as to facilitate more efficient sales management of building materials [31]. Zhang and Cui (2018) made a field survey of shenzhen building materials market and concluded that consumers pay more attention to the actual environmental protection effect of green building materials than to the price [32]. Considering the importance of green building materials, Yin et al. (2019) proposed that supply and demand are crucial to the future development of building materials industry, and the key point is to find the laws that restrict the development and transformation and upgrading of the industry [9]. From the perspective of consumers, He and Yuan (2019) studied the impact of consumers' quality perception of recycled building materials on production decisions of building materials enterprises by establishing Hotelling model [33]. Wang et al. (2021) found that with the continuous improvement of people's awareness of green environmental protection, the quality of green building materials has been paid more and more attention [34]. Yin et al. (2022) developed a conceptual partner selection framework for digital green innovation management of prefabricated construction enterprises [35]. Thus, the green transformation of building materials consumption has become a big trend.

Exploring the upgrading of building materials supply chain from the perspective of building materials logistics, Liu and Gong (2014) proposed to promote the transformation and upgrading of e-commerce logistics in traditional building materials market on the basis of upgrading the hard platform of logistics distribution center, the soft platform of logistics information system, the supply chain of building materials logistics service mode and the content of logistics service simultaneously [36]. From the perspective of stakeholders in the supply chain of building materials, some scholars carried out game analysis on the supply chain of building materials in order to solve the problem that both sides of the supply chain cannot achieve win-win situation in the traditional building materials market [37,38]. From the perspective of supply chain innovation, Harry (2018) believed that it is necessary to improve the supply chain of building materials and construction through innovation, so as to realize the innovation of national infrastructure [39]. Li et al. (2019) applied blockchain technology to the supply chain of building materials, establishing a complete transaction information chain in each link of material transaction, and promoting the coordinated operation of supply and demand parties of building materials and government regulatory authorities [40]. Wibowo et al. (2022) put forward the green logistics concept and mode of external collection and internal distribution, and reverse logistics performance indicators for the construction sector [41]. Thus, it can be seen that the building materials supply chain should constantly adapt to the market development for innovation and upgrading.

Many scholars have studied the building materials industry, green supply chain and the integration between the two. However, few scholars pay attention to the green intelligent supply chain industry from the perspective of industry chain. Based on the above analysis, the game analysis was carried out for the collaborative innovation behavior of green intelligent building materials among agents. The threshold of the impact of the ratio of collaborative innovation cost to collaborative revenue on the direction of system evolution is studied. Further, when the system evolves towards non collaborative innovation, this study studies the threshold and convergence speed of the impact of government cost subsidies and green intelligent building materials achievement rewards on the system. On the other hand, this study explores the threshold of the impact of the ratio of free rider income and prospect profit and loss to synergy income on the direction of system evolution. Further, when the system evolves towards non collaborative innovation, this study studies the impact of government punishment mechanism on the main game decision-making. This study not only theoretically expands the development theory of digital industry from the perspective of industrial chain by considering the maturity factor of database, but also provides policy guidance for the development of green intelligent building materials industry in practice.

The remaining structure of this study is as follows. Section 2 is methodology. Model results of evolutionary game is shown in Section 3. Section 4 is evolution results based on questionnaire analysis. Conclusions and future prospects are presented in Section 5.

2. Methodology

2.1. Innovation subject of green intelligent building materials

Green building materials refer to the non-toxic, pollution-free and non-radioactive building materials produced by using industrial, agricultural or urban solid wastes with clean production technology, no or less use of natural resources and energy, which can be recycled after reaching the service cycle and is conducive to environmental protection and human health [42]. The definition of green building materials revolves around the use of raw materials, product manufacturing, use and waste disposal 4 links. Green intelligent building materials are building materials that reorganize digital resources related to green building materials through the combination of information, computing, communication and connection technologies, and embed digital technology into green building materials, which can bring new products, production process improvement, and significantly improve the ecological environment [43,44]. Green intelligent building materials have the advantages of less resource and energy consumption, less environmental pollution and low carbon emission intensity [45]. It is not only an effective way for the building materials industry to reduce carbon in terms of industrial structure, energy consumption, production process, resource utilization, product supply and green manufacturing, but also an important starting point to promote China's economy and society to achieve the goal of carbon peak and carbon neutralization. Yingli Group has built three green building materials R&D and production bases in Baoding, Wuxi and Shenzhen, with a total investment of nearly 1 billion yuan. Yingli Group has four core technologies: optical nanoplating technology, building materials photovoltaic generation preparation technology, component system deepening development technology, and digital intelligent operation technology. In 2021, Yingli Group's "Photovoltaic + Passive + Intelligent" demonstration project was completed and put into use. The four freestanding buildings are made of new building materials developed with more than 20 patented technologies of integrated photovoltaic building. The demonstration project combines photovoltaic applications and buildings perfectly through energy technologies such as photovoltaic, ground source/air source heat pump, capillary radiant air conditioning system and intelligent systems such as smart energy management and control and smart office. This is not only architectural beauty, but also sustainable green electricity supply of 100,000 kilowatts per year. The related green and intelligent building materials products have been successfully applied in over 100 green building projects such as Xiongan High-speed Railway Station, Mass Innovation and Innovation Center of Jineng Holding Group, Hainan New Energy Management Center in Qinghai Province, and Photovoltaic Industry Technology Innovation Center of China Power Investment Corp.

There is a high correlation between green intelligent building materials industries. The development of building materials industry has a strong driving effect on green materials industry or information technology industry. Nanotechnology has been involved in information technology, building materials, environmental protection and other industries. The research and development of batteries and high-performance composites will drive the development of building materials and energy industry. The main body of green innovative building materials innovation in this paper is to randomly select two sub groups of manufacturing enterprises from different total groups of green intelligent building materials industry to match each other for multiple games. There are technical and economic links between game subgroups with inputs and products as the connecting link [46]. They have a high degree of relevance to the green innovative building materials industry. After choosing partners based on their knowledge attributes, the two sides of the game can choose to simply cooperate with the existing products instead of adopting the mode of collaborative innovation of green innovation and building materials. They can also choose the collaborative innovation mode of green innovative building materials by adopting personalized customization and jointly developing cutting-edge technologies according to the market demand. In the initial stage of green innovation, the selection strategy of building materials innovation behavior is not optimal, and will reach equilibrium after continuous adjustment.

2.2. Collaborative innovation model of green building materials under market mechanism

Hypothesis 1: In the natural environment, subject 1 is a sub-group of green intelligent building materials enterprises in the upstream of the green innovative building materials supply chain. Subject 2 is a sub-group of green intelligent building materials enterprises downstream of the green innovative building materials supply chain. They are all finite and rational, and they have the fact of information asymmetry.

Hypothesis 2: The basic income they can get when cooperating is $\pi_i (i = 1,2)$.

