Can Green Finance Drive the Development of the Green Building Industry?—Based on the Evolutionary Game Theory

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Abstract: The construction industry has a significant impact on the environment, and green buildings provide an effective means of reducing environmental impact. Green finance can facilitate industrial transformation and upgrading, reduce construction costs, attract investment, and promote green industry development. However, traditional financing models still dominate the financing of green building projects, even if they are not in line with the core principles of green building. To solve this problem, this paper establishes a three-party evolutionary game model, which, based on the assumption of finite rationality, considers three core stakeholders: bank and financial institutions, developers, and consumers. The conditions for evolutionary stable equilibrium are identified through an equilibrium analysis of the strategic behavior of each subject, followed by a replication dynamic analysis. Simulation analysis was used to study the effects of key parameters on cooperative behavior and evolution. The results of the study show that (1) The high initial willingness of bank and financial institutions and consumers has a significant driving effect on the market. (2) When the market willingness is high, the government can steer the market towards the desired goal at relatively low policy costs. (3) With the support of green finance, green buildings can still flourish even if the return is slightly lower than traditional building projects. The results of the study reveal cooperative behavior and its evolutionary patterns, which help stakeholders coordinate their goals and promote the development of the green building industry.

Keywords: green buildings; green finance; green finance in green buildings; evolutionary game

1. Introduction

The construction industry is responsible for 34% and 37% of global energy consumption and carbon emissions, respectively [1]. The promotion of green buildings is a crucial imperative for the construction industry to protect the environment, conserve resources, and seek opportunities for high-quality development. Green buildings are defined by the World Green Building Council as integrated designs that maximize positive impacts on climate, environment, and occupants in both residential and commercial buildings. Such buildings accomplish low carbon emissions, energy savings, and significantly lower lifecycle costs of projects. From an environmental perspective, the promotion of green buildings can reduce energy consumption by 50%, conserve 60% of water resources, and reduce carbon dioxide emissions by 45% [2]. From an economic standpoint, the green building sector is expected to offer USD 24.7 trillion in investment opportunities by 2030 [3]. Therefore, the development of green buildings can not only effectively alleviate the impact of the construction industry on the environment but also bring new development opportunities for the construction industry [4,5].

The development of green buildings involves a range of stakeholders, and the selection of key stakeholders is critical to the development process. From a consumer perspective, green buildings can enhance residents’ health and productivity. Nevertheless, the additional cost of purchasing green buildings significantly reduces consumers’ willingness to
buy them. From a developer perspective, the green building market is still in its early stages, but the high costs of technology and materials lead to higher construction costs for green buildings [6]. Moreover, green buildings have significant positive externalities, and there are issues of cost and benefit time mismatch [7], which hinder the growth of the green building market. From a bank and financial institutions (BFI) perspective, green buildings have significant economic importance and provide new investment opportunities for investors and financiers, with a potential scale of trillions of dollars [8]. However, since green building projects are a new investment field, they are still in their early stages and lack case support. It is challenging to estimate their levels of returns accurately, and investors do not pay enough attention to or provide critical support for such projects, hence limiting the development of green buildings.

Green finance is considered the most targeted approach to addressing challenges in the development of green buildings [9,10]. This approach combines financial development with environmental protection [11] and offers low-cost financial support to the green building industry through green financial instruments such as green fiscal investments, green credit, green insurance, and green bonds. Unlike traditional financial models, green finance places greater emphasis on ecological and environmental benefits and directs funds towards projects with higher environmental benefits [12]. BFI, developers, and consumers play central roles in the green building development chain. When BFI invest in such projects, developers opt to develop green building products, and consumers embrace and purchase green buildings. All parties’ expectations and anticipated benefits are met, enabling the development of green buildings under market mechanisms.

Currently, the green building industry is in a period of rapid development, and many scholars have researched how to promote the green building industry. Meng [13], Li [14], Wang [15], etc., use the method of evolutionary games, taking developers, BFI, and the government as the main subjects of the study to analyze the impact of government incentives and penalties on the market. However, these studies have overlooked a key stakeholder—the consumers. In the research conducted by Yang [16] and Feng [17], consumers were included, but the conclusions still rely on administrative power and financial support as the driving forces, and a market-oriented approach has yet to be established. Research on green finance in the field of green buildings is limited [18,19].

There is still a gap in the research on the interaction between BFI, developers and consumers in the context of green finance for green buildings. Green building development relies heavily on government administrative policy intervention and financial funding support. The introduction of green finance will bring market-based operation mechanisms and vitality to green building development. Meanwhile, it effectively solves the problems of insufficient development of the green building market, an inactive demand side, and unclear interests of developers.

Therefore, this study adopts an evolutionary game approach to investigate the group decision-making behavior of BFI, developers, and consumers. A tripartite evolutionary game model is established to analyze the cooperative willingness of stakeholders, determine the equilibrium state of the game, and identify the sensitivity levels of the key factors. The goal is to explore the cooperative potential among BFI, developers, and consumers in the development process of green buildings. This research intends to provide valuable insights for government agencies in formulating policies and for industry practitioners in developing more targeted policies and business models.

This paper is structured as follows: Section 2 provides a summary of existing literature on green building and green finance, exploring the current state of development and challenges associated with green building and progress made in green finance in this field. The objective is to highlight the innovation of this study in comparison to prior research. Section 3 outlines the modeling details and assumptions. Section 4 covers the process of building and implementing the model. In Section 5, we conduct a stability analysis of the model and obtain the evolutionary equilibrium point. Section 6 presents
the simulation results and discussion. Ultimately, in Section 7, we draw conclusions with relevant recommendations based on the simulation results.

