

Article

Evolution of the Behavioural Strategies of Stakeholders in Green Supply within Government Compensation Mechanisms

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Abstract: Since economic development and environmental protection constitute a multidimensional and complex interaction process, government regulatory mechanisms, as policy tools for green development, have become significant means for environmental conservation. The motivation of this paper is to reveal the government's promotion mechanism for the green development of the supply chain. To achieve this objective, an evolutionary game model (EGM) method is applied in this paper. The specific steps of this method include the following: a unified theoretical analysis framework was first developed in which integrated suppliers (ISs), government agencies (GAs), and financial institutions (FIs) were integrated into the EGM. Second, on the basis of dynamic evolution and differential equations, the evolution and stabilisation strategies of the stakeholders were examined separately. Finally, adopting a supply chain that includes ISs, GAs, and FIs as a case study, stability strategies under changes in various parameters were investigated. The research results indicated that the behavioural strategies of GAs could serve as a weathervane for ISs and FIs. Within a certain range, government compensation mechanisms could positively impact product R&D, as well as IS green development, while the government subsidy phase-out system could be more suitable at the maturity stage. The contribution of this paper is to provide methodological support for the operational decision-making of GAs, FIs, and ISs.

Keywords: green supply; integrated suppliers; government agencies; financial institutions; evolutionary game theory



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1. Introduction

Faced with increasingly severe environmental pollution and strict energy constraints, an increasing number of countries have formulated relevant green action plans [1]. For example, China has proposed action plans for achieving peak carbon emissions and carbon neutrality, announcing that it will reach a peak in carbon emissions by 2030 and achieve carbon neutrality by 2060; notably, carbon emissions and carbon absorption will be maintained in sync [2,3]. According to a report on CO₂ emissions in 2023 released by the International Energy Agency (IEA), global energy-related CO₂ emissions reached a record high of 37.4 billion tons, an increase of 410 million tons compared with the emissions in 2022 [4]. Owing to the development of new technologies such as electric vehicles [5], the increase was less than the value of 490 million tons in 2022. Therefore, the rapid development of new energy vehicles plays an important role in promoting green and sustainable social and economic development [6]. In addition, Fuqiang Lu et al. [7] indicated that the rapid development of new energy vehicles is a key driver for improving the green transport structure in cities. Among representative approaches, Xiaomi Group successfully released a new energy vehicle (namely, SU7) within three years by integrating suppliers, thus significantly contributing to carbon emission reduction.

However, as the production and manufacturing of new energy vehicles involve a long industrial chain with more than 200 primary suppliers, conducting integrated management of numerous suppliers and achieving green development of new energy vehicle manufacturing has become increasingly complex [8,9]. Therefore, many local governments have introduced implementation plans to promote the green transformation of the automobile industry, which has provided an impetus for enterprises to achieve green development [10]. However, not every enterprise can achieve satisfactory results. For example, Apple abandoned the development of a new energy vehicle business after 10 years of research and development.

Thus, the comprehensive management of integrated suppliers (ISs) and achieving green development are complex processes and require the joint implementation of multiple participants. In the green development process of the new energy vehicle industry chain, the stakeholders involved include ISs [11], government agencies (GAs) [12], and financial institutions (FIs) [13]. Therefore, in contrast to previous studies, in this paper, SU7 was chosen as the case background to establish a symmetric evolutionary game model among ISs, GAs, and FIs, and the decision-making behaviour of each stakeholder and the key factors influencing the decision-making process were explored. In the research process, the following three issues are addressed:

(1) If ISs fulfil an active role, does a stable strategy exist for ISs, GAs, and FIs in the dynamic evolutionary game process?

(2) How do the initial behaviour strategies of the ISs, GAs, and FIs affect the final stability strategy of the system? Does the initial behaviour of stakeholders affect their decision-making processes?

(3) Can the evolutionary stable strategy (EES) be improved by adjusting the GA subsidy and penalty mechanism for ISs and FIs? Is there an effective time interval?

To address the above issues, this paper studies the evolution of green supply chain stakeholders' behaviour strategies under the government compensation mechanism. The research results indicated that within a certain range, government compensation mechanisms could positively impact product R&D, as well as IS green development, while the government subsidy phase-out system could be more suitable at the maturity stage. The main research conclusions include that the government should guide the sustainable development of the green supply chain industry through the downhill subsidy policy so that consumers can accept more green products through free-riding.

The main contributions of this article are threefold. First, considering the significant role of GAs in the green and sustainable development process of supply chains, government policies were incorporated into an evolutionary model, and the game among ISs, GAs, and FIs was investigated. Second, by comparing the final equilibrium results under different initial conditions, the evolutionary process among ISs, GAs, and FIs was analysed under the condition of bounded rationality, revealing the key factors that determine the strategic choices of ISs, GAs, and FIs. Finally, the key factors of the government were investigated, and the extent to which changes in the government reward and the punishment system affect EES was assessed.

The remainder of this article is organised as follows: Section 2 provides a literature review. The methodology adopted in this study is detailed in Section 3. In Section 4, the equilibrium results are compared on the basis of a single case. Section 5 provides a discussion. In Section 6, conclusions are outlined.

2. Literature Review

The preliminary research related to this article includes evolutionary game theory (EGT) and its application in the supply chain. Therefore, in this section, the literature is reviewed from two perspectives.

2.1. Evolutionary Game Theory

EGT was first proposed by genetic ecologists Fisher and Hamilton, who noted that in the process of plant and animal cooperation, most cases can be explained by EGT without relying on other theories [14]. Szabó and Fáth [15] used EGT to conduct a dynamic behavioural simulation of a prisoner's dilemma. Roca, Cuesta [16] reviewed EGT, analysed the linear hypothesis and its relationship with the choice of strategy update rules, and constructed a replicator equation. Madani [17] applied game theory to water resource management, identifying and revealing the behavioural strategies of various parties in the face of water resource issues. Hodgson and Huang [18] explained the relationship between EGT and evolutionary economics, suggesting that there is tremendous potential for collaboration between the two. Adami, Schossau [19] noted that, compared with agent-based methods, EGT-based equations provide significant advantages in simulating the evolutionary behaviour of heterogeneous populations.

However, in the process of the global pursuit of sustainable development, increasing attention has been given to the green supply chain, including Fangfang Guo's [20] use of differential game theory to solve the issue of correlation between decision-making behaviours of different roles in the supply chain. Muhammad Riaz [21] focused more on how to improve the efficiency of the green supply chain and proposed an effective method to improve its efficiency. Babu and Mohan [22] integrated environmental, social, economic, cultural, and governance factors into the issue of supply chain sustainability and employed EGT to explain the differences in behavioural strategies among different entities. Zhang, Xue [23] established a two-level dynamic EGT-based method that included suppliers and manufacturers to address decision-making issues in a supply chain. Zhang, Jiang [24] combined prospect theory with EGT to study noncooperative game behaviour between the government and residents in the process of waste classification. Yu and Khan [25] designed a financing system based on EGT. Traulsen and Glynatsi [26] noted that EGT offers a notable advantage over other methods in terms of interpretation and visual display capabilities and has been widely applied in different fields. Stein, Salvioli [27] established the interactive relationship between rational leaders and evolutionary followers on the basis of EGT. Under the conditions of limited rationality and uncertainty, Wang, Fu [28] established an evolutionary game model involving GAs, recyclers, and manufacturers, demonstrating that GAs should strive to establish a stable recycling environment.

As the assumption of bounded rationality is adopted in the EGT model, it allows for imperfections in the rationality and capabilities of participants, providing a better explanation of the equilibrium choices of enterprises [29–31]. Consequently, the application scope of EGT has continuously increased, covering various industries, such as energy [32,33], construction [34], manufacturing [35], and logistics [36]. In this paper, primarily EGT research in the field of supply chains is reviewed.

2.2. Application of EGT in the Supply Chain

As an important field of low-carbon development, the green development of the supply chain has been widely studied [37–39]. For example, Hafezalkotob, Mahmoudi [40] investigated a green supply chain that includes risk-averse and risk-neutral retailers and noted that if retailers choose risk-averse strategies in the short term, they may alter their strategies in the long term. Qu, Wang [41] studied a game model that included suppliers, the government, and downstream enterprises and analysed the evolutionary path of the participants. Zhu, Wang [42] established an evolutionary game model between enterprises and consumers on the basis of the factor of green sensitivity. Hou, Zhang [12] analysed the impact of government subsidies on enterprises and noted that moderate government subsidies positively affect the motivation of enterprises to choose sustainable supply chains. In the supply chain system, channel coordination can be achieved through incentives and contracts. To solve this problem, Hosseini-Motlagh, Choi [43] constructed a supply chain coordination profit surplus allocation model and studied the long-term behavioural evolution of internal members.

Bera and Giri [44] examined the issue of used product recycling and reported that in a highly competitive procurement and low-profit environment, the best strategy for manufacturers is to purchase second-hand products. Naini, Aliahmadi [45] combined EGT with the balanced scorecard to measure and evaluate enterprise operations from different perspectives and determined that government subsidies are often applied, but green sensitivity has seldom been accounted for. For this reason, Long, Tao [46] considered green sensitivity factors and constructed a general EGT model comprising consumers, enterprises, and the government. Xu, Cao [47] combined system dynamics with EGT to study the evolution of behavioural strategies in supply chains and noted that when the proportion of green supply chains is low, it is recommended that the government oversees the implementation of compensation mechanisms. In addition, fairness preference is an important issue in supply chain income distribution. Fuqiang Lu et al. [48] proposed an effective benefit method to solve this issue of income distribution in the supply chain.

However, there are still some research gaps to be filled in the current literature. The concept of integrated suppliers is rarely considered in the current literature; the current literature ignores the environmental issues caused by non-green development and the issue of the fake costs paid to obtain green development funds for ISs. In addition, it is not clear how government subsidies and the lending willingness of financial institutions affect the behavioural decisions of integrated suppliers. On the basis of the above summary of previous research findings, with increasing environmental issues, an increasing number of scholars have applied EGT to address green development issues in the field of supply chains [13,49–51], aiming to obtain the best shortcut for green development in supply chains. However, in previous research, most scholars have studied supply chain issues from the perspective of individual suppliers, lacking the integration of suppliers. To fill the research gaps above, this paper innovatively integrates integrated suppliers into the EGT model and uses a dynamic replication equation and the control variable method to conduct in-depth research on tripartite behaviour decision-making. In this paper, EGT issues involving ISs, GAs, and FIs were studied, aiming to provide additional guidance for achieving green supply chain development.

3. Methodology

3.1. Stakeholders

Adopting the Xiaomi SU7 vehicle as an example, the key to manufacturing green new energy vehicles is the integration of various suppliers. Therefore, green innovation in the supply chain cannot be separated from the role of ISs, mainly because they enable the screening and elimination of suppliers that do not meet the requirements of green standards. GAs play a key role in promoting the green and sustainable development of supply chains. Notably, a GA is both an important driver of green development and a beneficiary in the development process. The main reason is that GAs can guide the behavioural strategies of ISs through policy regulation and improve the social welfare of people. In addition, the realisation of green development is inseparable from the support of FIs, so the main players participating in the evolutionary game are ISs, GAs and FIs.

