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Research Article

Evolutionary Game Analysis of Green Technology Innovation Behaviour for Enterprises from the Perspective of Prospect Theory

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Boosting green technology innovation of enterprise is the key to achieving a win-win situation for both environmental performance and economic performance. However, some Chinese enterprises still have hesitations and misgivings as to whether they should adopt green technology. Considering the uncertainty of the innovation and the irrational psychological factors of decision makers, the purpose of this paper is to analyse the driving mechanisms and the long-term behaviour of enterprises green technology innovation, as well as to explore what preconditions are required for enterprises to adopt green technology innovation. The methods are prospect theory and evolutionary games. This paper first calculates the equilibrium stability and evolutionary stability strategies of the enterprise green technology innovation system and then simulates the effect of subjective gains and losses values and other psychological parameters in the prospect editing and evaluation stage. Results show that increase in subjective gain and decrease in reference points and subjective spill benefit will motivate enterprises to adopt green technology innovation in the prospect editing stage; higher risk preference and lower loss aversion will increase enterprises' motivation for green technology innovation in the prospect evaluation stage. Besides, we find that enterprise decisions are influenced by risk perception and loss aversion rather than just the magnitude of the benefits and cost. Small- and medium-sized enterprises are more likely to turn to green technology innovation than large enterprises under the same level of risk preference and loss aversion. Finally, some suggestions are put forward for the government to encourage enterprises to adopt green technology innovation. This paper can provide a reference for theoretical and practical research on evolutionary game and prospect theory on green technology innovation of enterprises.

1. Introduction

In response to the challenge of global climate change, more and more countries are putting forward the vision of "net zero" carbon emissions. As one of the largest carbon emitters [1], China has also proposed the strategic goal of reaching "carbon neutrality" by 2060 at the 75th session of the UN General Assembly. Actually, China has promulgated many policies at different levels to stimulate the market demand for green technologies and promote the construction of ecological civilization. In 2019, "Guidance on Building a Market-Oriented Green Technology Innovation System" was issued in order to strengthen support for enterprises green technology innovation.

Green technology innovation is a form of technological innovation aiming at environmental protection, and it is also a general term for new technologies, processes, and products that reduce environmental pollution and energy consumption [2]. With the rise of digital technology, digital innovations in the form of digital products, digital processes, and digital organization are integrated with green innovation to achieve energy savings and cost reductions by managing and improving enterprises production activities [3]. Green technology innovations can be accelerated by digital technology [4]. Green technology innovations in any forms all emphasize the "green concept" throughout the life cycle of technology development and application [5] and are also regarded as the key element in reducing carbon emissions and achieving carbon neutrality [6]. If we do not succeed in making an effective breakthrough in green technology, the emission of sewage, waste gas, and waste will not be controlled, and the objective of green transformation and high-quality development will not be guaranteed [7].

Enterprises are important implementing subjects that can improve the market competitiveness through green technology innovation [8]. In recent years, many Chinese enterprises have invested heavily in green technologies. A national survey including nearly 10,000 key enterprises in the environmental protection industry released by the China Environmental Protection Industry Association in 2018 shows that the R&D expenditure accounts for 3.0% of business revenue, which is higher than the level of national industrial enterprises. According to the report of PricewaterhouseCoopers, annual investment by Chinese venture capital enterprises in green technologies has a significant increase in the 2017–2018 compared to 2014–2016. Due to the relative maturity of industry development, more investments of new technologies have emerged in the areas of solar, wind energy, electronic vehicles, and new energy batteries.

But it is worth noting that most green technology innovations are undertaken by industry leaders, rather than start-ups. High costs and risks [9], long payback cycles [10], inadequate patent systems [11], inefficient fiscal incentives [12], and even the limited market size of green products are barriers for enterprises to adopt green technology innovation. In particular, small- and medium-sized enterprises or those enterprises lacking green technology innovation experience are more likely to be eliminated from the market. Enterprises still are not sufficiently incentivized to adopt green technologies. According to the Patent Statistical Report (2015–2019) issued by the State Intellectual Property Office of China, the cumulative number of patent applications for green technologies in China from 2015 to 2019 only accounted for approximately 10.00% of all the patent applications in the same period. Among the top 20 green patent applicants, 16 were universities and only 3 were enterprises. These all enterprises were large state-owned enterprises.

Subjective factors, such as poor environmental awareness, personal decision-making preferences, and excessive dependence on traditional production methods, may also lead to weak initiatives for green technology innovation. Those enterprises that have adopted technology innovation may only innovate in the efficiency of traditional production methods rather than in green technologies that protect the environment and reduce carbon emissions. According to a Deloitte's report of the manufacturing innovation of China in 2021, only 9% of enterprises adopting innovation are practicing green technology innovators, and the majority are still innovating in the areas of product services and technology. Even parts of enterprises have a problem of overreliance on government subsidies. It can be seen that the effect of market mechanisms on promoting resource allocation of Chinese enterprises to green industries and the transition of investment, production, and consumption to green technology is still not sufficiently obvious.