2. Literature Review

2.1. Study on Green Buildings

As time progresses, nations worldwide are increasingly recognizing the gravity and immediacy of climate change. In pursuit of economic growth, reducing carbon emissions and energy consumption has become a goal across various industries, including the construction sector [20–22]. The construction industry bears a significant responsibility for global environmental changes, especially due to its high carbon emissions and energy consumption [23]. Thus, green building has been advocated and promoted as a guiding principle to make the construction industry more environmentally friendly.

The concept of green building can be traced back to the 19th century or earlier [24]. In recent years, it has gained widespread acceptance [25]. The mainstream view acknowledges several advantages of green building: (1) it can reduce carbon emissions and resource consumption [26]; (2) it can provide more comfortable and healthier living and working environments [4]; and (3) from a lifecycle perspective, green buildings are cost-effective and have lower operating expenses [27]. The financial benefits resulting from reduced energy consumption outweigh the additional costs. However, the development of green buildings still faces many challenges that hinder progress.

From the perspective of the developer, the higher initial construction costs of green buildings are a significant factor that impedes investment in green buildings [28,29]. Cheng collected and compared 37 certified green residential cases with 36 conventional residential cases and found that the cost increase for green buildings ranged from 6.7% to 9.3% [30]. There is limited experience among stakeholders in making decisions regarding green building construction contracts, which have a shorter application time [31]. Additionally, there is insufficient government support and incentives for the green building industry [32], a lack of investor support [29], low customer acceptance [33], low government capacity [8], and a lack of assessment and disclosure mechanisms for the “green benefits” of green buildings. These are all practical issues that hinder the development of green buildings.

From the perspective of the consumer (homeowner), there is a lack of awareness and price sensitivity towards green buildings. Certified green buildings have a premium of about 4% in the presale stage and a premium of about 10% in the resale stage compared to traditional buildings [34]. Most consumers focus on factors such as location and amenities when choosing a property and rarely consider the benefits brought by the green attributes of a building. Therefore, to increase consumer awareness of the advantages of green buildings, potential homebuyers must be willing to pay a higher premium [35]. Considering these additional expenses, core stakeholders must ensure these extra costs are reasonable.

In conclusion, the promotion of green buildings faces numerous practical obstacles. Developers often abandon green projects because of relatively high costs, longer development cycles, and financing difficulties. Many consumers lack the ability to calculate the full lifecycle benefits of green buildings and have limited awareness of their advantages when making purchasing decisions. Although the green building market has achieved some success in its development, it heavily relies on government administrative efforts and financial support, lacking a market-driven operational mechanism and vitality. Taking a long-term perspective, the introduction of green finance into the field of green buildings, along with the establishment of a more market-oriented development mechanism, can stimulate the vitality of market entities and foster the intrinsic motivation for the development of green buildings.

2.2. Study on Green Finance in Green Buildings

The field of research and investment in green building projects is insufficient [36]. Statistical data reveals that out of USD 5.6 trillion invested worldwide in the construction sector in 2019, only USD 148 billion was allocated to green building investments. Presently, funding
for green building projects is reliant on conventional financial models that do not align with the green characteristics of green buildings. There is an absence of suitable financing models, specifically tailored green finance solutions designed for green building projects.

Green finance plays a constructive role in the advancement of the green building industry [37]. It helps bridge the investment gap and reduce cost barriers, thereby accelerating industry transformation. Wang [10] established a multilevel indicator system for factors influencing green building and used the RBF-WINGS model to determine the direct intensity impact matrix. They objectively analyzed various indicators influencing green building development and confirmed that the support of green finance is one of the significant factors affecting the development of green buildings. He [9] compared the impact of different combinations of financial instruments on green building development, highlighting the significant effects of green fiscal investment, insurance, and credit support. The higher return on investment in green buildings attracts more investors from the construction and real estate industries to invest in green finance [38]. For consumers, BFI offering more green housing loans can reduce their borrowing costs and increase their willingness to purchase. Additionally, it is important to focus on cultivating green awareness to help stakeholders in the construction industry understand the necessity of transitioning to green finance models [39]. Previous literature has examined the driving factors and barriers to green finance application in the green building sector, as well as summarized the current development status. However, the methods used in those studies have been predominantly qualitative, lacking in-depth quantitative analysis of the mechanisms and effects of green finance applications in the green building sector.

The evolutionary game theory was initially proposed by Smith and Price, employing the theory of bounded rationality to simulate the group strategies of participants [40,41]. Evolutionary game theory rejects the assumption of absolute rationality in traditional game theory as it does not accurately reflect limited rationality among participants. Starting with limited rationality, the Nash equilibrium analysis of participant choices is carried out, followed by replication dynamic analysis. These analyses are then combined to draw conclusions on interactions and influences between different strategies. This method allows for reliable prediction of strategic interactions. Since its introduction, this approach has been widely applied in the field of construction [42–44]. Numerous studies have analyzed the influencing factors of promoting green buildings, with the government and developers as the core entities in green building promotion. Under government reward and punishment mechanisms, administrative measures have a significant impact on promoting green building development. Chen [45] and Meng [13] used a two-player evolutionary game model to study the intrinsic mechanisms of government and construction enterprise behavior evolution. The results indicated that the combination of dynamic subsidies and static penalties achieved the best outcomes for promoting green construction by enterprises. Li [46], employing system dynamics for simulation analysis, found that increasing subsidies or inspection intensity alone does not effectively improve the probability of developers constructing green buildings. Regarding the issue of “greenwashing” faced by construction companies in the current development of green buildings in China, Wang [47] developed a game model involving commercial banks, core enterprises, and small and medium-sized enterprises. The study revealed that the support of green finance can help address the financing difficulties faced by small and medium-sized enterprises and provide support for their green innovation and the transformation of the supply chain towards green practices.