Hypothesis 3: If they all choose to carry out green innovation building materials collaborative innovation when cooperation, they can gain synergistic benefits. The synergistic income of green innovation building materials in this paper includes technical income and market risk income. Technical income refers to the benefits obtained by both parties from the technological transformation, optimization and upgrading of green innovative building materials through collaborative innovation [47]. Here, it is assumed that the technique can be expressed in quantities. The technical income is recorded as $\alpha_i(P = P_1P_2)(i = 1,2)$. P_1 is the amount of technology generated by collaborative green innovation. P_2 is the amount of technology generated by collaborative intelligent innovation. α is the technology revenue coefficient, that is, the ability of an enterprise to transform collaborative innovation technology into revenue. Different from traditional industries, the market of green intelligent building materials industry is highly uncertain. Market demand is highly dynamic, and market positioning is easy to cause deviation. The mismatch between products and the market exacerbates the risk of investment turning into revenue. However, the upstream green intelligent building materials enterprises process the information flow generated by collaborative innovation through advanced information technology such as network crawler and big data mining. Upstream enterprises can grasp the dynamics of existing and potential competitors and accurately locate market demand information can reduce market risk. The resulting market risk and return is recorded as βq. β is the upstream green intelligent building materials enterprise database marketing maturity. Upstream green intelligent building materials enterprises will use the information flow generated by collaborative innovation to expand the existing database of the enterprises. Enterprises take data mining as the core, intelligent processing of market information, to realize precision marketing. This helps to obtain the market risk and return. The higher the maturity, the stronger the ability of the enterprise to obtain revenue through database marketing. q is the amount of information generated from collaborative innovation. This part of the income is jointly distributed by the main parties. The distribution coefficient of subject 1 is $\delta \in [0,1]$. The distribution coefficient of subject 2 is $(1 - \delta)$. The market risk income in this paper mainly refers to the income obtained by processing the information flow generated by collaborative innovation through database marketing to reduce the market risk. In general, compared with the downstream green intelligent building materials enterprises of the information supplier, the upstream green intelligent building materials enterprises as the information demander can obtain more market risk benefits through the information resources of their own industry and downstream industries shared by both parties. It is difficult for upstream green intelligent building materials enterprises to share the information of consumers of downstream green intelligent building materials enterprises. Therefore, this paper only considers the market risk income generated by the upstream green intelligent building materials enterprises. According to the information sharing willingness of the downstream green intelligent building materials enterprises, the risk income is distributed between the two sides of the game.

Hypothesis 4: The game subject is the upstream and downstream green intelligent building materials enterprises of the green intelligent building materials supply chain, with a high industrial correlation. But they still come from different fields of green intelligent building materials, and there are certain industrial barriers. After the main body chooses collaborative innovation, it should invest the corresponding manpower, material resources and financial resources, which includes the cost caused by reducing or eliminating industrial barriers. The total cost of collaborative innovation of green intelligent building materials is $C_i(i = 1,2)$. When one party adopts collaborative innovation and the other party adopts non-collaborative innovation, the green intelligent building materials enterprises that adopt non-collaborative strategy have free ride behavior, which can generate additional benefits $N_i (i = 1,2)$.

Hypothesis 5: Green intelligent building materials industry belongs to knowledge intensive industry, and has obvious externalities. This makes technology more spillover between and within industries. There is a stronger technological mobility among the subjects of the collaborative innovation of green intelligent building materials. Even if the confidentiality agreement between the subjects can temporarily inhibit the spillover of the technology to the environment outside the subject within a certain scope, there is also the possibility that a certain party can adopt the forward integration or backward integration by following the innovation or imitating the innovation. Or due to malicious competition, interest inducement and other moral acts or other circumstances in the subjective and objective cause information disclosure. This causes the choice partner to bear the risk of the technology being copied, resulting in future gains and losses $\varepsilon A_i (i = 1,2)$. $\varepsilon \in [0,1]$ is a barrier factor for profit and loss, which means that the intellectual property protection system, the spirit of the contract, and the laws and regulations of both parties can hinder the production of profit and loss. A value of 0 indicates that the profit or loss barrier factor can play a complete blocking effect and produce no future profit or loss. This value of 1 indicates that the profit and loss barrier factor is basically no hindrance.

Hypothesis 6: Both strategies choices an unstable state before final selection. The proportion of individuals in the upstream group of green intelligent building materials who choose collaborative innovation is assumed to be x. The proportion of selected non-collaborative innovation is $1 - x$. The proportion of individuals choosing collaborative innovation in the downstream groups of green intelligent building materials is y. The proportion of selected non-collaborative innovation is $1 - y$. There is $x, y \in [0,1]$.

Table 1. Revenue matrix of both parties in the game under the market mechanism.

		Downstream green intelligent building materials enterprises	
		Collaborative innovation	No-collaborative innovation
Upstream green intelligent building materials enterprises	Collaborative innovation	$\pi_1 + \alpha_1 P + \delta\beta q - C_1 - \varepsilon A_1$, $\pi_2 + \alpha_2 P + (1-\delta)\beta q - C_2 - \varepsilon A_2$	$\pi_1 - C_1 - \varepsilon A_1$, $\pi_2 + N_2$
	No-collaborative innovation	$\pi_1 + N_1$, $\pi_2 - C_2 - \varepsilon A_2$	π_1, π_2

Under the market mechanism, both sides of the game have a competitive advantage in the market, and occupy a high market share to maximize their own interests. They play multiple games in the choice of synergy and no synergy, and the payoff matrix is shown in Table 1.

2.3. *Collaborative innovation model of green innovative building materials under government mechanism*

Green intelligent building materials industry is highly valued by the country because of its strategy. In order to break through technical bottlenecks in key areas, local governments at all levels provide full policy guarantees from government subsidies, equity investment, loan interest discount and risk compensation. At the same time, the government departments and constantly create a good environment for collaborative innovation in terms of supervision.

Table 2. Revenue matrix of both parties in the game under government incentives.

		Downstream green intelligent building materials enterprises	
		Collaborative innovation	No-collaborative innovation
Upstream green intelligent building materials enterprises	Collaborative innovation	$\pi_1 + \alpha_1 P + \delta\beta q - C_1 - \varepsilon A_1 + aC_1 + \eta bB$, $\pi_2 + \alpha_2 P + (1-\delta)\beta q - C_2 - \varepsilon A_2 + aC_2 + (1-\eta)bB$	$\pi_1 - C_1 - \varepsilon A_1 + aC_1$, $\pi_2 + N_2 - mD$
	No-collaborative innovation	$\pi_1 + N_1 - mD$, $\pi_2 - C_2 - \varepsilon A_2 + aC_2$	π_1, π_2

Table 3. Definition of parameter.

Parameter setting	Parameter description
$i(i = 1,2)$	The i-th green intelligent building materials enterprise group.
π_i	The basic benefits of the cooperation.
P_1	The amount of technology generated by collaborative green innovation.
P_2	The amount of technology generated by collaborative intelligent innovation.
α	The ability of an enterprise to transform collaborative innovation technology into revenue.
β	The upstream green intelligent building materials enterprise database marketing maturity.
q	The amount of information generated from collaborative innovation.
$\delta \in [0,1]$	The distribution coefficient of subject 1.
$C_i(i = 1,2)$	The total cost of collaborative innovation of green intelligent building materials.
$N_i(i = 1,2)$	The green intelligent building materials enterprises that adopt non-collaborative strategy have free ride behavior, which can generate additional benefits.
$\varepsilon \in [0,1]$	Barrier factor for profit and loss, which means that the intellectual property protection system, the spirit of the contract, and the laws and regulations of both parties can hinder the production of profit and loss.
$A_i(i = 1,2)$	The choice partner to bear the risk of the technology being copied, resulting in future gains and losses.
x	The proportion of individuals in the upstream group of green intelligent building materials who choose collaborative innovation.
y	The proportion of individuals choosing collaborative innovation in the downstream groups of green intelligent building materials.
$a \in [0,1]$	The government green intelligent cost subsidy strength
b	The social benefit coefficient
B	The reward base set by the government
$\eta \in [0,1]$	The reward will be distributed between subjects with the distribution coefficient
m	The strength of government supervision
D	The government imposed a fine on this subject who do not participate in the collaborative innovation.