In the process of evolution, ISs are always accustomed to the pursuit of profit maximisation, and the motivation for choosing green development mainly comes from the government's subsidy mechanism and willingness to assume social responsibility. In the early stage of evolution, the government guides ISs and FIs to participate in green development through a subsidy mechanism, and whether FIs are willing to provide financial support to ISs depends on the profitability of the ISs, and the sustained profitability of ISs will attract more FIs to participate in green development. However, in the development of a green supply chain in which ISs, GAs, and FIs participate, the decision-making behaviours of the three and their influence relationships are extremely complex, and the correlation relationships among them need to be further analysed through the EGM. Therefore, this paper studies the evolution of green supply chain stakeholders' behaviour strategies under

the government compensation mechanism. The evolutionary relationships among the three stakeholders are shown in Figure 1.

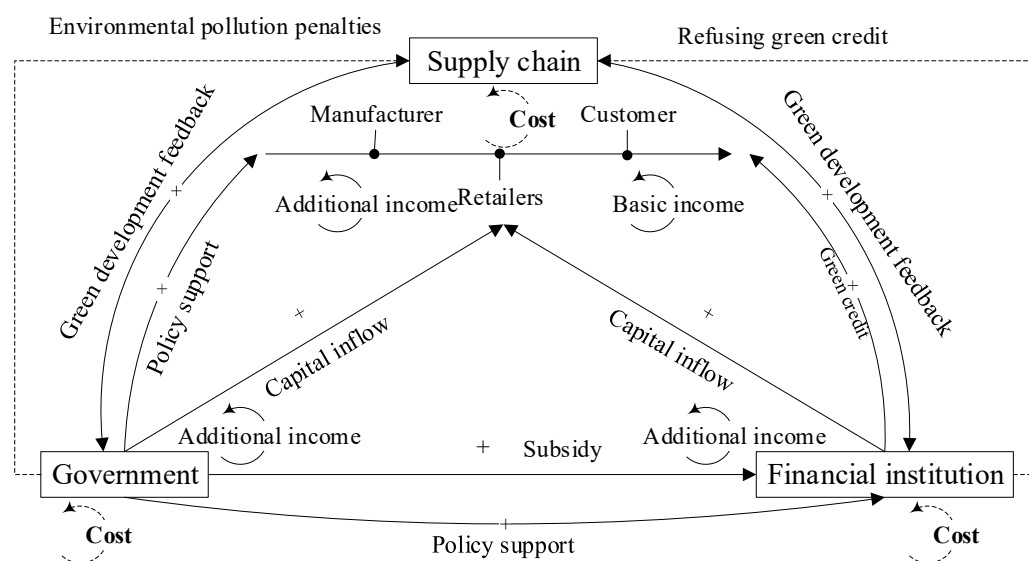


Figure 1. Evolutionary relationships among the three stakeholders.

On the basis of the literature, three assumptions are made regarding the evolutionary game encompassing ISs, GAs, and FIs.

Assumption 1. The participating entities are ISs, GAs, and FIs. The strategy selection of ISs includes two options: investing in green technology to achieve green development (GD), and not engaging in green technology innovation to achieve conventional development (CD). The strategy selection of GAs includes positive support (PS) and negative support (NS). The strategy selection of FIs includes two options, namely, open green credit (OGC) and closed green credit (CGC). The probabilities of an IS choosing the GD strategy, a GA choosing the PS strategy, and an FI choosing the OGC strategy are $x, y, z \in [0, 1]$, respectively.

Assumption 2. All participants are rational individuals, and all three parties adopt the best strategies to maximise their profits [52–54]. When an IS chooses green technology innovation, the FI gains greater benefits from conducting a green credit business. Conversely, when an IS does not choose green technology innovation, the FI gains greater profits from not conducting green credit business.

Assumption 3. To encourage ISs to choose green technology innovation and FIs to conduct green credit business, the GA must implement certain regulatory measures [39,55,56]. In this paper, the considered GA measures include subsidies or punishments. When the ISs implement green measures and the FI conducts green credit business, the GA will provide certain rewards and subsidies to the ISs and FIs. Conversely, when the ISs do not implement green measures and the FI does not conduct green credit business, the GA will impose certain penalties on the ISs and FIs. The mathematical symbols are defined in Table 1.

Table 1. Mathematical symbol descriptions.

Parameters	Descriptions	Notes
e_1	Revenue from the ISs receiving green credit	$e_1 > 0$
e_2	Revenue from the ISs not receiving green credit	$e_2 > 0$
e_n	Benefits for the ISs of selecting green investments	$e_n > 0$
e_g	Value-added benefits for the IS of green innovation	$e_g > 0$
e_k	Value-added benefits for the FI conducting green credit business	$e_k > 0$
c_1	Cost of choosing GDs for the ISs	$c_1 > 0$
c_2	Credit costs when the IS does not choose GDs	$c_2 > 0$
b_1	Basic benefits of green credit provided by the FI to the ISs	$b_1 > 0$
b_2	Basic benefits of non-green credit provided by the FI to the ISs	$b_2 > 0$
b_3	Basic benefits of the FIs not engaging in green credit business for the ISs	$b_3 > 0$
c_k	Cost paid by the FIs to conduct OGC business	$c_k > 0$
c_g	Cost of GAs' participation in regulation	$c_g > 0$
M	IS to receive GA rewards for green innovation	$M > 0$
α	Coefficient related to the amount of GA rewards	$\alpha > 0$
F	The ISs are punished by the GAs for not engaging in green innovation	$F > 0$
β	Coefficient related to GA penalties	$\beta > 0$
Q	The FIs receives GA subsidies when providing green loans	$Q > 0$
γ	Coefficient of subsidies received by the FIs	$\gamma > 0$
δ	Additional feedback subsidies obtained by the ISs for green innovation	$\delta > 0$
μ	Coefficient related to credit returns	$\mu > 0$
c_w	Governance costs of the GAs when suppliers do not implement green innovation	$c_w > 0$
t_g	GA punishment for environmental pollution caused by suppliers	$T_g > 0$
x	ISs	$0 \leq x \leq 1$
y	GAs	$0 \leq y \leq 1$
z	FIs	$0 \leq z \leq 1$

The ISs can choose between the GD and CD strategies, the probability of choosing the GD is x , and the probability of choosing the CD is $(1 - x)$. The GA can choose between the PS and NS strategies, the probability of choosing the PS strategy is y , and the probability of choosing the NS strategy is $(1 - y)$. The FI can choose between the OGC and CGC strategies. The probability of choosing OGC is z , and the probability of choosing CGC is $(1 - z)$.

3.2. Payoffs for Various Stakeholders

According to the different selection strategies of the different stakeholders, 8 scenarios can be defined, as detailed in Table 2.

Table 2. Scenarios of different combinations of strategies.

Items	ISs		GAs		FIs		Strategy Combination
	GD	CD	PS	NS	OGC	CGC	
1	●		●		●		GPO
2	●		●			●	GPC
3	●			●	●		GNO
4	●			●			GNC
5		●	●		●		CPO
6		●	●			●	CPC
7		●		●	●		CNO
8		●		●		●	CNC

Note: ● indicates the selected policy.

Under the GPO scenario, the ISs choose the GD strategy, the GA chooses the PS strategy, and the FI chooses the OGC strategy. The income obtained by the ISs comprises

the credit income μe_1 obtained from the green credit provided by the FI; the investment income e_n obtained from the green upgrade provided by the ISs; the added value for the green innovation benefits of the ISs μe_k ; the GAs incentive mechanism added value for the green innovation benefits of the ISs e_g ; and the incentive income $M\alpha$ obtained from the GAs. The investment cost of green transformation and upgrading is c_1 .

According to the literature [22,57,58], the benefits of the GA include the following: the investment feedback income $e_n\delta$ obtained by the ISs from green innovation, the feedback income $\mu e_k\delta$ of innovation benefit appreciation obtained by the FIs through green credit, the feedback income $e_g\delta$ of green innovation benefit appreciation obtained by the GAs, the cost of the incentive subsidy $M\alpha$ issued by the GA to the ISs, and the incentive subsidy $I\gamma$ issued by the GA to the FI. The cost of GA participation in green transformation is c_g , in which GA subsidies and value-added feedback are variables. The income functions are expressed as Equations (1)–(3).

$$\pi_{111}^x = \mu e_1 + e_n + \mu e_k + e_g + M\alpha - c_1 \quad (1)$$

$$\pi_{111}^y = (e_n + \mu e_k + e_g)\delta - M\alpha - Q\gamma - c_g \quad (2)$$

$$\pi_{111}^z = \mu b_1 + Q\gamma - c_k \quad (3)$$

The benefits π_{111}^z of the FI include the following: the basic benefits μb_1 obtained by the FIs for conducting green credit business with the ISs; the GA subsidies $I\gamma$ obtained by the FIs for conducting green credit business with the ISs; and the costs c_k incurred by the FIs for conducting green credit business.

Under the CPO scenario, the ISs choose the CD strategy, the GA chooses the PS strategy, and the FI chooses the OGC strategy. The benefits of the ISs include credit income μe_1 , the cost of obtaining green credit without green innovation c_2 , and the GA penalty $F\beta$ for not implementing green innovation. The benefits provided by the FIs in supporting the green development of the ISs include the basic benefits μb_3 for the ISs not to implement GD when conducting green credit business; the subsidies $I\gamma$ obtained from the GAs when conducting green credit business; and the cost c_k of conducting green credit business. The benefits resulting from active GA participation in the green transformation of the ISs include the following: the GA penalties $F\beta$ applied to the ISs when they do not implement green innovation, GA subsidies $Q\gamma$, management costs c_g , and governance costs c_w . Under this scenario, the income functions of ISs, FIs, and GAs are expressed as Equations (4)–(6).

$$\pi_{011}^x = \mu e_1 - c_2 - F\beta \quad (4)$$

$$\pi_{011}^y = F\beta - Q\gamma - c_g - c_w \quad (5)$$

$$\pi_{011}^z = \mu b_3 + Q\gamma - c_k \quad (6)$$

Under the GPC scenario, the ISs choose the GD strategy, the GA chooses the PS strategy, and the FIs choose the CGC strategy. The revenue components resulting from the green transformation and upgrading of the ISs include the following: when the FIs do not open a special fund for green credit to the ISs, the latter receives credit income e_2 . Moreover, the ISs receive investment income e_s when implementing green upgrading, the ISs receive government incentive mechanism added value for green innovation benefits e_g , the GAs receive incentive income $M\alpha$, and the ISs pay the cost of green transformation and upgrading c_1 . The benefits resulting from FI support for the transformation and upgrading of the ISs are the basic benefits b_2 resulting from the FIs not conducting green credit business with the ISs. The benefits of the GAs' participation in the green transformation of the ISs include the following: the investment income feedback $e_n\delta$ received by the ISs when implementing green upgrading; the government incentive mechanism feedback $e_g\delta$ on the value added of IS green innovation benefits; the incentive and subsidy cost paid by the GAs

to the ISs $M\alpha$; and the cost paid by the GAs for participating in green transformation c_g . The revenue functions obtained by the ISs, FIs, and GAs are expressed in Equations (7)–(9).