Previous research has primarily focused on the role of the government, BFI, and developers in green building development, neglecting the essential role of consumers. As the ultimate players in the process of green building development, consumer behavior and choices are key factors in the growth of the green building market. To address this gap, this study seeks to center consumers in a tripartite evolutionary game model that includes BFI, developers, and consumers. The influence of green finance will also be incorporated to analyze the trajectory of the green building market. Moreover, the government will be
regarded as a regulatory entity for the behavior of BFI rather than a participant in the game in constructing the model.

3. Model Description and Assumptions

Assumption 1: This paper constructs a tripartite evolutionary game theory model consisting of “developer,” “BFI,” and “consumer”.

Assumption 2: The strategy choices of the developer include “implement” and “not implement” green building technologies, with a strategy space denoted as \( S_D = \{\text{implement}, \text{not implement}\} \). Let \( x \) represent the probability of implementing green building technologies, and \((1 - x)\) represent the probability of not implementing them. The strategy choices of BFI include “adopt” and “not adopt” green finance policies. The strategy space is denoted as \( S_B = \{\text{adopt}, \text{not adopt}\} \), with \( y \) representing the probability of adopting green finance and \((1 - y)\) representing the probability of not adopting it. The strategy choices of the consumer include “endorse” and “not endorse” green buildings, with a strategy space denoted as \( S_C = \{\text{endorse, not endorse}\} \). The probability of the consumer endorsing the concept of green buildings is represented by \( z \), while the probability of not endorsing it is represented by \((1 - z)\). The structure of the strategy evolutionary game tree is illustrated in Figure 1.

Assumption 3: The baseline profit of developers is denoted as \( R_2 \). Developers incur interest expenses when obtaining financing. Under the implementation of green finance by BFI, projects implementing green building technologies can obtain funding more easily, and the corresponding cost is denoted as \( I_1 \). In this case, it becomes difficult for developers to secure financing for traditional projects, and the cost of capital is denoted as \( I_3 \). In the absence of the green finance environment implemented by BFI, the financing cost incurred by the developer is denoted as \( I_2 \). The financing costs should satisfy the condition \( I_3 > I_2 > I_1 \). When developers obtain financing from BFI and construct green buildings, both the developer and BFI will benefit from environmental gains denoted as \( E \). If the developer fails to understand consumer preferences and fails to construct products that meet market demand, it will increase the difficulty of sales and prolong the delivery period, resulting in certain losses.

When developers construct green buildings but consumers do not endorse the concept of green buildings, the loss is denoted as \( W_1 \). When developers construct traditional buildings but consumers endorse the concept of green buildings, the loss is denoted as \( W_2 \), and \( W_1 > W_2 \). If both developers and consumers possess green attributes, both parties will reduce a portion of their advertising and communication costs, denoted as \( B \).
Assumption 4: The baseline profit of BFI is denoted as $R_1$. BFI need to establish governance systems, assessment mechanisms, and differentiated support policies for green finance to provide institutional support for its implementation, and the cost associated with this is denoted as $C_b$. The government departments involved in promoting green finance policies and facilitating the green transformation of the construction industry provide policy and financial incentives to BFI, which is denoted as $G_b$. BFI that respond negatively to the requirements of promoting green finance will face punitive measures by government departments, and this loss is denoted as $L_1$. When developers engage in green building development, it will drive the research, development, and manufacturing of energy-saving wall materials, energy-efficient doors and windows, prefabricated building components, and external wall insulation materials by companies in the industrial chain. BFI provide financing to supply chain enterprises, and this results in gains denoted as $E$. BFI provide individual green housing loans to consumers who endorse the concept of green buildings, resulting in gains denoted as $J$. Considering the circumstances, funds are more inclined to favor traditional projects with mature business models and a clearer market environment. Traditional projects also tend to have higher profit margins, so lending funds to green building projects will reduce a portion of the returns, and this difference in returns is denoted as $Q$.

Assumption 5: Green construction can effectively lower energy and water expenses for home buyers. Incorporating ecofriendly materials in such buildings can ameliorate indoor air quality and enhance illumination and air circulation. The ultimate advantage of green buildings for consumers throughout their lifespan is measured in $U_g$. Consumers who purchase green buildings also enjoy the advantage of preferential loan interest rates, which can save a part of the interest expense denoted as $G_c$. However, since green buildings incorporate new construction materials and technologies, consumers may incur additional costs compared to traditional buildings, denoted as $C_c$. On the other hand, consumers who endorse green buildings but end up purchasing traditional buildings may incur costs in the future for green modifications, such as installing ventilation systems and high-performance doors and windows. This cost is denoted as $C_g$.

4. Model Construction and Analysis

According to the aforementioned assumptions, the tripartite game matrix is shown in Table 1, and the payoffs for each player are shown in Table 2.

Table 1. Tripartite game matrix.