Hypothesis 7: The government chooses the collaborative innovation strategy to encourage both sides of the game and subsidize the green intelligent cost generated by the collaborative innovation of

green intelligent building materials. The green and intelligent cost subsidies that enterprises can obtain are $aC_i(i = 1,2)$. $a \in [0,1]$ is the government green intelligent cost subsidy strength. In addition, the government will actively guide the collaborative innovation among industries to have social benefits in green, healthy, sustainable and other aspects. green intelligent building materials for collaborative innovation that meet the conditions will be rewarded as bB. b is the social benefit coefficient and B is the reward base set by the government. The reward will be distributed between subjects, with the distribution coefficient of $\eta \in [0,1]$. The distribution coefficient of subject 2 is $(1-\eta)$. At the same time, in order to realize the effective allocation of innovation resources, the government will recover the green and intelligent cost subsidies for those who do not participate in the collaborative innovation. The government imposed a fine mD on this subject. m is the strength of government supervision. The mutual earnings matrix is shown in Table 2.

According to the above hypotheses, parameters are described in Table 3.

3. Results

3.1. Evolutionary game analysis under market mechanism

Revenues of upstream green intelligent building materials enterprises choose "No-collaborative innovation strategy" or "Collaborative innovation strategy" are π_{11} and π_{12}. The average expected revenues $\overline{\pi}_1$ are as follows:

$$\pi_{11} = y(\pi_1 + \alpha_1 P + \delta\beta q - C_1 - \varepsilon A_1) + (1-y)(\pi_1 - C_1 - \varepsilon A_1) = y\alpha_1 P + y\delta\beta q + \pi_1 - C_1 - \varepsilon A_1, \tag{1}$$

$$\pi_{12} = y(\pi_1 + N_1) + (1-y)\pi_1 = \pi_1 + yN_1, \tag{2}$$

$$\overline{\pi}_1 = x\pi_{11} + (1-x)\pi_{12} = xy(\alpha_1 P + \delta\beta q - N_1) + \pi_1 + yN_1 - xC_1 - x\varepsilon A_1. \tag{3}$$

The replication dynamic equations of upstream green intelligent building materials enterprises are as follows:

$$F(x) = dx/dt = x(\pi_{11} - \overline{\pi}_1) = x(1-x)(\pi_{11} - \pi_{12}) = x(1-x)(y\alpha_1 P + y\delta\beta q - yN_1 - C_1 - \varepsilon A_1). \tag{4}$$

Revenues of downstream green intelligent building materials enterprises choose "No-collaborative innovation strategy" or "Collaborative innovation strategy" are π_{21} and π_{22}. The average expected revenues $\overline{\pi}_2$ are as follows:

$$\begin{aligned} \pi_{21} &= x[\pi_2 + \alpha_2 P + (1-\delta)\beta q - C_2 - \varepsilon A_2] + (1-x)(\pi_2 - C_2 - \varepsilon A_2) \\ &= x\alpha_2 P + x(1-\delta)\beta q + \pi_2 - C_2 - \varepsilon A_2 \\ &= x\alpha_2 P + x(1-\delta)\beta q + \pi_2 - C_2 - \varepsilon A_2, \end{aligned} \tag{5}$$

$$\pi_{22} = x(\pi_2 + N_2) + (1-x)\pi_2 = \pi_2 + xN_2, \tag{6}$$

$$\overline{\pi}_2 = y\pi_{21} + (1-y)\pi_{22} = xy[\alpha_2 P + (1-\delta)\beta q - N_2] + \pi_2 + xN_2 - yC_2 - y\varepsilon A_2. \tag{7}$$

The replication dynamic equations of downstream green intelligent building materials enterprises are as follows:

$$F(y) = dy/dt = y(\pi_{21} - \overline{\pi}_2) = y(1-y)(\pi_{21} - \pi_{22})$$
$$= y(1-y)[x\alpha_2 P + x(1-\delta)\beta q - xN_2 - C_2 - \varepsilon A_2]. \quad (8)$$

The conditions are as follows $F(x) = 0$ and $F(y) = 0$. In $R = \{(x,y)|0 \le x \le 1, 0 \le y \le 1\}$, there are five local equilibrium points $O(0,0)$、$A(1,0)$、$B(1,1)$、$C(0,1)$、$D(x*, y*)$ in the game strategy of both sides, where $x* = \frac{C_2+\varepsilon A_2}{\alpha_2 P+(1-\delta)\beta q-N_2}$ and $y* = \frac{C_1+\varepsilon A_1}{\alpha_1 P+\delta\beta q-N_1}$. The $F(x)$ and $F(y)$ partial derivatives were acquired to obtain the Jacobian matrix of the system as shown follows:

$$J = \begin{bmatrix} (1-2x)[y(\alpha_1 P + \delta\beta q - N_1) - C_1 - \varepsilon A_1] & x(1-x)(\alpha_1 P + \delta\beta q - N_1) \\ y(1-y)[\alpha_2 P + (1-\delta)\beta q - N_2] & (1-2y)\{x[\alpha_2 P + (1-\delta)\beta q - N_2] - C_2 - \varepsilon A_2\} \end{bmatrix}. \quad (9)$$

The discriminant method by Friedman, when the Jacobian matrices satisfy $Det(J) > 0, Tr(J) < 0$, the local equilibrium point is the stable strategy of the system. Both $x*$ and $y*$ are located in the $R = \{(x,y)|0 \le x \le 1, 0 \le y \le 1\}$ plane. According to the above conditions, when $0 \le C_1 + \varepsilon A_1 \le \alpha_1 P + \delta\beta q - N_1$ and $0 \le C_2 + \varepsilon A_2 \le \alpha_2 P + (1-\delta)\beta q - N_2$ are satisfied, the system has five local equilibrium points, as shown in Table 4.

Table 4. Stability analysis of local equilibrium points under market mechanism.

Equilibrium positions	Det(J)	Tr(J)	Local stability
$O(0,0)$	+	-	ESS point
$A(1,0)$	+	+	Unstabitily point
$B(1,1)$	+	-	ESS point
$C(0,1)$	+	+	Unstabitily point
$D(x*, y*)$	-	0	Saddle point

It can be seen from Table 4, among the five local equilibrium points, points $O(0,0)$ and $B(1,1)$ are the stable strategies of upstream green intelligent building materials enterprises and downstream green intelligent building materials enterprises in the green intelligent building materials industry under the market mechanism. Both sides choose collaborative innovation and both sides choose no collaborative innovation. While one party chooses collaborative innovation, the other party chooses not collaborative innovation is an unstable point. Table 4 can plot the evolutionary game under the market mechanism, as shown in Figure 1.