$$\pi_{110}^x = e_2 + e_n + e_g + M\alpha - c_1 \quad (7)$$

$$\pi_{110}^y = (e_n + e_g)\delta - M\alpha - c_g \quad (8)$$

$$\pi_{110}^z = b_2 \quad (9)$$

Under the CPC scenario, the ISs choose the CD strategy, the GA chooses the PS strategy, and the FI chooses the CGC strategy. The income components resulting from the ISs not implementing green transformation and upgrading include the credit income e_2 obtained by the ISs when the FIs do not open a special fund for green credit and the GA penalty $F\beta$. The benefits resulting from FIs' support for green transformation and upgrading of the IS are the basic benefits b_2 obtained by the FIs from not conducting green credit business with the ISs. The benefits of active GA participation in IS green transformation include the penalty $F\beta$ for the IS when it does not implement green innovation, the cost c_g for GA participation in green transformation, and the cost c_w for treating environmental pollution by the GAs when the IS does not implement green transformation. Under this scenario, the revenue functions obtained by the ISs, FIs, and GAs are expressed in Equations (10)–(12).

$$\pi_{010}^x = e_2 - F\beta \quad (10)$$

$$\pi_{010}^y = F\beta - c_g - c_w \quad (11)$$

$$\pi_{010}^z = b_2 \quad (12)$$

Under the GNO scenario, the ISs choose the GD strategy, the GA chooses the NS strategy, and the FIs choose the OGC strategy. The benefits of the ISs when implementing green transformation and upgrading include the following: the credit return μe_1 when the FIs establish a special fund for green credit, the investment return e_n obtained during green upgrading, the value added μe_k of green innovation benefits when conducting green credit business with the FIs, and the investment cost c_1 of green transformation and upgrading. The benefits of FI support for IS green transformation and upgrading include the basic returns μb_1 obtained by the FIs from providing green credit to the ISs, and the cost paid is the cost c_k of FIs' green credit. The benefits of active GA participation in IS green transformation include the investment return feedback $e_n\delta$ obtained during green upgrading and the value-added feedback $e_k\delta$ of green innovation benefits through FI green credit. The income functions obtained by ISs, FIs, and GAs are expressed as Equations (13)–(15).

$$\pi_{101}^x = \mu e_1 + e_n + \mu e_k - c_1 \quad (13)$$

$$\pi_{101}^y = (e_n + \mu e_k)\delta \quad (14)$$

$$\pi_{101}^z = \mu b_1 - c_k \quad (15)$$

Under the CNO scenario, the ISs choose the CD strategy, the GA chooses the NS strategy, and the FI chooses the OGC strategy. The revenue components generated by the ISs when not implementing green transformation and upgrading include the following: the credit income μe_1 obtained when the FI establishes a special green credit fund and the cost c_2 incurred when obtaining green credit without conducting green innovation. The revenue generated by FI support for the ISs' green transformation and upgrading comprises the basic income μb_3 earned by the FIs from providing green credit to the ISs, whereas the ISs do not undergo green transformation and the cost c_k is incurred by the FIs in offering green credit. Moreover, the revenue generated by active GA participation in IS green transformation includes the penalty t_g imposed on the GAs for adopting a passive policy

towards local governments and the governance cost c_w incurred by the GA. Under this scenario, the revenue functions of ISs, FIs, and GAs are expressed as Equations (16)–(18).

$$\pi_{001}^x = \mu e_1 - c_2 \quad (16)$$

$$\pi_{001}^y = -t_g - c_w \quad (17)$$

$$\pi_{001}^z = \mu b_3 - c_k \quad (18)$$

Under the GNC scenario, the ISs choose the GD strategy, the GA chooses the NS strategy, and the FIs choose the CGC strategy. The revenue components generated by IS green transformation and upgrading include the credit revenue e_2 obtained when the FI does not establish a special green credit fund, the investment return e_n obtained through green upgrading, and the investment cost c_1 of green transformation and upgrading. The revenue generated by FIs to support IS green transformation and upgrading is the basic revenue b_2 obtained by the FIs from not providing green credit to the ISs. The revenue generated by active GA participation in IS green transformation is the investment return feedback $e_n \delta$ obtained by the ISs through green upgrading. Under this scenario, the revenue functions obtained by ISs, FIs, and GAs are expressed as Equations (19)–(21).

$$\pi_{100}^x = e_2 + e_n - c_1 \quad (19)$$

$$\pi_{100}^y = e_n \delta \quad (20)$$

$$\pi_{100}^z = b_2 \quad (21)$$

Under the CNC scenario, the ISs choose the CD strategy, the GA chooses the NS strategy, and the FIs choose the CGC strategy. The revenue generated by the ISs when not implementing green transformation and upgrading is the credit revenue e_2 when the FIs do not establish a special green credit fund. The revenue generated by FI support for IS transformation and upgrading is the basic revenue b_2 when green credit is not provided to the ISs, and the revenue generated by active GA participation in IS green transformation includes the punishment t_g imposed on the ISs by the GAs and the governance cost c_w paid by the GAs. Under this scenario, the revenue functions obtained by ISs, FAs, and GAs are expressed in Equations (22)–(24).

$$\pi_{000}^x = e_2 \quad (22)$$

$$\pi_{000}^y = -t_g - c_w \quad (23)$$

$$\pi_{000}^z = b_2 \quad (24)$$

In the decision-making process, stakeholders make decisions on the basis of maximising their interests, and their decision strategies ultimately affect the evolutionary trend. The payoff matrices of the ISs, GAs, and FIs are summarised in Table 3.

Table 3. Payoff matrices of ISs, GAs, and FIs.

	y		$(1 - y)$	
	z	$(1 - z)$	z	$(1 - z)$
x	$\pi_{111}^x = \mu e_1 + e_n + \mu e_k + e_g + M\alpha - c_1$ $\pi_{111}^y = (e_n + \mu e_k + e_g)\delta - M\alpha - Q\gamma - c_g$ $\pi_{111}^z = \mu b_1 + Q\gamma - c_k$	$\pi_{110}^x = e_2 + e_n + e_g + M\alpha - c_1$ $\pi_{110}^y = (e_n + e_g)\delta - M\alpha - c_g$ $\pi_{110}^z = b_2$	$\pi_{101}^x = \mu e_1 + e_n + \mu e_k - c_1$ $\pi_{101}^y = (e_n + \mu e_k)\delta$ $\pi_{101}^z = \mu b_1 - c_k$	$\pi_{100}^x = e_2 + e_n - c_1$ $\pi_{100}^y = e_n \delta$ $\pi_{100}^z = b_2$
$(1 - x)$	$\pi_{011}^x = \mu e_1 - c_2 - F\beta$ $\pi_{011}^y = F\beta - Q\gamma - c_g - c_w$ $\pi_{011}^z = \mu b_3 + Q\gamma - c_k$	$\pi_{010}^x = e_2 - F\beta$ $\pi_{010}^y = F\beta - c_g - c_w$ $\pi_{010}^z = b_2$	$\pi_{001}^x = \mu e_1 - c_2$ $\pi_{001}^y = -t_g - c_w$ $\pi_{001}^z = \mu b_3 - c_k$	$\pi_{000}^x = e_2$ $\pi_{000}^y = -t_g - c_w$ $\pi_{000}^z = b_2$

Next, on the basis of the payoff matrices, the stability strategies of the stakeholders can be analysed via differential equations and dynamic evolution equations.

3.3. Stakeholders' Analysis of Stability

For ISs, the initial benefits of choosing the GD and CD strategies are E_{x1} and E_{x0} , respectively, as expressed in Equations (24) and (26) respectively.

$$E_{x1} = -c_1 + e_2 + e_n + (e_g + \alpha M)y - e_2z + u(e_1 + e_k)z \quad (25)$$

$$E_{x0} = e_2 - \beta Fy - (c_2 + e_2 - e_1u)z \quad (26)$$

The Malthusian dynamic equation indicates that within a game theory context, when the strategy chosen by the ISs exceeds the average payoff of the FI and GA, it possesses the ability to resist mutant strategies and is better suited to adapt to population evolution [59]. The dynamic replication equation for ISs can be expressed as Equations (27) and (28).

$$Fx = -((-1+x)x(-c_1 + e_n + (e_g + \beta F + \alpha M)y + (c_2 + e_k\mu)z)) \quad (27)$$

$$d(F(x))/dx = (1-2x)(-c_1 + e_n + (e_g + \beta F + \alpha M)y + (c_2 + e_k\mu)z) \quad (28)$$

Assuming that $m(z) = -c_1 + e_n + (e_g + \beta F + \alpha M)y + (c_2 + e_k\mu)z$, the stability theorem of differential equations indicates that for $F(x) = 0$, $d(F(x))/dx < 0$, the probability of the ISs choosing the GD strategy will remain stable since $d(m(z))/dz = c_2 + e_k\mu > 0$, where $m(z)$ is a monotonically increasing function. Therefore, when $z = z_1$, $m(z) = 0$, $d(F(x))/dx \equiv 0$, and $F(z_1) \equiv 0$, the ISs cannot determine a stable strategy. Moreover, for $z > z_1$, $m(z) > 0$, $d(F(x))/dx < 0|_{x=1} < 0$, and $x = 1$ are ESS points. Conversely, $x = 0$ is an ESS point. Notably, z_1 can be expressed as Equation (29):

$$z_1 = \frac{c_1 - e_n - (e_g + \beta F + \alpha M)y}{c_2 + e_k\mu} \quad (29)$$

Assuming that the probabilities of the ISs adopting the GD and CD strategies are V_1 and V_2 , respectively, the intersection points of the projection line of z_1 onto the yOz plane with the y and z axes are $(0, 0, (c_1 - e_n)/(c_2 + e_k\mu))$ and $(0, (c_1 - e_n)/(e_g + \beta F + \alpha M), 0)$, respectively. In this case, V_1 and V_2 can be calculated via Equations (30) and (31) respectively.

$$V_1 = \frac{(c_1 - e_n)^2}{(c_2 + e_k\mu)(e_g + \beta F + \alpha M)} \quad (30)$$

$$V_2 = 1 - \frac{(c_1 - e_n)^2}{(c_2 + e_k\mu)(e_g + \beta F + \alpha M)} \quad (31)$$

Proposition 1. When $c_1 = e_n$, $V_1 = 0, V_2 = 1$ occurs, and when $c_1 > e_n$, there is a positive correlation between c_1 and the probability of the IS adopting the GD strategy. Moreover, $e_n, e_k, u, \alpha, \beta, F, M$ is inversely proportional to the probability of the IS adopting the GD strategy, and c_2, e_g is independent of V_1 .