<table>
<thead>
<tr>
<th>BFI</th>
<th>Endorse ($z$)</th>
<th>Not Endorse ($1 - z$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adopt ($x$)</td>
<td>Not Adopt ($1 - x$)</td>
</tr>
<tr>
<td>Not imply ($1 - y$)</td>
<td>(A5, A5, A5)</td>
<td>(A6, A6, A6)</td>
</tr>
</tbody>
</table>

Table 2. The payoff matrix.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Developer</th>
<th>BFI</th>
<th>Consumer</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A1, A1, A1)</td>
<td>$R_2 - I_1 + E + B$</td>
<td>$R_1 - C_b + G_b + E + J$</td>
<td>$U_g - C_c + G_c + B$</td>
</tr>
<tr>
<td>(A2, A2, A2)</td>
<td>$R_2 - I_3 - W_2$</td>
<td>$R_1 - C_b + G_b + J$</td>
<td>$-C_g$</td>
</tr>
<tr>
<td>(A3, A3, A3)</td>
<td>$R_2 - I_1 + E - W_1$</td>
<td>$R_1 - C_b + G_b + E$</td>
<td>0</td>
</tr>
<tr>
<td>(A4, A4, A4)</td>
<td>$R_2 - I_3 + B$</td>
<td>$R_1 - C_b + G_b$</td>
<td>$B$</td>
</tr>
<tr>
<td>(A5, A5, A5)</td>
<td>$R_2 - I_2 + B + E$</td>
<td>$R_1 + Q - L_1 + E$</td>
<td>$U_g - C_c + B$</td>
</tr>
<tr>
<td>(A6, A6, A6)</td>
<td>$R_2 - I_2 - W_2$</td>
<td>$R_1 - L_1 + Q$</td>
<td>$-C_g$</td>
</tr>
<tr>
<td>(A7, A7, A7)</td>
<td>$R_2 - I_2 - W_1 + E$</td>
<td>$R_1 + Q - L_1 + E$</td>
<td>0</td>
</tr>
<tr>
<td>(A8, A8, A8)</td>
<td>$R_2 - I_2 + B$</td>
<td>$R_1 - L_1 + Q$</td>
<td>$B$</td>
</tr>
</tbody>
</table>
Based on Tables 1 and 2, the expected payoffs $E_{11}$ and $E_{12}$ for the developer’s choices of “implement” or “not implement” green building technology, respectively, and their average expected payoff $E_3$ are as follows:

$$
\begin{align*}
E_{11} &= y * [z * (R_2 - I_1 + E + B) + (1 - z) * (R_2 - I_2 + E - W_1)] + (1 - y) * [z * (R_2 - I_2 + B + E) + (1 - z) * (R_2 - I_2 - W_1)] \\
E_{12} &= y * [z * (R_2 - I_3 - W_2) + (1 - z) * (R_2 - I_3 + B)] + (1 - y) * [z * (R_2 - I_3 - W_2) + (1 - z) * (R_2 - I_3 + E + B)] \\
E_3 &= x * E_{11} + (1 - x) * E_{12}
\end{align*}
$$

(1)

Based on Tables 1 and 2, the expected payoffs $E_{21}$ and $E_{22}$ for the BFI choices of “adopt” and “not adopt” green finance strategy, as well as the average expected payoff $E_2$ are as follows:

$$
\begin{align*}
E_{21} &= x * [z * (R_1 - C_b + G_b + E + J) + (1 - z) * (R_1 - C_b + G_b + E)] + (1 - x) * [z * (R_1 - C_b + G_b + J) + (1 - z) * (R_1 - C_b + G_b)] \\
E_{22} &= x * [z * (R_1 + Q - L_1 + E) + (1 - z) * (R_1 + Q - L_1 + E)] + (1 - x) * [z * (R_1 - L_1 + Q) + (1 - z) * (R_1 - L_1 + Q)] \\
E_2 &= y * E_{21} + (1 - y) * E_{22}
\end{align*}
$$

(2)

Based on Tables 1 and 2, the expected payoffs $E_{31}$ and $E_{32}$ for the consumer’s choices of “Endorsing” and “Not Endorsing” the green part-time group, as well as the average expected payoff $E_3$ are as follows:

$$
\begin{align*}
E_{31} &= x * [y * (U_g - C_g + G_c + B) + (1 - y) * (U_g - C_g + B)] + (1 - x) * [y(-C_g) + (1 - y) * (-C_g)] \\
E_{32} &= x * [y * 0 + (1 - y) * 0] + (1 - x) * [(1 - y) * B + y * B] \\
E_3 &= z * E_{31} + (1 - z) * E_{32}
\end{align*}
$$

(3)

5. Evolutionary Equilibrium Points and Stability Analysis

5.1. Three-Dimensional Replicator Dynamic Equations

The replicator dynamic equation for the probability of the developer choosing the “implement” green building technology strategy is:

$$
F(x) = \frac{dx}{dt} = x(E_{11} - E_1)
= x * (x - 1) * (2 * B * z - W_1 - B + 2 * E * y + 2 * E * z - I_1 * y + I_3 * y + W_1 + W_2 + z - 2 * E * y * z)
$$

(4)

The replicator dynamic equation for the probability of the BFI choosing the “adopt” green finance strategy is:

$$
F(y) = \frac{dy}{dt} = y(E_{21} - E_2)
= -y * (y - 1) * (G_b - C_b + L_1 - Q + J * z)
$$

(5)

The replicator dynamic equation for the probability of the consumer choosing the “endorse” green building concept strategy is:

$$
F(z) = \frac{dz}{dt} = z(E_{31} - E_3)
= -z * (z - 1) * (2 * B * x - C_g - B - C_c * x + G_c * x * y * z)
$$