According to Figure 1, no matter how the initial game of the two sides decides, it will evolve in the direction of (collaborative innovation, collaborative innovation) or (no collaborative innovation) after a continuous long-term game. When $S_{AOCD} < S_{ABCD}$, the probability of both parties will be greater than non-collaborative innovation. When $S_{AOCD} > S_{ABCD}$, both parties prefer to choose not collaborative innovation. When $S_{AOCD} = S_{ABCD}$, the system evolves with the same probability towards two stable points, and the evolution direction is unclear. So the strategy choice of both parties in the final game is related to the relative size of S_{AOCD} and S_{ABCD}. According to the factors affecting the area change, the direction of the system evolution can be inferred.

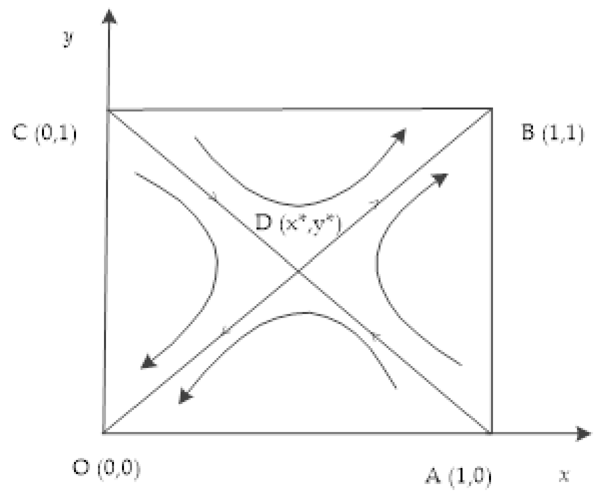

Figure 1. Evolutionary phase diagram of game parties under market mechanism.

Proposition 1. Under the market mechanism, the probability of green intelligent building materials enterprises in the upstream and downstream of the green intelligent building materials industry to choose collaborative innovation decreases with the increase of the cost of collaborative innovation.

$$S_1 = \frac{1}{2}(x * + y *) = \frac{1}{2}\left(\frac{C_2+\varepsilon A_2}{\alpha_2 P+(1-\delta)\beta q-N_2} + \frac{C_1+\varepsilon A_1}{\alpha_1 P+\delta\beta q-N_1}\right). \tag{10}$$

Proof. According to $\frac{\partial S_1}{\partial C_1} = \frac{1}{2(\alpha_1 P+\delta\beta q-N_1)}$, because $x *$ and $y *$ both are above $R = \{(x, y)|0 \leq x \leq 1, 0 \leq y \leq 1\}$, therefore $\frac{\partial S_1}{\partial C_1} > 0$. Similarly, we can get the $\frac{\partial S_1}{\partial C_2} > 0$. Thus, S_1 is a monotonic additive function of C_1 and C_2. S_1 increases with the increasing input cost of collaborative innovation for both sides of the game. S_{ABCD} will decrease, and the probability that the system will evolve towards point $O(0,0)$ increases. Both sides of the game prefer to choose no collaborative innovation. Because of the emerging characteristics of green intelligent building materials industry, most industries are in the formative period and development period. For enterprises that have not entered the mature period, their cost recovery cycle is long. When the cost of collaborative innovation in the game is high, the willingness of both sides to choose collaborative innovation will be reduced.

Proposition 2. Under the market mechanism, the reduction of the value of prospect profit and loss obstacle factor will increase the probability of upstream and downstream green intelligent building materials enterprises to choose collaborative innovation between green intelligent building materials industries.

Proof. The results of partial guidance based on prospect profit and profit and loss barrier factors are as follows: $\frac{\partial S_1}{\partial A_1} = \frac{\varepsilon}{2(\alpha_1 P+\delta\beta q-N_1)} > 0$. Similarly, we can get the $\frac{\partial S_1}{\partial A_2} > 0$ and $\frac{\partial S_1}{\partial \varepsilon} = \frac{1}{2}\left[\frac{A_2}{\alpha_2 P+(1-\delta)\beta q-N_2}\right] + \frac{A_1}{2(\alpha_1 P+\delta\beta q-N_1)} > 0$. Thus, S_1 is a monotonic additive function of ε, A_1 and

A_2. As ε. A_1, and A_2 decrease, the area of S_1 decreases and the probability that the system evolves towards point $B(1,1)$ increases. The technology spillover of the green intelligent building materials industry is more obvious for the enterprises that choose collaborative innovation. The existence of prospect profit and loss will diminish its probability of choosing collaborative innovation. However, the existence of profit and loss barriers such as the contract spirit of both parties and the protection of intellectual property rights will reduce the concerns caused by the prospect of profit and loss. The system will thus evolve towards the path of mutual choice of collaborative innovation.

Proposition 3. Under the market mechanism, the more mature the database marketing of green intelligent building materials enterprises among green intelligent building materials industry, the greater the information flow generated by collaborative innovation, the greater the probability of the game to choose collaborative innovation.

Proof. According to $\frac{\partial S_1}{\partial \beta} = -\frac{1}{2}\left\{\frac{(C_2+\varepsilon A_2)(1-\delta)q}{[(\alpha_2 P+(1-\delta)\beta q-N_2)]^2} + \frac{(C_1+\varepsilon A_1)\delta q}{(\alpha_1 P+\delta\beta q-N_1)^2}\right\} < 0$, we can get the $\frac{\partial S_1}{\partial q} < 0$. So S_1 is a monotonic decreasing function of β and q, and as β and q increase, the area of S_1 decreases and the probability of the system evolving towards the $B(1,1)$ point increases. green intelligent building materials enterprises in the upstream and downstream of the green intelligent building materials industry will establish information sharing platforms and carry out regular technical exchanges through collaborative innovation. The market information of the same industry and the upstream industry provided by the downstream green intelligent building materials enterprises can provide support for the technical quality improvement and product marketing of the upstream green intelligent building materials enterprises. This not only further expands the database of upstream green intelligent building materials enterprises, but also helps them to use the database to achieve precision marketing and reduce market risks. The purpose is to generate market risk and return. Therefore, the more mature the database marketing of upstream green intelligent building materials enterprises, the greater the information flow generated by collaborative innovation, the higher the market risk and return of both sides of the game, and the greater the probability of both sides of the game to evolve into collaborative innovation.

Proposition 4. Under the market mechanism, the probability of collaborative innovation of upstream and downstream green intelligent building materials enterprises among green intelligent building materials industries will increase with the increase of their respective technology revenue coefficient and the amount of technology generated by collaborative innovation.

Proof. According to $\frac{\partial S_1}{\partial \alpha_1} = \frac{-(C_1+\varepsilon A_1)P}{2(\alpha_1 P+\delta\beta q-N_1)^2} < 0$, we can get the $\frac{\partial S_1}{\partial \alpha_2} < 0, \frac{\partial S_1}{\partial P} < 0$. Thus, S_1 is a monotonic decreasing function of α_1, α_2 and P. As the technical yield coefficient of both sides of the game and the amount of technology generated through collaborative innovation increase, the area S will decrease, and the probability of the system evolving towards the point $B(1,1)$ increases. The heterogeneity of the industry and enterprises leads to differences in the benefits obtained by enterprises in technological transformation and product optimization and upgrading. Through collaborative innovation, both sides make full use of their own technical advantages to improve the overall technical level of the secondary supply chain in which both sides participate. Thus increasing their direct returns, both sides of the game will have a greater probability of choosing collaborative innovation.