Proof of Proposition 1. When $c_1 < e_n$, $c_1 - e_n < 0$ holds true, which suggests that $(c_1 - e_n)/(c_2 + e_k\mu) < 0$ and $(c_1 - e_n)/(e_g + \beta F + \alpha M) < 0$ are also valid. In this case, $P(z < z_1) = 0$ and $V_1 = 0, V_2 = 1$. When $c_1 > e_n$, $D(V_1)/d(c_1) = 2(c_1 - e_n)/(\beta F + e_g + \alpha M)(2c + e_k\mu)$ holds true. Because $c_1 > e_n$, both the numerator and denominator are non-negative numbers. Thus, $D(V_1)/d(c_1) > 0$ always holds true. Therefore, there is a positive correlation between c_1 and V_1 . Because $D(V_1)/d(e_n) = -2(c_1 - e_n)/(\beta F + e_g + \alpha M)(2c + e_k\mu) < 0$ is true, $D(V_1)/d(e_k) = -(c_1 - e_n)^2 u / (\beta F + e_g + \alpha M)(2c + e_k\mu)^2 < 0$, $D(V_1)/d(u) = -ek(c_1 - e_n)^2 / (\beta F + e_g + \alpha M)(2c + e_k\mu)^2 < 0$, $D(V_1)/d(\alpha) = -(c_1 - e_n)^2 M / (\beta F + e_g + \alpha M)^2(2c + e_k\mu) < 0$, $D(V_1)/d(\beta) = -(c_1 - e_n)^2 F / (\beta F + e_g + \alpha M)^2(2c + e_k\mu) < 0$, $D(V_1)/d(F) = -\beta(c_1 - e_n)^2 / (\beta F + e_g + \alpha M)^2(2c + e_k\mu) < 0$, and $D(V_1)/d(M) = -\alpha(c_1 - e_n)^2 / (\beta F + e_g + \alpha M)^2(2c + e_k\mu) < 0$. Notably, $D(V_1)/$

$d(e_n) < 0$, $D(V_1)/d(e_k) < 0$, $D(V_1)/d(u) < 0$, $D(V_1)/d(\alpha) < 0$, $D(V_1)/d(\beta) < 0$, $D(V_1)/d(F) < 0$, and $D(V_1)/d(M) < 0$ always hold true, indicating a negative correlation between $e_n, e_k, u, \alpha, \beta, F, M$ and V_1 . Owing to $D(V_1)/d(c_2) = 0$ and $D(V_1)/d(e_g) = 0$, c_2, e_g is independent of V_1 . $\square$

For GAs, the initial benefits of choosing the PS and SN strategies are E_{y1} and E_{y0} , respectively, as expressed in Equations (32) and (33) respectively.

$$E_{y1} = -c_g + \beta F + c_w(-1 + x) - \gamma Qz + x(-\beta F - \alpha M + \delta(e_g + e_n + e_k\mu z)) \quad (32)$$

$$E_{y1} = c_w(-1 + x) + t_g(-1 + x) + \delta x(e_n + e_k\mu z) \quad (33)$$

The dynamic replication equation for GAs can be expressed as Equations (34) and (35).

$$Fy = (-1 + y)y(c_g + \beta F(-1 + x) + t_g(-1 + x) + \alpha Mx - e_g\delta x + \gamma Qz) \quad (34)$$

$$d(F(y))/dy = (-1 + 2y)(c_g + \beta F(-1 + x) + t_g(-1 + x) + \alpha Mx - e_g\delta x + \gamma Qz) \quad (35)$$

When $Fy = 0$ and $d(F(y))/dy < 0$ are true, the probability of the GA choosing the PS strategy remains stable. Assuming that $m(z) = c_g + \beta F(-1 + x) + t_g(-1 + x) + \alpha Mx - e_g\delta x + \gamma Qz$, $d(m(z))/dz = \gamma Q > 0$ is always true since $m(z)$ is a monotonically increasing function. Therefore, z_1 can be chosen such that when $z = z_1$, $m(z_1) \equiv F(z_1) \equiv 0$ and $d(F(y))/dy \equiv 0$ are always true. At this time, the GA cannot determine a stable strategy. When $z > z_1$, $m(z) > 0$ and $d(F(y))/dy < 0|_{y=0} < 0$ are always true, and $y = 0$ is an ESS point. Otherwise, $y = 1$ is an ESS point. Notably, z_1 can be expressed as Equation (36).

$$z_1 = \frac{-c_g + \beta F + t_g - (\beta F + \alpha M - e_g\delta + t_g)x}{\gamma Q} \quad (36)$$

Assuming that the probability of the GA adopting the PS strategy is V_3 , the intersections of z_1 projected onto the xoz surface are $(0, 0, (\beta F + t_g - c_g)/\gamma Q)$ and $((\beta F + t_g - c_g)/(\beta F + \alpha M - e_g\delta + t_g), 0, 0)$. Notably, V_3 can be calculated with Equation (37).

$$V_3 = \frac{(-c_g + \beta F + t_g)^2}{\gamma Q(\beta F + \alpha M - e_g\delta + t_g)} \quad (37)$$

The probability of the GA adopting the NS strategy is $V_4 = 1 - V_3$, which can be calculated via Equation (38).

$$V_4 = 1 - \frac{(-c_g + \beta F + t_g)^2}{\gamma Q(\beta F + \alpha M - e_g\delta + t_g)} \quad (38)$$

Proposition 2. When $c_g = \beta F + t_g$, then $V_3 = 0$ and $V_4 = 1$. Moreover, α is negatively correlated with the probability of the GA adopting the PS strategy; e_g and δ are positively correlated with the probability of the GA adopting the PS strategy; and the values of c_g, β, t_g, γ , and Q are uncertain.

Proof of Proposition 2. When $c_g = \beta F + t_g$, $-c_g + \beta F + t_g = 0$ is always true. Therefore, $V_3 = 0$ and $V_4 = 1$ are always true. For any value, $D(V_3)/d(\alpha) = -M(-c_g + \beta F + t_g)^2/\gamma Q(\beta F + \alpha M - e_g\delta + t_g)^2 < 0$ is always true. Thus, α is negatively correlated with V_3 . When $D(V_3)/d(e_g) = \delta(-c_g + \beta F + t_g)^2/\gamma Q(\beta F + \alpha M - e_g\delta + t_g)^2 > 0$, $D(V_3)/d(\delta) = e_g(-c_g + \beta F + t_g)^2/\gamma Q(\beta F + \alpha M - e_g\delta + t_g)^2 > 0$ is always true. Hence, e_g and δ are positively correlated with V_3 . In addition, there is uncertainty in $D(V_3)/d(c_g) = 2(c_g - \beta F - t_g)/\gamma Q(\beta F + \alpha M - e_g\delta + t_g)$. For any value, $D(V_3)/d(\beta) = F(\beta F + t_g - c_g)(c_g + \beta F + 2\alpha M - 2e_s + t_g)/\gamma Q(\beta F + \alpha M - e_g\delta + t_g)^2$ and $D(V_3)/d(t_g) = (\beta F + T - c_g)(c_g + \beta F + 2\alpha M - 2e_s + t_g)/\gamma Q(\beta F + \alpha M - e_g\delta + t_g)^2$ are uncertain, which is also true for both $D(V_3)/d(\gamma)$

$= -(\beta F + t_g - c_g)^2 / \gamma^2 Q (\beta F + \alpha M - e_g \delta + t_g)$ and $D(V_3)/d(Q) = -(\beta F + t_g - c_g)^2 / \gamma Q^2 (\beta F + \alpha M - e_g \delta + t_g)$. Therefore, there is uncertainty in the relationships among c_g , β , t_g , γ , Q , and V_3 . $\square$

For FIs, the initial benefits of choosing the OGC and CGC strategies are E_{z1} and E_{z0} , respectively, as expressed in Equations (39) and (40) respectively.

$$E_{z1} = -c_k + \mu(b_3 + b_1x - b_3x) + \gamma Qy \quad (39)$$

$$E_{z2} = b_2 \quad (40)$$

The dynamic replication equation for GAs can be expressed as Equations (41) and (42).

$$Fz = z(z-1)(b_2 + c_k - b_3\mu - Q\gamma y - b_1\mu x + b_3\mu x) \quad (41)$$

$$d(F(z))/dz = (-1 + 2z)(b_2 + c_k - b_3\mu - b_1\mu x + b_3\mu x - \gamma Qy) \quad (42)$$

According to the fundamental theorem of differential equations [60], when both $F(z) = 0$ and $d(F(z))/dz < 0$ are true, the probability of the FI choosing the OGC strategy remains stable. Assuming that $m(y) = (b_2 + c_k - b_3\mu - b_1\mu x + b_3\mu x - \gamma Qy)$, $d(m(y))/dy = -\gamma Q < 0$ is always true, which indicates that $m(y)$ is a monotonically decreasing function. Therefore, there exists y_1 such that $m(y_1) \equiv F(y_1) \equiv 0$, and $d(F(z))/dz \equiv 0$ is always true for $y = y_1$. In this case, the GA cannot determine a stable strategy. However, when $y < y_1$ is true, $m(y) > 0$ and $d(F(z))/dz < 0|_{z=0} < 0$ are always true, which suggests that $z = 0$ is an ESS point. Otherwise, $z = 1$ is an ESS point. Notably, y_1 can be expressed as Equation (43).

$$y_1 = \frac{b_2 + c_k + b_3\mu(-1 + x) - b_1\mu x}{\gamma Q} \quad (43)$$

Assuming that the probability of the FI adopting the OGC strategy is V_5 , the intersection points of the projection of y_1 onto the plane xoy are $(0, (b_2 + c_k - b_3\mu)/\gamma Q, 0)$ and $((b_2 + c_k - b_3\mu)/(b_1 - b_3)\mu, 0, 0)$. Then, V_5 can be calculated via Equation (44).

$$V_5 = \frac{(b_2 + c_k - b_3\mu)^2}{\gamma Q(b_1 - b_3)\mu} \quad (44)$$

Then, the probability of the FI adopting the CGC strategy is $V_6 = 1 - V_5$, which can be calculated with Equation (45).

$$V_6 = 1 - \frac{(b_2 + c_k - b_3\mu)^2}{\gamma Q(b_1 - b_3)\mu} \quad (45)$$

Proposition 3. When $b_3\mu = b_2 + c_k$, $V_5 = 0$, and $V_6 = 1$ are positively correlated, then b_1 and V_5 are negatively correlated. However, when $b_1 > b_3$, γ , Q , and V_5 are negatively correlated, and b_1 and V_5 are positively correlated.

Proof of Proposition 3. When $\mu b_3 = b_2 + c_k$, $b_2 + c_k - \mu b_3 = 0$ can always be established, and at this time, $V_5 = 0$ and $V_6 = 1$. For any given value, $D(V_5)/d(b_1) = -(b_2 + c_k - \mu b_3)^2 / (b_1 - b_3)^2 \gamma Q \mu < 0$ is always valid. Therefore, b_1 and V_5 are negatively correlated. When $b_1 > b_3$ is met, $D(V_5)/d(\gamma) = -(b_2 + c_k - \mu b_3)^2 / (b_1 - b_3) \gamma^2 Q \mu < 0$ and $D(V_5)/d(Q) = -(b_2 + c_k - \mu b_3)^2 / (b_1 - b_3) \gamma Q^2 \mu < 0$ are always valid. Therefore, when $b_1 > b_3$, γ , Q , and V_5 are negatively correlated, and b_1 and V_5 are positively correlated. According to EGT, when all the eigenvalues of the Jacobian matrix are negative, the equilibrium point is the ESS point. The eigenvalues of the ESS points are provided in Table 4. $\square$

Table 4. Corresponding eigenvalues of the ESS points.