(6)

By combining Equations (4)–(6), we can obtain the replicated dynamic Equation (7) of the tripartite evolutionary game between the developer, BFI and the consumer.

$$
\begin{align*}
F(x) &= \frac{dx}{dt} = x(E_{11} - E_1) \\
F(y) &= \frac{dy}{dt} = y(E_{21} - E_2) \\
F(z) &= \frac{dz}{dt} = z(E_{31} - E_3)
\end{align*}
$$

(7)

In system L, let $F(x) = F(y) = F(z) = 0$ to obtain the local equilibrium points of the system. If the evolutionary game equilibrium point is an asymptotically stable state, then that point must be a pure strategy Nash equilibrium point. Therefore, for the given replicator dynamic system, we only need to consider the asymptotic stability of the following eight points: $E_1 (0,0,0), E_2 (0,0,1), E_3 (0,1,0), E_4 (1,0,0), E_5 (0,1,1), E_6 (1,0,1), E_7 (1,1,0), E_8 (1,1,1)$. All other points are nonasymptotically stable. All other points are nonasymptotically stable. The local stability of the system can be analyzed by examining the Jacobian matrix. The Jacobian matrix is as follows:
\[ J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix} \]

\[
\frac{\partial F(x)}{\partial x} = -(2x - 1) \ast (2B \ast z - E - W_1 - B + 2 \ast E \ast y + 2 \ast E \ast z - I_1 \ast y + I_3 \ast y + W_1 \ast z + W_2 \ast z - 2 \ast E \ast y \ast z)
\]

\[
\frac{\partial F(y)}{\partial y} = -x \ast (x - 1) \ast (2 \ast E - I_1 + I_3 - 2 \ast E \ast z)
\]

\[
\frac{\partial F(y)}{\partial z} = -x \ast (x - 1) \ast (2 \ast B + 2 \ast E + W_1 + W_2 - 2 \ast E \ast y)
\]

\[
\frac{\partial F(y)}{\partial x} = 0
\]

\[
\frac{\partial F(x)}{\partial y} = -(2y - 1) \ast (G_b - C_b + L_1 - Q + J \ast z)
\]

\[
\frac{\partial F(y)}{\partial z} = -J \ast y \ast (y - 1)
\]

\[
\frac{\partial F(z)}{\partial x} = -z \ast (z - 1) \ast (2 \ast B - C_c + C_g + U_g + G_c \ast y)
\]

\[
\frac{\partial F(z)}{\partial y} = -G_c \ast x \ast z \ast (z - 1)
\]

\[
\frac{\partial F(z)}{\partial z} = -(2z - 1) \ast (2 \ast B \ast x - C_g - B - C_c \ast x + C_g \ast x + U_g \ast x + C_c \ast x \ast y)
\]

### 5.2. Stability Analysis of Equilibrium States

For the convenience of analyzing the sign of eigenvalues corresponding to different equilibrium points and to maintain objectivity, this paper assumes the following: (1) \(U_g - C_g > 0\), indicating that the incremental benefits consumers receive from green buildings throughout their lifecycle are greater than the incremental costs of purchasing green buildings. (2) \(W_1 - E > 0\), indicating that the losses incurred by the developer due to the inability to meet consumer demands are greater than the environmental benefits gained from developing green buildings.

According to the first theorem of Lyapunov, if all eigenvalues of the Jacobian matrix have negative real parts, then the equilibrium point is asymptotically stable [48]. If the Jacobian matrix has at least one eigenvalue with a positive real part, then the equilibrium point is unstable. If all eigenvalues of the Jacobian matrix, except for those with zero real parts, have negative real parts, then the equilibrium point is in a critical state, and its stability cannot be determined solely by the sign of the eigenvalues. The eigenvalues of the Jacobian matrix corresponding to each equilibrium point (EQ) are shown in Table 3.

### Table 3. The eigenvalue of the Jacobian matrix.

<table>
<thead>
<tr>
<th>EQ</th>
<th>(\lambda_1)</th>
<th>(\lambda_2)</th>
<th>(\lambda_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(E_1) (0,0,0)</td>
<td>(-B - C_g)</td>
<td>(G_b - C_b + L_1 - Q)</td>
<td>(-B - C_g)</td>
</tr>
<tr>
<td>(E_2) (0,0,1)</td>
<td>(B + E + W_2)</td>
<td>(G_b - C_b + J + L_1 - Q)</td>
<td>(B + C_g)</td>
</tr>
<tr>
<td>(E_3) (0,1,0)</td>
<td>(E - B - I_1 + I_3 - W_1)</td>
<td>(G_b - C_b - L_1 + Q)</td>
<td>(-B - C_g)</td>
</tr>
<tr>
<td>(E_4) (1,0,0)</td>
<td>(B - E + W_1)</td>
<td>(G_b - C_b + L_1 - Q)</td>
<td>(B - C_c + U_g)</td>
</tr>
<tr>
<td>(E_5) (0,1,1)</td>
<td>(B + E - I_1 + I_3 + W_2)</td>
<td>(G_b - C_b - J - L_1 + Q)</td>
<td>(B + C_g)</td>
</tr>
<tr>
<td>(E_6) (1,0,1)</td>
<td>(-B - E - W_2)</td>
<td>(G_b - C_b + J + L_1 - Q)</td>
<td>(C_c - B - U_g)</td>
</tr>
<tr>
<td>(E_7) (1,1,0)</td>
<td>(B - E + I_1 - I_3 + W_1)</td>
<td>(G_b - C_b - L_1 + Q)</td>
<td>(B - C_c + C_g + U_g)</td>
</tr>
<tr>
<td>(E_8) (1,1,1)</td>
<td>(I_1 - E - B - I_3 - W_2)</td>
<td>(G_b - C_b - L_1 + Q)</td>
<td>(C_c - B - C_c - U_g)</td>
</tr>
</tbody>
</table>