Proposition 5. Under the market mechanism, the greater the income of green intelligent building materials enterprises between the upstream and downstream green intelligent building materials industry, the greater the probability of the two sides to choose no collaborative innovation.

Proof. According to $\frac{\partial S_1}{\partial N_1} = \frac{C_1+\varepsilon A_1}{2(\alpha_1 P+\delta\beta q-N_1)^2} > 0$, we can get the $\frac{\partial S_1}{\partial N_2} > 0$. Thus, S_1 is a monotonic additive function of N_1 and N_2. As the parameter values increase, the area S_1 increases, and the probability of the system evolving towards the point $O(0,0)$ increases. Enterprises that choose collaborative innovation should bear the costs and risks of innovation. The resulting transformation and upgrading of technical products will directly drive the development of upstream or downstream green intelligent building materials enterprises, and obtain free-ride income. Both sides expect the other side to choose collaborative innovation and enjoy their own free-riding benefits. With the increase of the other party, the stronger sense of unfairness will cause both sides of the game to evolve to the direction of non-collaborative innovation after many games.

Proposition 6. Under the market mechanism, the distribution coefficient of market risk and return between the upstream and downstream green intelligent building materials enterprises on the final decision of both sides of the game is determined according to the specific situation.

Proof. According to $\frac{\partial S_1}{\partial \delta} = \frac{1}{2}\left\{\frac{(C_2+\varepsilon A_2)\beta q}{[\alpha_2 P+(1-\delta)\beta q-N_2]^2} - \frac{(C_1+\varepsilon A_1)\beta q}{(\alpha_1 P+\delta\beta q-N_1)^2}\right\}$, the size of the S_1 and the market. The distribution coefficient of risk and return is not a monotonic function, and the final evolution result of the system depends on the specific situation. When $\left[\frac{\alpha_1 P+\delta\beta q-N_1}{\alpha_2 P+(1-\delta)\beta q-N_2}\right]^2 > \frac{C_1+\varepsilon A_1}{C_2+\varepsilon A_2}$ and $\frac{\partial S_1}{\partial \delta} > 0$, S_1 is an additive function of δ. As δ increases, the system goes to the probability of point $O(0,0)$ evolution increases. S_1 is a decreasing function of δ. As δ increases, the system goes to the probability of point $B(1,1)$ evolution increases.

3.2. Evolutionary game analysis under government mechanism

Similar to the solution process under the market mechanism, the replication dynamic equations of the upstream green and downstream green intelligent building materials enterprises under the government incentive are as follows:

$$dx/dt = x(1-x)(y\alpha_1 P + y\delta\beta q + y\eta bB - C_1 - \varepsilon A_1 + aC_1 - yN_1 + ymD), \tag{11}$$

$$dy/dt = y(1-y)(x\alpha_2 P + x(1-\delta)\beta q + x(1-\eta)bB - C_2 - \varepsilon A_2 + aC_2 - xN_2 + xmD). \tag{12}$$

The conditions are as follows $dx/dt = 0, dy/dt = 0$. In $R = \{(x,y)|0 \le x \le 1, 0 \le y \le 1\}$, there are five local equilibrium points $O(0,0)$、$A(1,0)$、$B(1,1)$、$C(0,1)$、$D(x*,y*)$ in the game strategy of both sides, where $x* = \frac{C_2+\varepsilon A_2-aC_2}{\alpha_2 P+(1-\delta)\beta q-N_2+(1-\eta)bB+mD}$ and $y* = \frac{C_1+\varepsilon A_1-aC_1}{\alpha_1 P+\delta\beta q-N_1+\eta bB+mD}$. The $F(x)$ and $F(y)$ partial derivatives were acquired to obtain the Jacobian matrix of the system as shown follows:

$$J = \begin{bmatrix} (1-2x)[y(\alpha_1 P+\delta\beta q+\eta bB-N_1+mD)-C_1-\varepsilon A_1+aC_1] & x(1-x)(\alpha_1 P+\delta\beta q+\eta bB-N_1+mD) \\ y(1-y)[\alpha_2 P+(1-\delta)\beta q+(1-\eta)bB-N_2+mD] & (1-2y)\{x[\alpha_2 P+(1-\delta)\beta q+(1-\eta)bB-N_2+mD]-C_2-\varepsilon A_2+aC_2\} \end{bmatrix}. \tag{13}$$

Also, according to the discriminant method of Friedman, the stability strategy of the system is found from the local equilibrium point according to the sign of the determinant and the trace. Thus, the constraints are met as follows $0 < x* = \frac{C_2+\varepsilon A_2-aC_2}{\alpha_2 P+(1-\delta)\beta q-N_2+(1-\eta)bB+mD} < 1$ and $0 < y* = \frac{C_1+\varepsilon A_1-aC_1}{\alpha_1 P+\delta\beta q-N_1+\eta bB+mD} < 1$. Since the government's financial subsidies are given a certain proportion according to the cost input, the actual amount is less than the amount of collaborative innovation input. Then the molecular denominator is both positive. Driven by the government, the sum of the input cost and prospect profit and loss under the collaborative innovation of the upstream and downstream green intelligent building materials enterprises in the green intelligent building materials industry will be greater than the financial subsidies given by the government. And the total revenue from collaborative innovation will be worse than the hitchhiking revenue and government fines. Under this constraint, the sign and stability of the determinants and traces of the Jacobian matrix of the five local equilibrium points are shown in Table 5.

Table 5. Stability analysis of local equilibrium points driven by government.

Equilibrium positions	Det(J)	Tr(J)	Local stability
$O(0,0)$	+	+	ESS point
$A(1,0)$	+	-	Unstabitily point
$B(1,1)$	+	+	ESS point
$C(0,1)$	+	-	Unstabitily point
$D(x*,y*)$	-	0	Saddle point

According to Table 5, $O(0,0)$ and $B(1,1)$ remain stable points of the system. While one side chooses collaborative innovation, the other side chooses no collaborative innovation is the unstable point of the system. $D(x*,y*)$ is the saddle point of the system, from which the system evolution phase diagram is the same as in Figure 1. The instability will eventually stabilize toward points $O(0,0)$ or $B(1,1)$, still depending on the relative size of S_{ABCD} and S_{AOCD}. S_{AOCD} can be expressed as follows:

$$S_2 = \frac{1}{2}(x*+y*) = \frac{1}{2}\left(\frac{C_2+\varepsilon A_2-aC_2}{\alpha_2 P+(1-\delta)\beta q-N_2+(1-\eta)bB+mD}+\frac{C_1+\varepsilon A_1-aC_1}{\alpha_1 P+\delta\beta q-N_1+\eta bB+mD}\right). \tag{14}$$

Proposition 7. With the increase of government cost subsidies and green intelligent building materials achievement awards, the probability of collaborative innovation between upstream and downstream green intelligent building materials enterprises in green intelligent building materials industries is enhanced.