Equilibrium Point	Eigenvalues		
	Eigenvalue 1	Eigenvalue 2	Eigenvalue 3
$E_1(0,0,0)$	$e_n - c_1$	$t_g - c_g + \beta F$	$\mu b_3 - c_k - b_2$
$E_2(1,0,0)$	$c_1 - e_n$	$\theta e_g - \alpha M - c_g$	$\mu b_1 - c_k - b_2$
$E_3(0,1,0)$	$e_g - c_1 + e_n + \beta F + \alpha M$	$c_g - t_g - \beta F$	$\gamma Q - c_k - b_2 + \mu b_3$
$E_4(0,0,1)$	$c_2 - c_1 + e_n + \mu e_k$	$t_g - c_g + \beta F - \gamma Q$	$b_2 + c_k - \mu b_3$
$E_5(1,1,0)$	$c_1 - e_g - e_n - \beta F - \alpha M$	$c_g + \alpha M - \theta e_g$	$\gamma Q - c_k - b_2 + \mu b_1$
$E_6(1,0,1)$	$c_1 - c_2 - e_n - \mu e_k$	$\theta e_g - \alpha M - \gamma Q - c_g$	$b_2 + c_k - \mu b_1$
$E_7(0,1,1)$	$c_2 - c_1 + e_g + e_n + \beta F + \alpha M + \mu e_k$	$c_g - t_g - \beta F + \gamma Q$	$b_2 + c_k - \gamma Q - \mu b_3$
$E_8(1,1,1)$	$c_1 - c_2 - e_g - e_n - \beta F - \alpha M - \mu e_k$	$c_g + \alpha M + \gamma Q - \theta e_g$	$b_2 + c_k - \gamma Q - \mu b_1$

Proposition 4. $E_1(0,0,0)$ and $E_2(1,0,0)$ cannot be ESS points simultaneously, $E_3(0,1,0)$ and $E_5(1,1,0)$ cannot be ESS points simultaneously, $E_4(0,0,1)$ and $E_6(1,0,1)$ cannot be ESS points simultaneously, and $E_7(0,1,1)$ and $E_8(1,1,1)$ cannot be ESS points simultaneously.

Proof of Proposition 4. With the initial values remaining unchanged, as $e_n - c_1$ and $c_1 - e_n$ are opposite numbers, $E_1(0,0,0)$ and $E_2(1,0,0)$ cannot be ESS points simultaneously. Moreover, $e_g - c_1 + e_n + \beta F + \alpha M$ and $c_1 - e_g - e_n - \beta F - \alpha M$ are opposite numbers, so $E_3(0,1,0)$ and $E_5(1,1,0)$ cannot be ESS points simultaneously. Similarly, $c_2 - c_1 + e_n + \mu e_k$ and $c_1 - c_2 - e_n - \mu e_k$ are opposite numbers, so $E_4(0,0,1)$ and $E_6(1,0,1)$ cannot be ESS points simultaneously. Analogously, $c_2 - c_1 + e_g + e_n + \beta F + \alpha M + \mu e_k$ and $c_1 - c_2 - e_g - e_n - \beta F - \alpha M - \mu e_k$ are opposite numbers, so $E_7(0,1,1)$ and $E_8(1,1,1)$ cannot be ESS points simultaneously. $\square$

Proposition 5. $E_1(0,0,0)$ and $E_3(0,1,0)$ cannot be simultaneous ESS points, $E_2(1,0,0)$ and $E_5(1,1,0)$ cannot be simultaneous ESS points, $E_4(0,0,1)$ and $E_7(0,1,1)$ cannot be simultaneous ESS points, and $E_6(1,0,1)$ and $E_8(1,1,1)$ cannot be simultaneous ESS points.

Proof of Proposition 5. With the initial values remaining unchanged, as $t_g - c_g + \beta F$ and $c_g - t_g - \beta F$ are opposite numbers, $E_1(0,0,0)$ and $E_3(0,1,0)$ cannot be simultaneous ESS points. Moreover, $\theta e_g - \alpha M - c_g$ and $c_g + \alpha M - \theta e_g$ are opposite numbers, so $E_2(1,0,0)$ and $E_5(1,1,0)$ cannot be simultaneous ESS points. Similarly, $t_g - c_g + \beta F - \gamma Q$ and $c_g - t_g - \beta F + \gamma Q$ are opposite numbers, so $E_4(0,0,1)$ and $E_7(0,1,1)$ cannot be simultaneous ESS points. Analogously, $\theta e_g - \alpha M - \gamma Q - c_g$ and $c_g + \alpha M + \gamma Q - \theta e_g$ are opposite numbers, so $E_6(1,0,1)$ and $E_8(1,1,1)$ cannot be simultaneous ESS points. $\square$

4. Case Study

On 28 March 2024, the Xiaomi Group convened a press conference in Beijing to officially unveil the inaugural electric vehicle Xiaomi SU7. Within 24 h of its release, the order volume surpassed 88,898 units, setting a new sales record for new energy vehicles [61]. The successful launch of SU7 can be attributed to the collaborative efforts of more than 3000 Xiaomi auto workers and more than 1000 supply chain partners, as well as support from GAs and FIs. Therefore, in this work, the production of SU7 was adopted as a case study, and the involvement of ISs, GAs, and FIs was examined to reveal the behavioural strategies and evolutionary patterns at different stages. Among them, the parameters related to SU7 and other products [62] are shown in Table 5.

Table 5. The parameters related to SU7 and other products.

Product	Maximum Speed	Peak Torque	Peak Power	Power Density
SU7 V6s	21,000 rpm	500 N•m	275 KW	6.78 KW/kg
Model S Plaid	20,000 rpm	480 N•m	253 KW	6.22 KW/kg
Tavcan Turbo	16,000 rpm	610 N•m	370 KW	5.29 KW/kg

The aim of this paper was to determine the evolutionary patterns of ISs, GAs, and FIs within the context of green development. To capture the actual operational environment more accurately, the developmental history of the Xiaomi automobile in Beijing, China, was surveyed. The results revealed that system effectiveness was ensured by stakeholders and that the green integrated innovation of suppliers was successfully implemented and promoted, thus positively contributing to achieving economic development and carbon neutrality goals. In the process of surveying, a consensus of confidentiality was reached with the enterprise, and the research data were encrypted by the densification method in the research process; however, this method did not affect the analysis of the evolution law. The relevant parameters of the different stability points are listed in Tables 6 and 7.

Table 6. Relevant parameters of the different stability points.

Item	e_1	e_2	e_n	e_g	e_k	c_1	c_2	c_k	c_g	c_w	b_1
$E_1(0,0,0)$	35	25	30	30	25	50	30	90	35	10	50
$E_2(1,0,0)$	35	25	30	30	25	20	30	50	35	10	50
$E_3(0,1,0)$	35	25	20	10	25	60	30	50	35	10	50
$E_4(0,0,1)$	35	25	20	10	25	105	30	50	40	10	50
$E_5(1,1,0)$	35	25	25	60	25	20	30	50	40	10	50
$E_6(1,0,1)$	35	25	45	52	25	120	30	40	15	10	90
$E_7(0,1,1)$	35	25	15	20	25	120	20	50	30	10	50
$E_8(1,1,1)$	35	25	25	30	25	120	20	30	15	10	80

Table 7. Relevant parameters of the different stability points.

Item	b_2	b_3	M	α	F	β	Q	γ	θ	t_g	μ
$E_1(0,0,0)$	130	80	30	0.1	15	0.1	10	0.1	0.8	10	2
$E_2(1,0,0)$	130	80	30	0.1	15	0.1	10	0.1	0.8	10	2
$E_3(0,1,0)$	130	80	15	0.1	35	0.8	10	0.1	0.8	10	2
$E_4(0,0,1)$	130	95	15	0.1	35	0.8	10	0.1	0.8	10	2
$E_5(1,1,0)$	130	95	15	0.1	35	0.8	10	0.1	0.8	10	2
$E_6(1,0,1)$	130	100	30	0.9	15	0.9	10	0.8	0.8	10	2
$E_7(0,1,1)$	130	95	15	0.1	35	0.1	10	0.1	0.8	30	2
$E_8(1,1,1)$	130	81	30	0.1	15	0.1	10	0.1	0.9	30	2

In this work, the parameters were set under different scenarios. To conduct simulation analysis, the GA subsidy and penalty coefficients were determined by disturbance.

The survey results indicate that investment returns are the key factors influencing the ultimate stability of ISs and FIs, whereas GAs focus more on environmental and economic development benefits.

4.1. Analysis of Evolutionary Paths under Unconstrained Scenarios

Under the unconstrained scenario, there is uncertainty in the benefits of green technology innovation, as well as in the cost of choosing green technology. The sink $E_1(0,0,0)$ is a unique ESS point when $e_n < c_1$, $t_g + \beta F < c_g$ and $\mu b_3 < c_k + b_2$. To meet this condition, $e_n = 30$, $c_1 = 50$, $t_g = 10$, $\beta F = 1.5$, $c_g = 35$, $\mu b_3 = 160$, $c_k = 90$, and $b_2 = 130$ are set. Combined with the simulation results shown in Figure 2a,b, the strategy selection of x, y, and z finally converges to $E_1(0,0,0)$.

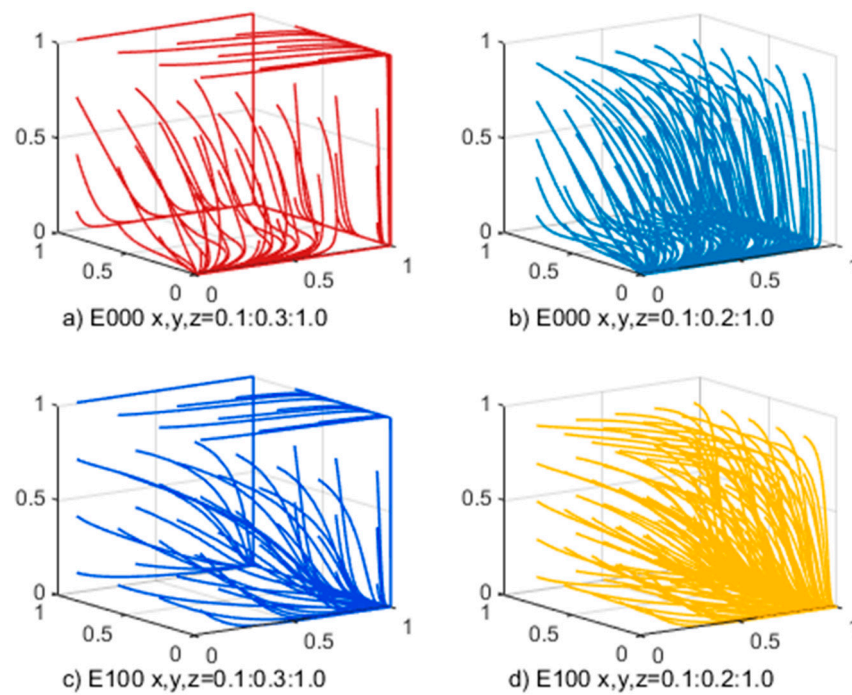


Figure 2. Evolution towards the sinks $E_1(0,0,0)$ and $E_2(1,0,0)$.