Scenario 1: When \(G_b - C_b + J + L_1 < Q > 0\) and \(G_b - C_b + L_1 < Q > 0\), it indicates that the regulatory authority’s incentives and penalties on BFI for implementing green finance policies are sufficiently strong. In this case, the combined effect of policy incentives for implementing green finance and the penalties for not implementing it outweighs the cost of implementing green finance and the difference in benefits from not implementing it. Therefore, the system tends towards the desired state of (implement, adopt, endorse).

Scenario 2: When \(G_b - C_b + J + L_1 > Q > 0\), but \(G_b - C_b + L_1 < Q < 0\), relying solely on regulatory incentives and penalties is not enough to bring the system into an ideal stable state. It requires consumers who embrace the concept of green buildings to use green loans provided by BFI. In this scenario, BFI need to have a sufficient profit margin for the system state to stabilize. In this case, the system may evolve into two stable strategy states:
Scenario 3: When $G_b - C_b + J + L_1 - Q < 0$, the incremental profit for BFI from consumer use of green loans, combined with the incentives and penalties from the regulatory authority, is smaller than the cost and loss of benefits from implementing green loans. In this case, BFI will spontaneously refrain from implementing green finance, and the system tends towards the stable strategy of (not implement, not adopt, not endorse). The stability analysis for the above scenarios is shown in Table 4.

### Table 4. Stability Analysis

<table>
<thead>
<tr>
<th>EQ</th>
<th>Situation 1</th>
<th>Situation 2</th>
<th>Situation 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\lambda_1$</td>
<td>$\lambda_2$</td>
<td>$\lambda_3$</td>
</tr>
<tr>
<td>$E_1$</td>
<td>-</td>
<td>+</td>
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<tr>
<td>$E_2$</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
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<td>-</td>
</tr>
<tr>
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<td>+</td>
<td>+</td>
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<tr>
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<td>-</td>
<td>+</td>
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<tr>
<td>$E_8$</td>
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</tbody>
</table>

### 6. Evolutionary Simulation Analysis

This section will simulate and analyze the uneven development of the green finance market based on parameters and real-world scenarios. In this paper, we follow the methodology of Feng [17], Chen [43], and Cui [49] and adapt it to our specific context, assigning value based on the constraints of situation 2. The parameter values are as follows: $R_1 = 6, C_b = 4, G_b = 6, E = 6, J = 6, L_1 = 4, Q = 8, R_2 = 4, I_1 = 3, I_2 = 5, I_3 = 7, W_1 = 5, W_2 = 3, B = 3, U_g = 4, C_c = 6, G_c = 2, C_g = 2$. The conditions for situation 2 are satisfied by Array 1, and numerical simulation analysis will be conducted using the ode45 function in MATLAB R2016a.

#### 6.1. The Impact of Initial Willingness

As illustrated in Figure 2, Array 1 sets four distinct combinations of initial willingness: low initial willingness, represented by (a) ($x = 0.2, y = 0.3, z = 0.4$); high initial willingness for developers, illustrated by (b) ($x = 0.8, y = 0.3, z = 0.4$); high initial willingness for BFI, exemplified by (c) ($x = 0.2, y = 0.8, z = 0.4$); and high initial willingness for consumers, demonstrated by (d) ($x = 0.2, y = 0.3, z = 0.8$). It is observed that when the initial willingness of all participants is relatively low, the system fails to reach the desired state. When solely the initial intention of developers ($x$) increases from 0.2 to 0.8, while the initial willingness of BFI ($y$) and consumers ($z$) are held constant ($y = 0.3, z = 0.4$), the system stabilizes at the state of (not implement, not adopt, not endorse). Conversely, when the initial intention of BFI ($y$) is raised from 0.3 to 0.8, while the other two parties’ willingness remains unchanged ($x = 0.3, z = 0.4$), the system stabilizes at the state of (implement, adopt, endorse). Also, when the initial intention of consumers ($z$) elevates from 0.4 to 0.8, while developers’ and BFI’s willingness remain unchanged ($x = 0.2, y = 0.3$), the system eventually attains stability at the state of (implement, adopt, endorse).

An initial increase in the willingness of BFI to implement green finance policies, as well as consumers endorsing green building concepts, will contribute to a convergence towards the ideal state of (implement, adopt, endorse). This suggests that the implementation of green finance policies can stimulate the development of the green building industry. In the same vein, increased consumer recognition of green buildings can also drive the adoption of green practices within the building industry. The implementation of green finance policies by financial institutions can effectively communicate a positive signal of ecofriendly development to the market. Hu [50] uses an econometric model to demonstrate the existence of a green credit “signal” effect, which can stimulate the greening of the financial industry and promote reductions in carbon emissions by enterprises. Additionally, this...
paper finds that increased consumer acceptance of green buildings can also communicate positive signals to the market, thereby further stimulating the development of the green building industry.