Proof. According to $\frac{\partial S_2}{\partial a} = \frac{1}{2}\left(\frac{-C_2}{\alpha_2 P+(1-\delta)\beta q-N_2+(1-\eta)bB+mD}+\frac{-C_1}{\alpha_1 P+\delta\beta q-N_1+\eta bB+mD}\right)$, we can get the $\frac{\partial S_2}{\partial a} < 0$. Similarly, we can get the $\frac{\partial S_2}{\partial b} < 0$, $\frac{\partial S_2}{\partial B} < 0$. S_2 decreases with increasing a, b, and B, and the probability that the system evolves towards point $B(1,1)$ increases.

Compared with traditional industries, the green intelligent building materials industry is more supported by government policies. As a national key development industry, the green intelligent building materials industry is also the vanguard of social responsibility. The development of green intelligent building materials industry should also pay more attention to social benefits, especially the ecological benefits emphasized by the state. Therefore, both the government's cost subsidies and rewards can effectively reduce enterprise green intelligent building materials costs, and encourage upstream and downstream green intelligent building materials enterprises to evolve in the direction of collaborative innovation.

Proposition 8. The increase of government supervision and punishment will increase the probability of green intelligent building materials enterprises between the upstream and downstream of green intelligent building materials industries.

Proof. According to $\frac{\partial S_2}{\partial m}=\frac{1}{2}\left\{\frac{-(C_2+\varepsilon A_2-aC_2)D}{[\alpha_2 P+(1-\delta)\beta q-N_2+(1-\eta)bB+mD]^2}+\frac{-(C_1+\varepsilon A_1-aC_1)D}{(\alpha_1 P+\delta\beta q-N_1+\eta bB+mD)^2}\right\}<0$, we can get the $\frac{\partial S_2}{\partial D}<0$. S_2 decreases with increasing m and D, and the probability that the system evolves towards point $B(1,1)$ increases. In order to prevent the occurrence of subsidy fraud and create a level playing field for enterprises, the government will punish the defaulting parties. The greater the supervision and punishment, it will increase the cost of default and encourage the game to evolve in the direction of collaborative innovation.

Proposition 9. The impact of the reward distribution coefficient of green intelligent building materials achievements on the final strategy selection of upstream and downstream green intelligent building materials enterprises among green intelligent building materials industries depends on the specific situation.

Proof. The reward distribution coefficient of green intelligent building materials and market risk and return distribution coefficient and S_2 is similar, depending on the specific situation. When $\left[\frac{\alpha_1 P+\delta\beta q-N_1+\eta bB+mD}{\alpha_2 P+(1-\delta)\beta q-N_2+(1-\eta)bB+mD}\right]^2>\frac{C_1+\varepsilon A_1-aC_1}{C_2+\varepsilon A_2-aC_2}$, we can get the $\frac{\partial S_2}{\partial \eta}>0$.

S_2 is an additive function of η, and the probability of the system evolving towards point $O(0,0)$ increases as η increases. Conversely, the probability that the system evolves towards point $B(1,1)$ increases.

4. Discussion

4.1. Questionnaire analysis

Referring to the relevant domestic and foreign literature, combined with the mature questionnaire design method, this paper adopts the semi open questionnaire. The questionnaire consists of three parts. The first part is the basic information of experts. The second part is the value of basic parameters and change parameters of the payment matrix, such as the value of basic parameters such as different subsidies, rewards and punishments. The third part is an open-ended issue, involving expert opinions on the impact of changing parameters (subsidies, coefficients and inputs) on the development of green intelligent building materials industry.

In order to reasonably set the simulation parameters, 120 experts are invited through network search and social network relationship to ensure the reliability and popularization of the research conclusions of the paper. The questionnaire was conducted in the form of real name questionnaire. Experts mainly include experts and scholars in relevant fields of colleges and universities, professional technicians and managers of green intelligent building materials industry, and experts in the field of public management. A total of 120 questionnaires were distributed and 95 were recovered, with a recovery rate of 79.17%. After the questionnaire is collected, the results given by each expert are simulated and tested. Only when it passes the test and conforms to the actual situation is the effective questionnaire. The final valid questionnaires were 87, and the effective recovery rate was 72.50%.

In this paper, Harman single-factor analysis method was used to conduct homology bias test based on the collected questionnaire data. Exploratory factor analysis results show that the load of the unrotated first principal component is 24.63%. No single factor explains most of the variance. Therefore, it can be determined that there is no homology bias in the sample data of this study. In this paper, Cronbach Alpha coefficient was used to evaluate the internal consistency of sample data and CR value test was used to test the combined reliability of sample data. KMO value and Bartlett sphere method were used to test the conception validity of sample data. At the same time, the scale was modified and improved on the basis of the mature scale, and a pre-survey was carried out. The content of the scale can effectively reflect variable information and has good content validity. Reliability and validity tests were carried out according to the questionnaire data. Cronbach Alpha coefficients were between 0.703–0.864, both greater than 0.7, indicating high internal consistency of sample data. CR values range from 0.801–0.863, all of which are greater than 0.7, indicating high reliability of sample data combination. The KMO values of factor analysis ranged from 0.726–0.867, greater than 0.7, and were significant at the level of 0.01%, indicating that the sample data had good conception validity.

On the basis of demonstrating the influence of various factors on the strategy choice of game players, this paper further analyzes the evolution law of collaborative innovation selected by upstream and downstream green intelligent building materials enterprises among green intelligent building materials industries on the basis of cooperation. Because government financial support can indirectly reduce costs, the supervision and punishment mechanism can affect free rider income and prospect profit and loss. Therefore, this paper considers the impact of government financial support, supervision and punishment mechanism on the direction of system evolution from the aspects of collaborative innovation cost, free rider income and prospect profit and loss.

4.2. The influence of the ratio of collaborative innovation cost to collaborative revenue on the evolution results

The cooperative innovation relationship between the two sides of the game is established on the basis of ultimately not damaging their own interests. Therefore, the ratio of benefit and cost of collaborative innovation will affect the final strategy choice of both sides of the game. From the above derivation and analysis, it can be seen that the lower the cost investment of collaborative innovation, the higher the technical income and market risk income, and the more likely it is to lead to the evolution of the system in the direction of collaborative innovation. Therefore, this paper further studies the impact of the relationship between cost and benefit on the evolution direction of game two-way collaborative innovation without considering government financial support. Evolution trajectory of the system under different relationship between cost and benefit can be shown in Figure 2.

In the Figure 2, without considering the government financial support, there is a threshold value for the ratio of cost to benefit between the two sides of the game. When the ratio is less than the threshold, the system will evolve in the direction of collaborative innovation. When the ratio is greater than the threshold, the system will evolve in the direction of non collaborative innovation. And the higher the ratio, the faster the evolution speed. In order to reduce the ratio of cost to income, upstream green intelligent building materials enterprises can set up special departments and positions to actively improve their own database marketing maturity. At the same time, both sides can establish an instant information sharing mechanism and sharing platform. Compared with references [8] and [35], this study can not only efficiently generate the amount of information and technology, but also help to improve the shared market risk return and technology return. However, for most green intelligent building materials enterprises, the ratio of cost to income is difficult to reach the threshold. Therefore, without the financial support of the government, it is difficult to promote both sides of the game to choose the stable strategy of collaborative innovation.