Game analysis approach plays an important role in industrial organization research and mutual decision-making behaviours of multiple individuals or groups subject to specific conditions [13]. Compared with other game methods, evolutionary game considers the dynamics of decision making from the perspective of limited rationality and learning mechanisms and focuses on evolutionary stable strategies among different groups [14, 15]. Evolutionary game theory assumes that a group playing a particular strategy grows in proportion to how well the strategy has performed in the previous period. In this study, the choice of enterprises to adopt or reject green technology innovation behaviour depends on enterprises capabilities, competitors, consumers, risks, governmental authorities, and so on. Enterprises often observe which strategies have worked well for other enterprises and themselves and then adopt them. Thus, evolutionary game theory is more suitable as a method for analyzing the long-term effect of enterprise decisions on the green technology innovation behaviour. Different groups of enterprises are also observing, learning, adjusting, and stabilizing the strategies of green technology innovation and ultimately achieve the stable development of the entire market. In general, whether an enterprise adopts green technology innovation depends on its costs and benefits. Singh et al. [16] explored the relationship between green innovation and environmental performance by approaching 669 SMEs in the United Arab Emirates. They confirmed that green innovation could increase enterprises' financial and environmental performance. However, some actual experiences show that green innovation does not always increase profits and may fail [17]. Xu and Qi [18] established an evolution game model of low-carbon technology innovation diffusion and concluded that enterprises would not adopt green technology innovation until the greater benefits of low-carbon technology innovation had outweighed the inputs.

Innovation policy measures can affect green technology innovation activities of enterprises and even can play an important role in driving the emergence of more green patents [19]. Strict environmental regulations and associated compliance costs could force industries and enterprises to innovate [20, 21]. Government always interferes with the development of enterprises by means of transfer payment, tax credit [22], reward mechanism, subsidies, taxes, and patents [23]. Xu et al. [24] built an evolutionary game model to analyze how government subsidies and carbon taxes affected the green innovation patterns choices of manufacturing enterprises, and they believed that carbon taxes were more effective. Jamali et al. [25] used evolutionary games to study manufacturers' renewable energy decisions of the cement, steel, and paper industries in Iran; they found that the cement and paper industries were more sensitive to subsidy allocation. Chen and Hu [26] proved that dynamic government incentives were more conducive to stimulating low-carbon behaviour of enterprises. Kim et al. [27] found that the increases of supporting interest rate and carbon tax rates can promote green evolutionary behaviour of government and building owners in the context of achieving Korea's carbon reduction targets. Zhang et al. [28]

investigated the different effects of government incentives on enterprises' green technology innovation in the early and late stages by building an evolutionary game model. Mix of incentives was more effective in the early stages, while the carbon tax would play a major role in the later stages. However, the level of government regulation and punishment should not be too strict; otherwise, it is not encouraging enterprises to adopt green technologies [29, 30].

Consumers' green preferences also can promote the development of green industries [31, 32]. More importantly, enterprises differ in entrepreneurial abilities, risk preference, or initial endowment. The uncertainty of the market's information greatly influences the rational decision-making of the enterprises [33]. Considering the vulnerability of green innovation ecosystems, Zou et al. [34] used evolutionary game theory to study the healthy operating conditions of the ecosystem led by core, upstream, and downstream enterprises. Barari et al. [35] focused on the maximizing economic profit of greenness and looked for a synergetic alliance between environmental and commercial benefits. Enterprise internal factors, such as value orientation, innovation willingness, heterogeneity of scale, and resource variances, will also affect the evolution direction of enterprise green technology innovation decision. Sun and Zhang [36] constructed an evolutionary game model of "greenwashing" behaviour on enterprises' scale heterogeneity and found that the government's tax subsidy mechanism did not inhibit the "greenwashing" behaviour of inferior enterprises. Kuechle [37] examined the impact of individual behaviours on the ratio of self-employment and showed that economic agents would choose strategies based on their particular skills and earn idiosyncratic payoffs.

Evolutionary game objectively constructs the payoff matrix but ignores the psychological influences of decision maker. Enterprises make decisions based not only on reference to the objective costs and benefits, but also on subjective costs and benefits according to their own reference point. The subjective reference point is derived from industry averages [38], historic data [39], enterprise characteristics, risk preference, and social responsibility. Therefore, enterprises' subjective judgments on gains and losses are fundamental to the development and evolution of green technology innovation markets.

Unlike the common assumption of fully rational decision makers, prospect theory emphasizes the relationship between the decision-making process and the decision maker's psychological factors in uncertain situations [40]. The decision process is divided into two stages under prospect theory: the editing stage and the evaluation stage. The editing stage focuses on framing losses and gains based on reference points in relation to the objective values. The evaluation stage aims at making decision choice based on the decision maker's subjective value function and estimate of probability.