When $c_1 < e_n$, $\theta e_g < \alpha M + c_g$ and $\mu b_1 < c_k + b_2$, the sink $E_2(1,0,0)$ is a unique ESS point. To meet this condition, $c_1 = 20$, $e_n = 30$, $\theta e_g = 24$, $\alpha M = 3$, $c_g = 35$, $\mu b_1 = 100$, $c_k = 50$, and $b_2 = 130$ are set. Combined with the simulation results depicted in Figure 2c,d, the selection probabilities of x , y , and z finally converge to $E_2(1,0,0)$. The sink $E_3(0,1,0)$ is a unique ESS point when $e_g + e_n + \beta F + \alpha M < c_1$, $c_g < t_g + \beta F$, and $\gamma Q + \mu b_3 < c_k + b_2$. To meet this condition, $e_g = 10$, $e_n = 20$, $\beta F = 28$, $\alpha M = 1.5$, $c_1 = 60$, $c_g = 35$, $t_g = 10$, $\gamma Q = 1$, $\mu b_3 = 160$, $c_k = 50$, and $b_2 = 130$ are set. Combined with the simulation results shown in Figure 3a,b, the selection probabilities of x , y , and z finally converge to $E_3(0,1,0)$.

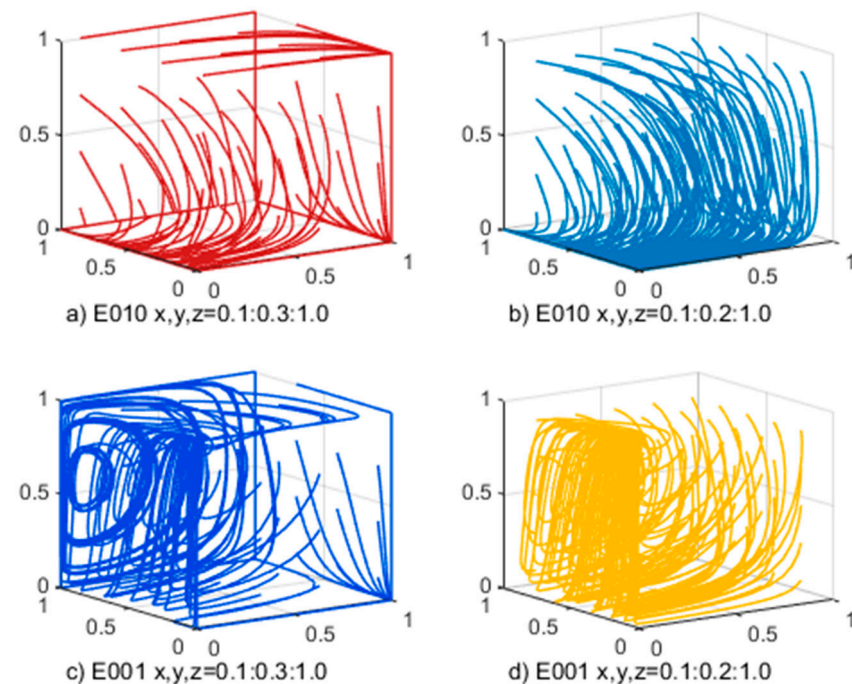


Figure 3. Evolution towards the sinks $E_3(0,1,0)$ and $E_4(0,0,1)$.

The sink $E_4(0,0,1)$ is a unique ESS point when $c_2 + e_n + \mu e_k < c_1$, $t_g + \beta F < c_g + \gamma Q$, and $b_2 + c_k < \mu b_3$. To meet this condition, $c_2 = 30$, $e_n = 20$, $\mu e_k = 50$, $c_1 = 105$, $t_g = 10$, $\beta F = 28$, $c_g = 40$, $\gamma Q = 1$, and $b_2 = 130$ are set, as well as $c_k = 50$ and $\mu b_3 = 190$. Combined with the simulation results depicted in Figure 3c,d, the strategy selection probabilities of x , y , and z finally converge to $E_4(0,0,1)$. This result shows that under the unconstrained scenario, there is uncertainty in the cost and benefits of green innovation adoption by the ISs, and all three parties develop distinct optimal behaviour strategies. The assignment and change rules of the relevant parameters are shown in Figure 4.

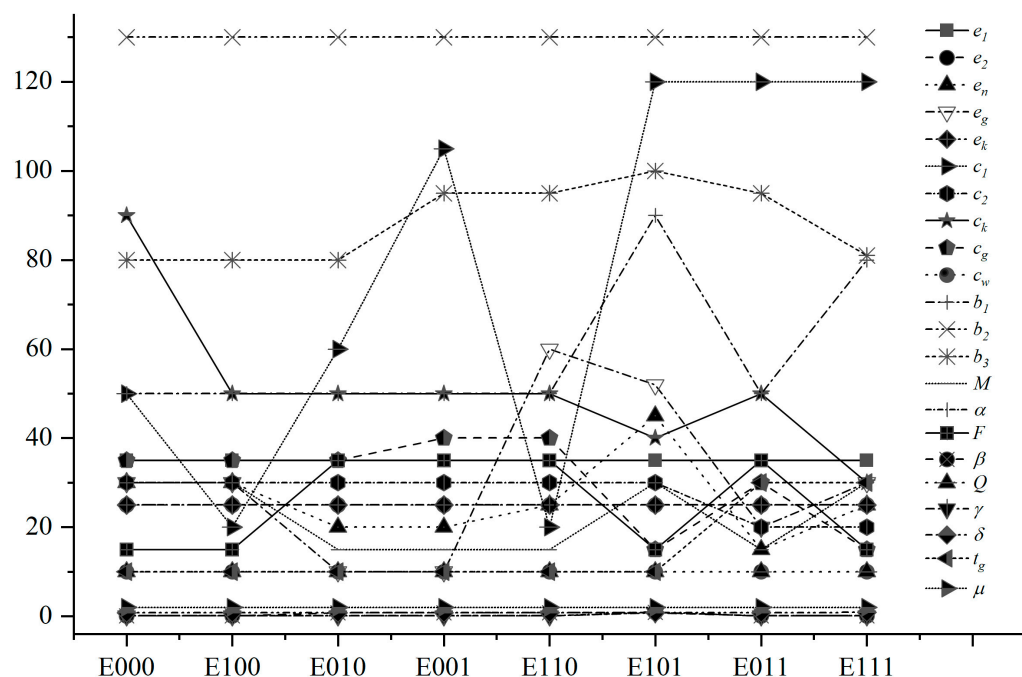


Figure 4. Assignment and change rules of the relevant parameters under the unconstrained scenario.

When $c_1 < e_g + e_n + \beta F + \alpha M$, $c_g + \alpha M < \theta e_g$ and $\gamma Q + \mu b_1 < c_k + b_2$, the sink $E_5(1,1,0)$ is a unique ESS point. To meet these conditions, $c_1 = 20$, $e_g = 60$, $e_n = 25$, $\beta F = 28$, $\alpha M = 1.5$, $c_g = 40$, $\theta e_g = 48$, $\gamma Q = 1$, $\mu b_1 = 100$, $c_k = 50$, and $b_2 = 130$ are set. Combined with the simulation results shown in Figure 5a,b, the selection probabilities of x , y , and z finally converge to $E_5(1,1,0)$.

The sink $E_6(1,0,1)$ is a unique ESS point when $c_1 < c_2 + e_n + \mu e_k$, $\theta e_g < \alpha M + \gamma Q + c_g$, and $b_2 + c_k < \mu b_1$. To meet this condition, $c_1 = 120$, $c_2 = 30$, $e_n = 45$, $\mu e_k = 50$, $\theta e_g = 41.6$, $\alpha M = 27$, $\gamma Q = 8$, $c_g = 15$, $b_2 = 130$, $c_k = 40$, and $\mu b_1 = 180$ are set. Combined with the simulation results depicted in Figure 5c,d, the selection probabilities of x , y , and z finally converge to $E_6(1,0,1)$. The sink $E_7(0,1,1)$ is a unique ESS point when $c_2 + e_g + e_n + \beta F + \alpha M + \mu e_k < c_1$, $c_g + \gamma Q < t_g + \beta F$, and $b_2 + c_k < \gamma Q + \mu b_3$. To meet this condition, $c_2 = 20$, $e_g = 20$, $e_n = 15$, $\beta F = 3.5$, $\alpha M = 1.5$, $c_1 = 120$, $c_g = 30$, $\gamma Q = 1$, $t_g = 30$, $\beta F = 3.5$, $b_2 = 130$, $c_k = 50$, and $\mu b_3 = 190$ are set. Combined with the simulation results depicted in Figure 6a,b, the strategy selection probabilities of x , y , and z finally converge to $E_7(0,1,1)$.

When $c_1 < c_2 + e_g + e_n + \beta F + \alpha M + \mu e_k$, $c_g + \alpha M + \gamma Q < \theta e_g$, and $b_2 + c_k < \gamma Q + \mu b_1$, the sink $E_8(1,1,1)$ is a unique ESS point. To meet this condition, $c_2 = 20$, $e_n = 25$, $\mu e_k = 50$, $c_1 = 120$, $t_g = 30$, $\beta F = 1.5$, $c_g = 15$, $\gamma Q = 1$, $b_2 = 130$, $c_k = 30$, and $\mu b_3 = 162$ are set. Combined with the simulation results provided in Figure 6c,d, the strategy selection probabilities of x , y , and z finally converge to $E_8(1,1,1)$.

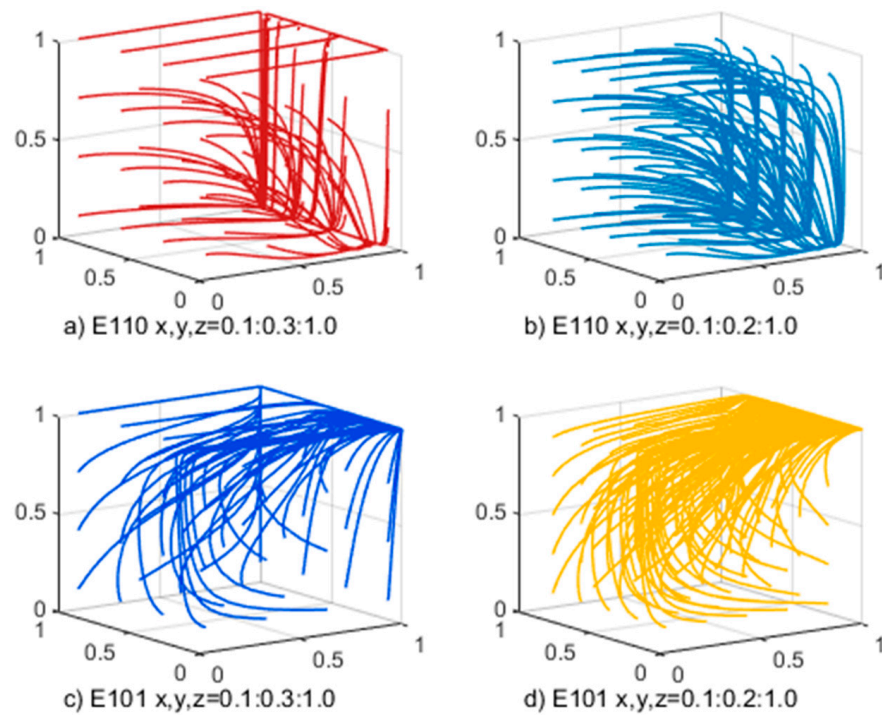


Figure 5. Evolution towards the sinks $E_5(1, 1, 0)$ and $E_6(1, 0, 1)$.