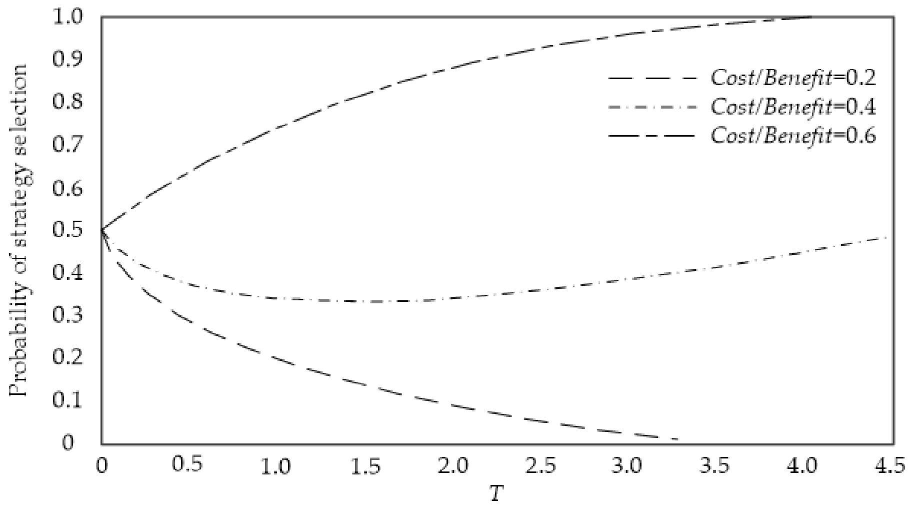

Figure 2. Evolution trajectory of the system under different relationship between cost and benefit.

The government's financial support for the green intelligent building materials industry can be realized from many aspects. When the enterprise's own cost-benefit ratio can not promote the two-way collaborative innovation of the game, the government's financial support will reduce the cost of collaborative innovation and make the ratio of cost-benefit tend to the threshold. This paper will further explore the impact of government cost subsidy and achievement reward of green intelligent building materials on the evolution trajectory of the system when the ratio of cost to benefit is non collaborative innovation.

(1) The influence of government cost subsidy on the evolution results of both sides of the game can be shown in Figure 3. As shown in Figure 3, in the case of government cost subsidy without achievement reward of green intelligent building materials, when the ratio of enterprise's own cost to income is difficult for both sides of the game to choose collaborative innovation, there is also a threshold for the strength of government cost subsidy. When the cost subsidy is greater than the threshold, the system will evolve in the direction of collaborative innovation. If the government's cost subsidy is too small, it can not encourage the evolution of two-way collaborative innovation in the game.

(2) The impact of government green intelligent building materials achievement reward on the evolution results of both sides of the game can be shown in Figure 4.

As shown in Figure 4, when the government rewards the achievements of green intelligent building materials without cost subsidies, the impact of the achievements of green intelligent building materials on the evolution of the system is similar to that of cost subsidies, and there are thresholds. The difference is that the incentive effect of the achievement reward of green intelligent building materials is more long-term, but the incentive effect is not obvious in the initial stage. The convergence speed under the effect of cost subsidy is faster than the achievement reward of green intelligent building materials. In general, although the incentive effect of green intelligent building materials achievement subsidy is long-term, the incentive efficiency and speed are not as good as cost subsidy. The government should combine the two means to promote the development of green intelligent building materials industry. Green intelligent building materials enterprises should also pay more attention to the social benefit coefficient of achievements in order to obtain more rewards for green intelligent building materials achievements. Government cost subsidy and achievement reward of green intelligent building materials can give full play to their respective advantages and promote the evolution of the system in the direction of collaborative innovation. When the government implements cost subsidy and achievement reward of green intelligent building materials at the same time, their respective thresholds will change.

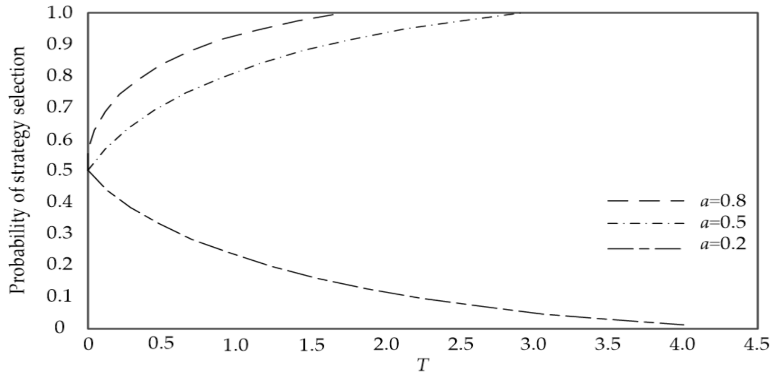

Figure 3. System evolution trajectory under different cost subsidies.

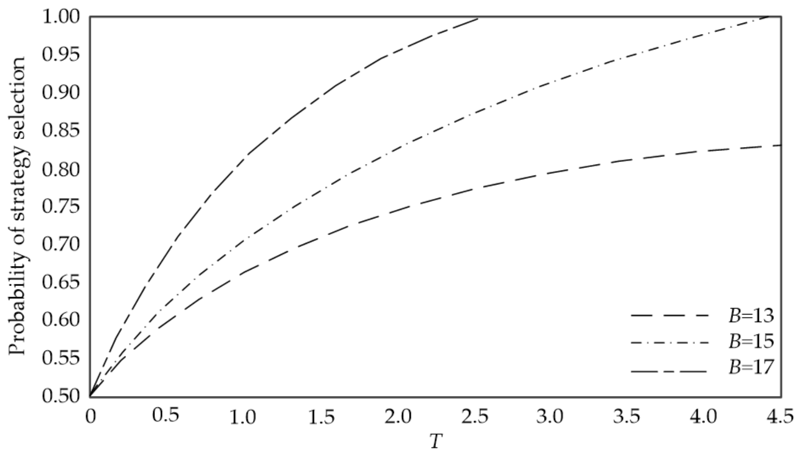

Figure 4. Evolution trajectory of the system under different rewards for achievements.

4.3. The influence of free rider income and prospect profit and loss on evolution results

The influence of income of free-riding and profit and loss of prospect on the evolutionary results of both sides of the game can be shown in Figure 5. Compared with references 8 and 35, income of free-riding and profit and loss of prospect is considered in the present study.