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As illustrated in Figure 2, Array 1 sets four distinct combinations of initial willingness: low initial willingness, represented by (a) \((x = 0.2, y = 0.3, z = 0.4)\); high initial willingness for developers, illustrated by (b) \((x = 0.8, y = 0.3, z = 0.4)\); high initial willingness for BFI, exemplified by (c) \((x = 0.2, y = 0.8, z = 0.4)\); and high initial willingness for consumers, demonstrated by (d) \((x = 0.2, y = 0.3, z = 0.8)\). It is observed that when the initial willingness of all participants is relatively low, the system fails to reach the desired state. When solely the initial intention of developers (\(x\)) increases from 0.2 to 0.8, while the initial willingness of BFI (\(y\)) and consumers (\(z\)) are held constant (\(y = 0.3, z = 0.4\)), the system stabilizes at the state of \((0,0,0)\) (not implement, not adopt, not endorse). Conversely, when the initial intention of BFI (\(y\)) is raised from 0.3 to 0.8, while the other two parties' willingness remains unchanged (\(x = 0.3, z = 0.4\)), the system stabilizes at the state of \((implement, adopt, endorse)\). Also, when the initial intention of consumers (\(z\)) elevates from 0.4 to 0.8, while developers' and BFI's willingness remain unchanged (\(x = 0.2, y = 0.3\)), the system eventually attains stability at the state of \((implement, adopt, endorse)\).

Figure 2. (a) The dynamic evolution process when the initial willingness of all parties is low; (b) The dynamic evolution process of the system when the initial willingness of the developer is high; (c) The dynamic evolution process of the system when the initial willingness of BFI is high; (d) The dynamic evolution process of the system when the initial willingness of the consumer is high.

The aforementioned analysis demonstrates that the awareness of BFI to implement green finance, as well as the level of consumer awareness regarding green buildings, can have a discernible driving effect on the construction industry’s transition towards sustainability. Conversely, developers alone are unlikely to catalyze the shift towards a greener construction market in the absence of green financial support and consumer awareness.

6.2. Equilibrium Results under Different Initial Willingness

Based on the analysis above, it is evident that the increased initial willingness of BFI and consumers enhances the willingness of developers to choose the “implement” strategy for green building technologies. Figure 3 represents the evolutionary outcomes formed by different initial willingness of the entities, using the parameter values from Array 1. From the figure, it can be observed that under relatively low initial willingness of all parties \((x = 0.2, y = 0.3, z = 0.4)\), the system evolves to the state of \((not implement, not adopt, not endorse)\). When the initial willingness of all participating entities is higher \((x = 0.6, y = 0.5, z = 0.6)\), the game eventually stabilizes at the desired outcome of \((implement, adopt, endorse)\). Therefore, in the subsequent simulation analysis, two combinations of initial willingness, one with low willingness and the other with high willingness, will be set to simulate the development of green finance and green building markets in different regions. In Figure 3, the blue line represent the case of low initial willingness \((x = 0.2, y = 0.3, z = 0.4)\), while the red line represent the case of high initial willingness \((x = 0.6, y = 0.5, z = 0.6)\).
6.3. The Impact of Government Rewards and Penalties

As illustrated in Figure 4, when holding other parameters constant, increasing the level of government subsidies for BFI (from two to six) has a significant impact on the system’s evolution towards the desired state under high initial willingness. As shown in Figure 4a, when the level of policy subsidies increases, the impact on the system is relatively small, and the entities eventually evolve to the state of (not implement, not adopt, not endorse). However, as shown in Figure 4b, under high initial willingness and increased subsidy intensity, the system transitions from a nonideal state to the ideal state of (implement, adopt, endorse). In situations where initial willingness is high, government incentives can steer the system towards an ideal state. This indicates that during the initial stage of promoting green buildings, it is important to appropriately stimulate BFI while also increasing policy guidance and public awareness to enhance the willingness of all parties to participate. Increased government policy support for BFI will enhance their confidence in implementing green financial policies. At the same time, bank and financial institutions will obtain sufficient cash flow, enhancing their willingness to carry out green finance, which will, in turn, lead to the participation of other stakeholders in the green building development chain. Li [51] proposed strengthening the synergistic role of fiscal policy tools in supporting green finance by considering two measures: first, financial incentives for institutions that implement good green finance policies. The second is to use monetary policy tools to give institutions implementing green financial policies appropriate risk compensation, tax relief, and other measures. Fully mobilize financial institutions to implement green financial policies. This approach is beneficial for the transformation of the construction market towards green practices and can yield significant results. In conclusion, lower subsidy levels do not lead to the desired state under both combinations of initial willingness, but when initial willingness is high and the government provides substantial incentives, green buildings can flourish with the support of green finance.
As shown in Figure 5, with other parameters held constant, increasing the level of government penalties (L1) for BFI from four to 10 has a significant impact on achieving the desired state of the game model under low initial willingness. As depicted in Figure 5a, under low initial willingness, increasing the penalty intensity leads the system to transition from the state of (not implement, not adopt, not endorse) to the desired state of (implement, adopt, endorse). Figure 5b shows that under high initial willingness, even a smaller penalty intensity can drive the system towards the ideal state, and increasing the penalty intensity accelerates the convergence of the system to the desired state. When the willingness of all participating entities in the market is high, even a smaller penalty intensity can alter the market’s trajectory. Rewards and penalties are commonly used regulatory policies, and the government should have good sensitivity to the market and dynamically adjust policies based on the willingness of market participants. By minimizing policy costs as much as possible, the government can guide the development of the construction market towards sustainability.

Figure 5. (a) The impact of changes in the level of government penalties for BFI when the initial willingness of all parties is low; (b) The impact of changes in the level of government penalties for BFI when the initial willingness of all parties is high.