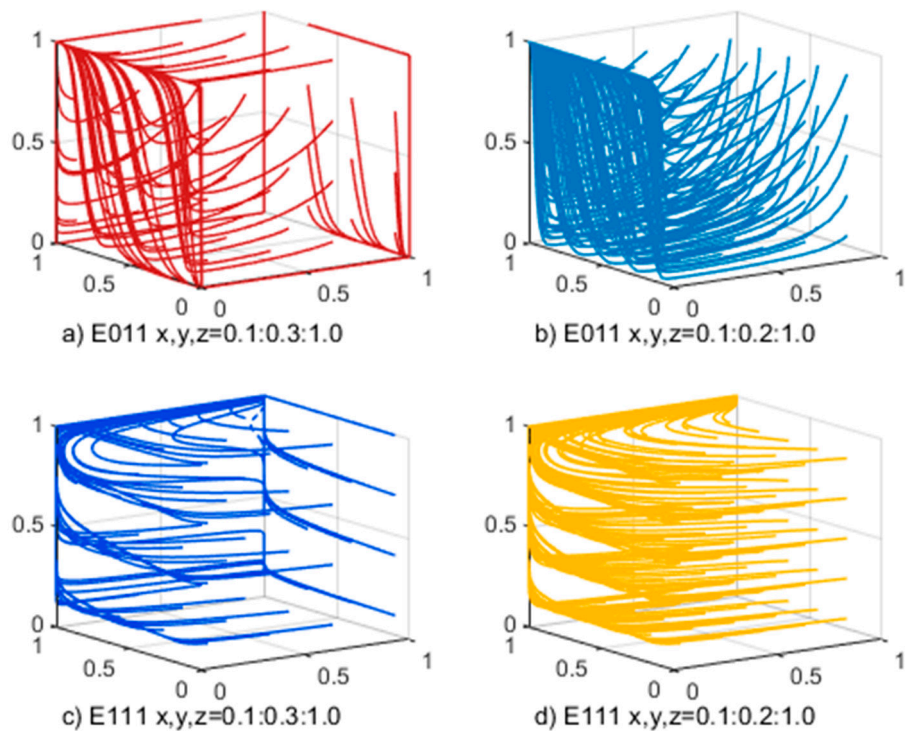


Figure 6. Evolution towards the sinks $E_7(0, 1, 1)$ and $E_8(1, 1, 1)$.

4.2. Analysis of Evolutionary Paths under Constrained Scenarios

When the ISs choose the GD strategy, the new investment income is less than the innovation cost because it cannot obtain long-term profit, which is an unsustainable strategy. In addition, when the ISs choose the GD strategy, the benefit to the FIs from providing green credit is greater than that from not providing green credit. FIs always benefit from extending credit to ISs. Therefore, under the constrained scenario, the conditions $c_1 < e_n$, $b_1 > b_3$, and $b_2 > b_3$ are always satisfied. Under this scenario, the tripartite behaviour

strategy can be divided into three stages, namely, the initial, development, and maturity stages. The initial stage is $E_8(1, 1, 1)$, and the evolution results are shown in Figure 7.

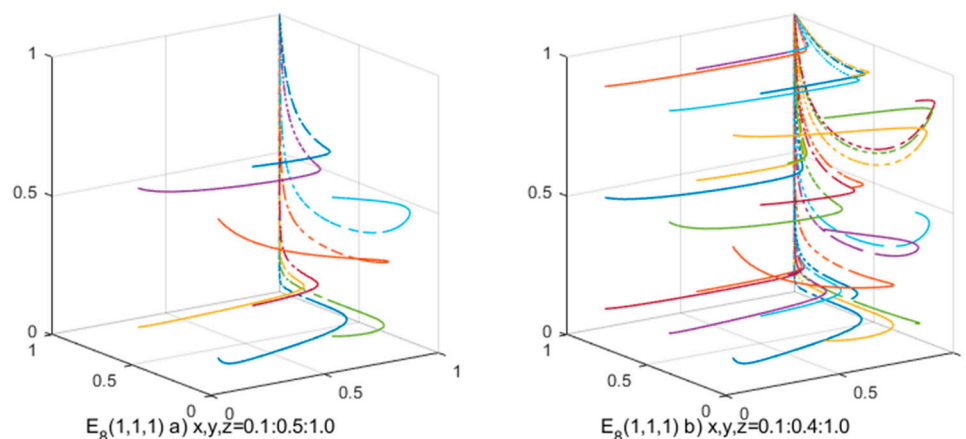


Figure 7. Evolutionary process at the initial stage. Note: Different colors indicate the evolution trend under different parameter states.

According to the evolution results in Figure 7, at the initial stage, the evolution of the tripartite behaviour strategies eventually converges to the stable point $E_8(1, 1, 1)$, and the convergence results are independent of the initial behaviour strategy of each stakeholder. This result shows that at the initial stage, the ISs, GAs, and FIs all choose to support green innovation. The main reason is that at the initial stage, relying solely on ISs for green innovation is not sustainable. At this stage, GAs must issue relevant policy support and guide FIs to provide green credit to ISs. The development stage is shown in Figure 8.

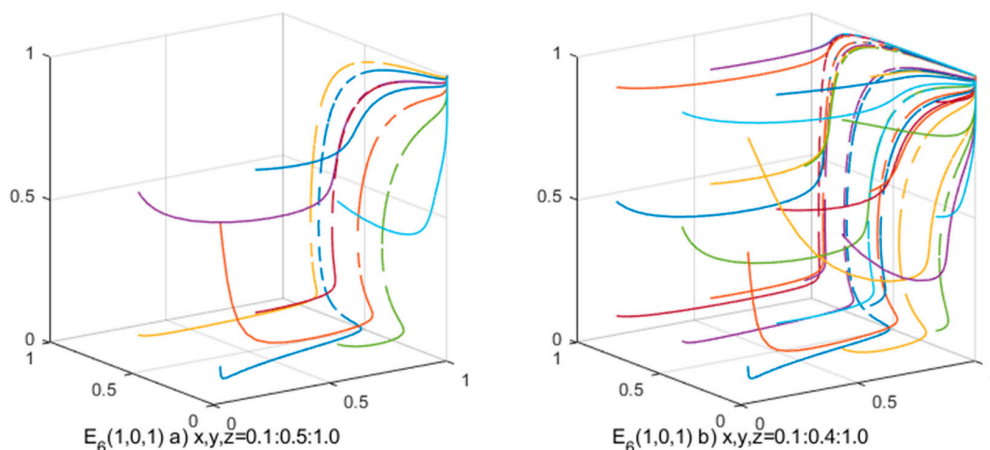


Figure 8. Evolutionary process at the development stage. Note: Different colors indicate the evolution trend under different parameter states.

With the support of GAs and the green credit provided by FIs, ISs have started to implement green technology innovation on a large scale. When the development stage has been reached, without the support of GAs, ISs can be responsible for their own profits and losses in the market. At this stage, the behavioural strategy of the three participants finally converges to $E_6(1, 0, 1)$. This result shows that the support of GA policies is the key to promoting the green development of the supply chain into the development period, mainly because the GA subsidy mechanism can affect the profits of enterprises to adjust the behaviour strategy of ISs. The maturity stage is shown in Figure 9.

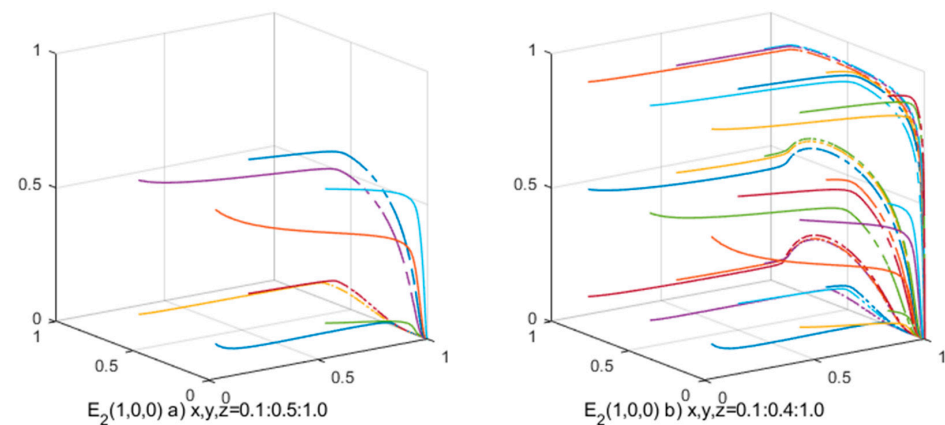


Figure 9. Evolutionary process at the maturity stage. Note: Different colors indicate the evolution trend under different parameter states.

According to Figure 9, when the tripartite participants evolve to the maturity stage, GAs gradually withdraw from the game process and no longer provide policy support for ISs. When ISs conduct large-scale green technology innovation, the cost of innovation continues to decline. At this point, it is no longer necessary for FIs to provide green credit. When the income from providing green credit falls below a certain threshold, FIs will no longer provide green credit. The final evolutionary outcome is that ISs independently choose green technology innovation through market behaviours, namely, convergence to $E_8(1,0,0)$ occurs.

5. Sensitivity Analysis and Discussion

The influence of different parameters on the evolution path at different stages, namely, the initial, development, and maturity stages, has been investigated [63,64]. First, the sensitivity is analysed at the initial stage, and the sensitivity analysis results are shown in Figure 10.