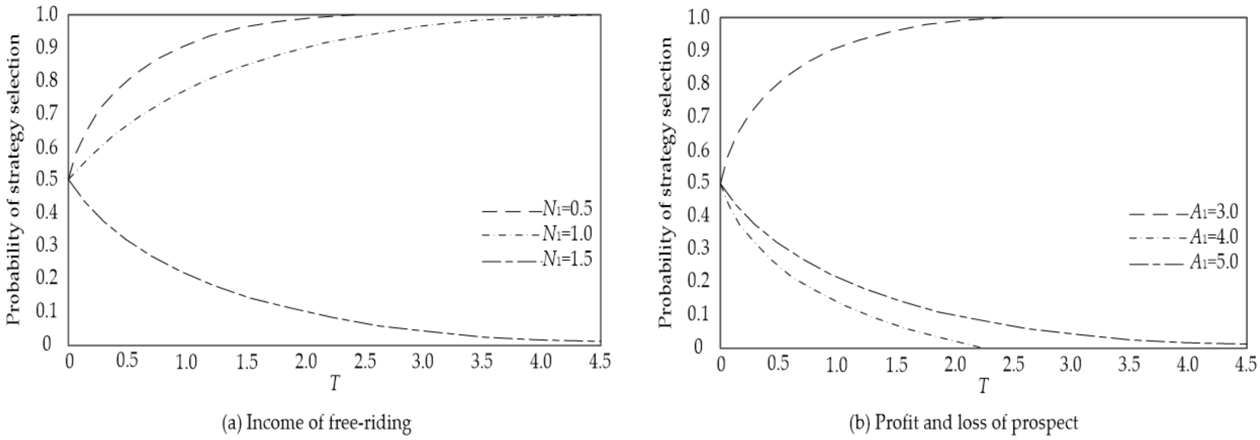

Figure 5. Influence of income of free-riding and profit and loss of prospect on the evolutionary results of both sides of the game.

As shown in Figure 5(a), since it is assumed that the synergy income of both sides of the game remains unchanged, the changes of free rider income and prospect profit and loss can also reflect the proportion of free rider income and prospect profit and loss in synergy income respectively. In the process of game, both sides of the game will measure the proportion of free riding income brought by non collaborative innovation in collaborative income and the proportion of prospect profit and loss caused by collaborative innovation in collaborative income. There is a threshold for the proportion of both. The threshold of free rider income is lower than the prospect profit and loss. The proportion of prospect profit and loss in synergy profit can better affect the final strategy choice of both sides of the game.

As shown in Figure 5(b), the government will punish enterprises that do not adopt collaborative innovation but can obtain free rider income to create a fair competitive environment among enterprises. At the same time, government regulation can also improve the quality of profit and loss barriers. There is a threshold for the impact of government punishment on the results of system evolution. Moderate supervision and punishment lower than free rider income can not guarantee fair competition among enterprises. The punishment above the threshold can drive the system to evolve in the direction of collaborative innovation. Moreover, the higher the punishment, the faster the convergence speed of the system.

5. Conclusions

5.1. Conclusions

With the change of people's cognitive concept of environment and energy, green building has gradually become people's pursuit. Within the design service life of buildings, green buildings not only save various energy consumption as much as possible, but also reduce the emission of pollutants, but also create a healthy, safe, livable and happy living environment for owners and social residents. The development of chip, communication, big data analysis and other technologies has led to more automation of modern green buildings. Intelligent building is to create a more convenient and comfortable environment for owners through equipment installation, structural change and management innovation. Green intelligent building materials are the material basis for the development of green intelligent buildings. Firstly, this study makes a theoretical analysis on the collaborative innovation behavior of supply chain enterprises among green intelligent building materials industries. Secondly, the game models under market mechanism and government regulation are constructed to solve the model and analyze the income distribution mechanism. Finally, the game strategy of collaborative innovation behavior among subjects is discussed through questionnaire survey. The results are as follows. When choosing the game strategy of collaborative innovation behavior among subjects, factors such as database marketing maturity, information flow and technology volume generated by collaborative innovation, technical benefit coefficient, social benefit coefficient and profit and loss barrier factors are conducive to the subjects to carry out collaborative innovation behavior. When the market mechanism fails, the incentive effect of cost subsidy adopted by the government is more efficient and fast, and the driving force of achievement reward is more lasting. The combination of the two incentives is the best. Moderate supervision and punishment lower than free rider income can not guarantee fair competition among enterprises. The punishment above the threshold can effectively restrain the negative impact of free rider income and prospect profit and loss.

5.2. Implications

1) Green intelligent building materials enterprise. Green intelligent building materials enterprises should improve their own technical level and establish an information sharing mechanism between the two sides. Technological return and market risk return can affect the ratio of collaborative innovation cost to collaborative return, thus affecting the final strategy choice of both sides of the game. Therefore, both sides of the game should actively improve their technical level and establish an information sharing mechanism. In addition, green intelligent building materials enterprises should deepen information sharing channels and strengthen full communication between the two sides. At the same time, green intelligent building materials enterprises should make full use of advanced information technology to improve the maturity of database marketing. Green intelligent building materials enterprises can enhance the online promotion and communication function of service management system and provide personalized and standardized innovative services for customers. This can not only effectively reduce the market risk of emerging products and obtain more market risk returns, but also promote both sides of the game to choose collaborative innovation behavior. Green intelligent building materials enterprises should not only pay attention to economic benefits, but also pay attention to social benefits. The development direction of green intelligent building materials industry must meet the needs of social benefits such as green, environmental protection and sustainability. Therefore, green intelligent building materials enterprises should lay out the development strategy of green intelligent technology innovation in the long run. In addition, green intelligent building materials enterprises should actively practice entrepreneurship and put an end to immoral behavior caused by interest inducement. The free riding behavior of innovation subjects is an important factor affecting their choice of collaborative innovation behavior. Therefore, the possibility of immoral behavior of enterprise subjects can be effectively reduced. Green intelligent building materials enterprises should adhere to the bottom line of the contract and create a collaborative innovation atmosphere of equality, mutual benefit and mutual trust to reduce risks and frictions in the process of cooperative innovation.

2) Government departments. Government departments should optimize incentive policies and give full play to the incentive role of the government in promoting the collaborative innovation

behavior of the main body. Government support is a long-term incentive means. By formulating targeted reward and punishment incentive mechanism, it can promote the emergence of subject collaborative innovation behavior. The government's incentive measures can include positive incentive, that is, through institutional preferential policies, incentive subjects' collaborative innovation behavior, and negative incentive, that is, punishment mechanism. In the positive incentive policy, the government can achieve the purpose of incentive by means of cost subsidy or achievement reward. Through the analysis of the behavior strategy choice of the game subject, it can be found that the government should take the cost subsidy as the main, the achievement reward as the supplement, and the combination of various incentive means is the best. The combined incentive mechanism can give full play to their incentive characteristics. Appropriate financial support can indirectly reduce the threshold of the ratio of collaborative innovation cost to collaborative income. In the negative incentive, the government should establish a dynamic supervision mechanism to supervise and restrict the collaborative innovation behavior of enterprises, and adopt strong supervision and punishment to ensure a fair competitive environment among enterprises. In addition, the government should strictly implement tax policies to encourage green innovation, such as income tax reduction and exemption for manufacturing enterprises, accelerated depreciation of fixed assets, pre tax addition and deduction of green R & D expenses, tax reduction and exemption and tax preference for venture capital and green technology transfer.

5.3. Limitations

This study has the following deficiencies, which need to be further studied in the future. First, consumer participation in the green intelligent building materials market has not been fully considered in this study. Future research should introduce multi-agents considering price, cost and other factors to explore the impact of consumers on the green intelligent building materials market. Second, evolutionary game is a qualitative research method in this study, which also reflects the limitations of this study. In the future, quantitative methods should be used to explore the development mechanism of green intelligent building materials industry.

Data availability statement

The data presented in this study are available on request from the corresponding author.

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Conflict of interest

The authors declare no conflict of interest.

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