### 6.4. The Impact of Differences in Benefits

As shown in Figure 6, with other parameters held constant, reducing the difference in returns (Q) between conventional projects and green building projects (from eight to two) leads to system convergence toward (1,1,1) under low initial willingness. Under high initial willingness, the system converges to the ideal state at a faster rate. In the current stage of financial market development, BFI tend to provide higher financing for conventional projects compared to green projects, which restricts the flow of funds towards green finance.
and hinders the development of green buildings. To encourage more social capital to invest in the green industry, efforts can be made to increase the return on investment in green projects and reduce the return on investment in polluting projects. The key to promoting the development of green buildings lies in reducing the difference in returns and shifting the focus of funds from “money-oriented” to “forward-oriented”, under the premise of controlling the total amount of real estate financing, optimizing the real estate financing structure, promoting market funds to tilt towards green buildings, and optimizing the financing structure of the construction industry.

Figure 6. (a) The impact of the difference in returns between green building projects and conventional projects when the initial willingness of all parties is low; (b) The impact of the difference in returns between green building projects and conventional projects when the initial willingness of all parties is high.

6.5. The Impact of Incremental Consumer Benefits

As shown in Figure 7, with other parameters held constant, when the incremental benefits to consumers from green building are low ($U_g = 1$), the market cannot stabilize at the ideal state regardless of the initial willingness of the participants. In the case of high initial willingness, when green building brings higher incremental benefits to consumers ($U_g = 4$), it promotes the development of green building and the implementation of green finance policies, leading to the system stabilizing at the ideal state. Some developers engage in false marketing to divert consumer attention, making it difficult for consumers to experience the real performance and advantages of green buildings during their subsequent use. This, in turn, affects the market’s perception and differentiation between green buildings and conventional buildings. Therefore, it is important for green building developers and BFI to take proactive measures to promote green buildings and enable consumers to clearly perceive the actual advantages of green buildings and the cost savings in their long-term usage. It is necessary to improve the information disclosure mechanism of market participants to ensure that all stakeholders can timely understand the effective information, such as the energy-saving and emission reduction effects of green construction rent. At the same time, it is necessary to emphasize the authenticity and integrity of disclosure information to avoid “greenwashing” behavior. According to a study by Chen [45] that used the evolutionary game approach, the implementation of flexible subsidies and consistent penalties can efficiently discourage construction companies from indulging in deceptive environmental advertising. These measures will enable financial institutions to proficiently identify and oversee green building projects, assuage their apprehensions, and expedite the allocation of financial resources into the green building industry.
1. Significant market-driving effects result from the high initial willingness of both BFI and consumers. It analyzes the progression of the green buildings market under the support of green finance and identifies critical areas of focus during the transition towards sustainability in the construction industry. Various combinations of initial willingness are considered to account for regional differences in the development of the green building market. By analyzing simulation data, effective measures for different scenarios are identified. Based on this, the following recommendations are proposed for the role of green finance in promoting sustainable building development:

1. Significant market-driving effects result from the high initial willingness of both BFI and consumers. Support should be provided to BFI in playing a leading role in the green building market, promoting the adoption of green finance and green practices within the construction industry. While recognizing the pivotal role of consumers in the market, efforts should be made to encourage green building and cultivate green attributes among both BFI and consumers. Assuming greater social responsibility can partially replace government administrative measures and facilitate the green transformation of the construction industry. As an illustration, China’s Hubei Province has implemented a scheme that offers increased provident fund loans to purchasers of green buildings, thus diminishing property acquisition expenses and significantly enhancing the appeal of green buildings to potential buyers [52].

2. Instead of relying solely on a “carrot and stick” approach, policymakers should utilize policy instruments effectively, serving as a policy compass to guide financial support for green building and generate endogenous market development dynamics while minimizing the policy costs.

3. Even with a certain disparity in returns between traditional projects and green building projects, green buildings can still develop with the support of green finance, even when the willingness of all parties to participate in the market is relatively low. Gradually increasing taxes, fees, and other expenses for traditional building projects while decreasing them for green building projects can help reduce the gap in returns and promote the role of green finance in the construction industry’s transition towards sustainability.

4. Green building must deliver concrete benefits and user experiences to consumers, and it is essential to eliminate deceptive marketing practices employed by developers. The establishment of disclosure standards for green building information must be expedited, with clear indicators and calculation methods defined for energy efficiency.
efficiency, water and electricity conservation, air quality optimization, and other practical applications. Relevant information should be disseminated in a timely manner to all stakeholders involved. For instance, the municipality of Huzhou in China has established a digital platform for divulging sustainable construction information. This platform delivers the entire information process of green building projects, from program design to maintenance and operation, to society in a timely manner. Furthermore, it efficiently safeguards against the risk of deceptive environmental commitments in construction projects [53].

The policy recommendations presented in this paper concentrate on nations and areas where the green building industry is emerging, market-driven development mechanisms have yet to be established, and where it presently relies on government regulatory efforts and financial backing. As the market transitions into a period of stable growth, further research is needed to examine how green finance policies should be adjusted and how market choices may evolve. This area of study warrants further exploration through a variety of research methodologies to improve the implementation of green finance practices within the green building industry. For instance, an inventory management system [54] could be developed to investigate the impact of green finance on the growth and development of green buildings within the context of carbon tax legislation [55]. Additionally, conducting an analysis of the business strategies employed by green building supply chain enterprises using a multiwarehouse inventory model [56] could yield valuable insights.

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