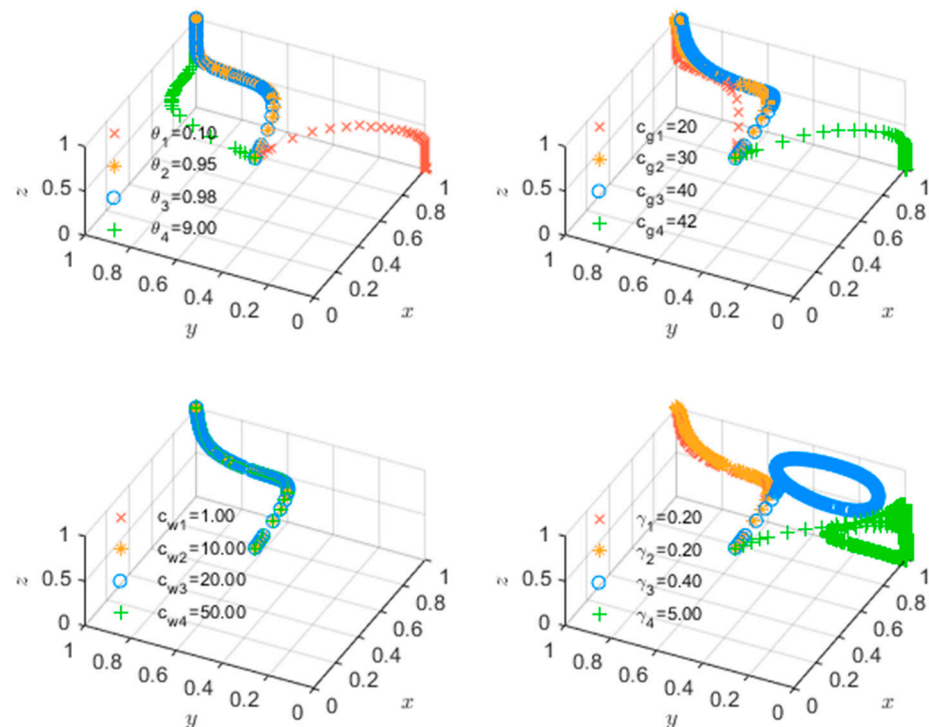


Figure 10. Results at the initial stage.

According to the results shown in Figure 10, when the IS conducts green technology innovation in the initial stage, the governance cost c_w borne by the GA does not affect the evolution results. The main reason is that when the IS chooses to conduct green technology innovation, the GA will not bear the corresponding governance cost [65]. The feedback subsidy coefficient θ associated with IS green technology innovation affects the evolution results. The threshold value of θ is approximately 0.98. When the threshold is exceeded, a jump occurs in the evolution results to $E_2(1, 0, 0)$. The main reason for this jump is that the higher the feedback subsidy coefficient is, the greater the IS profitability, thereby enabling the evolutionary process to quickly enter the maturity stage. Threshold values for the regulation cost c_g of GA participation and the FI subsidy coefficient γ also exist at approximately 40 and 0.5, respectively. When these thresholds are exceeded, a jump will occur in the evolutionary process, and this phenomenon arises mainly from the fact that increases in regulation costs and subsidies will force GAs to withdraw or suspend policies. The sensitivity analysis for the development stage is shown in Figure 11.

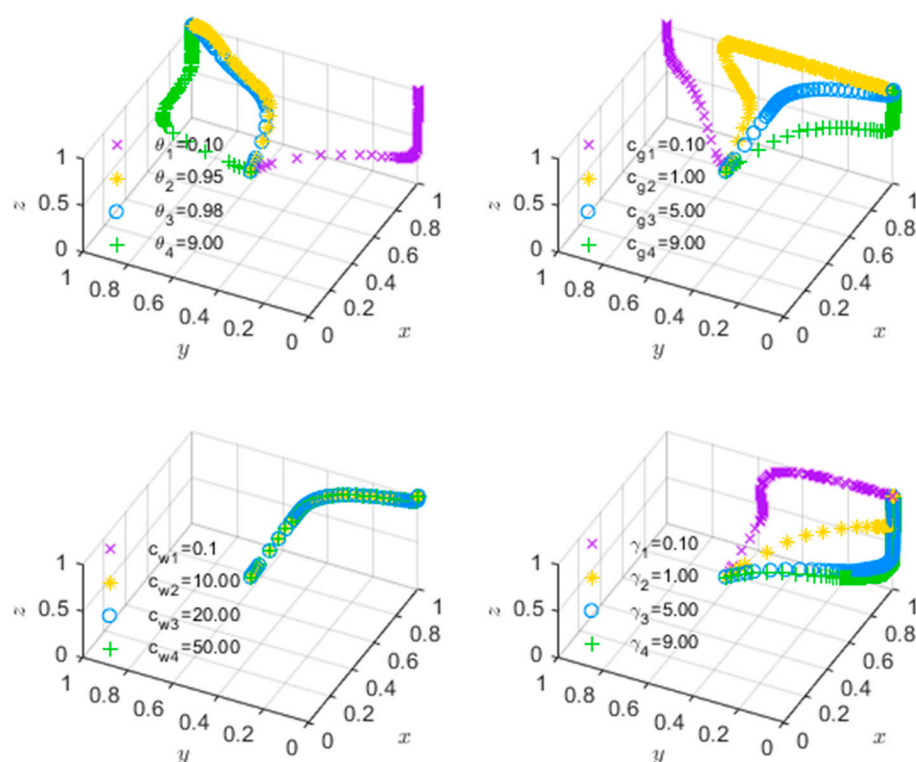


Figure 11. Results at the development stage.

According to the results depicted in Figure 11, when ISs engage in green technology innovation at the development stage, the evolution outcome is not affected by the GA governance cost c_w or the FI subsidy coefficient γ . This occurs because when choosing green technology innovation, ISs do not impose corresponding governance costs on GAs. However, the feedback subsidy coefficient θ and GA participation cost c_g resulting from IS green technology innovation impact the evolution outcome within a threshold range of approximately 0.90–5.00. Exceeding this threshold will directly lead to a jump in the evolutionary process to $E_8(1, 1, 1)$, as an increase in the feedback subsidy coefficient and regulation cost can cause abnormal market development, requiring macrocontrol by GAs to achieve stable development. The sensitivity analysis results for the maturity stage are shown in Figure 12.

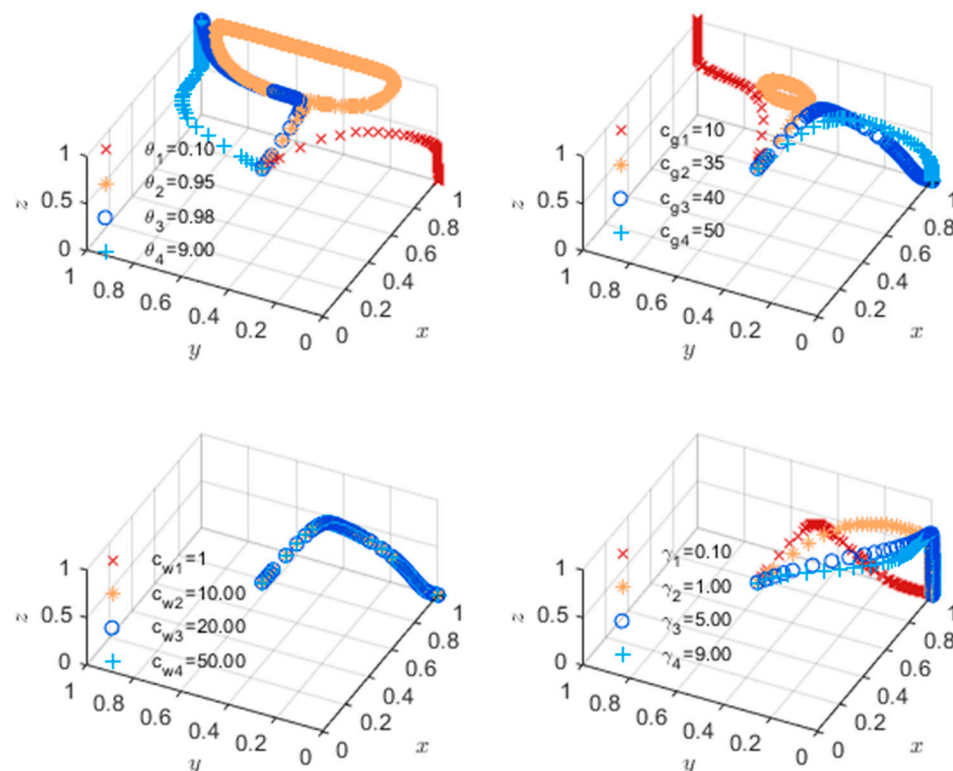


Figure 12. Results at the maturity stage.

On the basis of the results shown in Figure 12, at the maturity stage, ISs spontaneously implement green technology innovation, and the governance cost c_w borne by GAs and the subsidy coefficient γ obtained by FIs do not affect the evolution result. The main reasons for the obtained GA governance commitment level are similar to those at the initial stage, while FI subsidies do not affect the behavioural strategies of individuals. In contrast, the feedback subsidy coefficient θ resulting from IS green technology innovation and the governance cost c_g borne by GAs affect the evolution result, and the threshold range is approximately 0.10–40.00. When the threshold is exceeded, the evolutionary process jumps directly to the ESS point of $E_8(1, 1, 1)$.

6. Conclusions

The green development and management of ISs is a multidimensional and complex interactive process. In this paper, an evolutionary game model that includes three entities, namely, ISs, GAs, and FIs, was constructed. As the primary executors of green development, the strategic choices of ISs are influenced by GA policy supervision and FI investment decisions. As regulators, GAs affect IS behaviour by formulating and implementing relevant policies and are indirectly influenced by FI policy responses. FIs determine their investment strategy on the basis of the green development performance of ISs and the policy environment. In this paper, dynamic evolution and differential equations were used to describe this evolutionary process. The dynamic evolution equations were employed to analyse the dynamic changes in the strategic choices of each entity, whereas the differential equations revealed the stable state strategies of the entire system.

In view of the three issues mentioned in the introduction, if the ISs play an active role, the ISs, GAs, and FAs have stable strategies in the dynamic evolution process, including the initial stage, development stage, and maturity stage. The initial behaviour strategies of the three parties differ in influencing the convergence time of the final stability, and the initial behaviour of the GAs usually affects the final stability strategy. The government's subsidy mechanism and regulation measures can effectively improve the evolutionary stability strategy, and the best strategy for government agencies is to adopt the retrograde

subsidy mechanism. The contribution of this paper is to provide methodological support for the operational decision-making of GAs, FIs, and ISs. The main research process and conclusions of this study include the following three aspects:

First, in the green development process, ISs face various pressures, including costs, credits, technologies, the market, and regulations. With the promotion of policies and changes in the market, ISs must adjust their green development strategy to adapt to external environmental changes, with the general trend evolving from a passive response to proactive innovation.

Second, as regulators, GA policy formulation and execution significantly impact IS behaviour. In the evolutionary game model, the GAs adjust their policy strategy on the basis of the behaviour of the ISs and the response of the FIs to achieve an environmental protection balance. At the early stages of development, the GAs play a crucial role as leaders in promoting rapid development of the ISs, whereas at the later stages, when they function as regulators, the GAs should pay more attention to ensuring fair market development.

Third, as investors, FI investment decisions are influenced by the ISs' green performance and the policy environment. According to the evolutionary game model, FIs adjust their investment strategy on the basis of their green development performance and changes in the policy environment. Particularly at the maturity stage of development, excessive investment in FIs can inhibit the normal development of the industry.

Although the evolutionary patterns of behavioural strategies and stable state strategies among the three major entities (ISs, GAs, and FIs) are explored, the theoretical model and conclusions are verified through case studies. However, the limitation of this research is that it does not consider the fair distribution of benefits after the green development of ISs. In future research plans, we will pay more attention to the fair distribution of supply chain benefits to better guide the green development and management practices of supply chains.

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