Prospect theory has been used in a wide variety of fields. Vamvakas et al. [41] eliminated the assumption of subject-neutral maximization and modelled dynamic spectrum management in 5G wireless networks according to the principles of prospect theory. Yu et al. [42] studied the interaction game mechanism among governments, financial institutions, and investors with considering their risk attitudes. Sawa [43] studied the long-run outcomes of bargaining games when negotiators obey prospect theory. Song et al. [44] considered buyers' risk attitudes and integrated the subjective and objective information of online-products based on prospect theory, which is more in line with the actual buying behaviour. Jou and Chen [45] used the cumulative prospect theory (CPT) to model the drivers' gains and losses aiming at reflecting the risk attitudes of freeway drivers in Taiwan. In the aspect of reference dependence, Butler [46] studied the differences between expected value and prospect theory by discussing four types of reference points in coercive bargaining behaviour. These studies all confirm that prospect theory is more in line with reality than general expected utility theory.

Some scholars also explore social issues in the context of prospect theory and evolutionary games. Tan and Xu [47] made use of benefit perception and loss aversion to make up for the lack of limited rationality of evolutionary games in the field of interest conflict. Yang et al. [38] introduced the reference point into analyzing the utility of the innovation subject and the cooperative innovation revenue matrix, which eliminated the bias from the traditional expected utility. In order to ensure the safe evacuation of people in a high stress emergency evacuation situation, Mason et al. [48] developed an evolutionary game model based on prospect theory by considering the psychological characteristics of the evacuating crowd. Abass et al. [49] examined the cooperative decisions of portfolio enterprises in the framework of both objective expected utility theory and subjective prospect theory, respectively; they found that subjective players were more likely to cooperate by sharing information than objective players.

The policy instruments can also influence the prospective preferences and decisions of the players in the framework of evolutionary game. An evolutionary game model based on prospect theory was proposed to examine the behavioural decisions of contractors and manufacturers in clean energy recovery under environmental regulation [50]. Results showed that the government subsidies and publicity would improve the benefits perception of stakeholders. Liu et al. [51] constructed an evolutionary game model to explore the government's influence on the adoption of prefabricated buildings by construction units, and the findings concluded that government incentives should shift from subsidies to targeted construction cost reduction.

The main purpose of this paper is to analyse the driving mechanisms and the long-term behaviour of enterprises green technology innovation and find preconditions for heterogeneous enterprises adopting green technology innovation. So, we built the novel decision framework for green technology innovation by combining evolutionary game and prospect theory among competing enterprises. This decision framework can internalize the government policy environment and enterprises characteristics as factors in decisions and provide more useful insights about enterprises' decision of green technology innovation under realistic context.

This may specifically include the following topics.

(1) What are the stable equilibrium states and corresponding preconditions for enterprises to adopt green technology innovations?

(2) How key factors influence the strategic choices of the subjects and the equilibrium evolution of the system during the prospect editing stage and the prospect evaluation stage?

(3) What impacts does enterprise heterogeneity have on green technology innovation?

Unlike other studies that have constructed evolutionary game model solely in terms of objective market values and government policy instruments, this paper analyses the choice of enterprise green technology innovation behaviour in the context of subjective value, policy instruments, and spill benefit. Our study argues that both subjective and objective factors influence the behaviour of enterprise in green technology innovation, emphasizing that mutual learning among enterprises will determine whether they will eventually enter the green technology innovation market and develop in a stable way over the long term.

To give the findings more theoretical significance and practical significance, our study selects some appropriate scenarios for simulation based on the current state of Chinese green technology innovation market. How reference points, subjective net benefits and portion coefficients, spill benefit, risk preference, and loss aversion affect the behaviour of the different enterprises towards green technology innovation are analysed and discussed.

In particular, the study focuses more on the impact of government policies on the subjective prospect value of enterprises and explores how government can develop more rational policies to help enterprises be more optimistic about green technology innovation and become more proactive in transition to green technology innovation. It provides a reference to the green innovation decisions of enterprises in other similar developing countries or regions. This paper can also serve as a basis for decisions to enable enterprises to make optimum green technology innovation strategic choices under various conditions. Furthermore, it also provides a reference to the government to formulate a more reasonable driving mechanism of green technology innovation. All these are beneficial to the development of green technology innovation market and the improvement to overall environmental and social welfare.

The rest of this paper are structured as follows: Section 2 presents the hypotheses and the evolutionary model based on a prospect theory perspective. Section 3 solves the replicated dynamic equations and analyses the stability of each equilibrium point. Section 4 analyses the evolutionary stabilization strategy (ESS) under four scenarios. Section 5 analyses the numerical simulations results of subjective gains and losses values and risk parameters on enterprises green technology innovation in the editing stage and the evaluation stage. Section 6 is the discussion. Finally, Section 7 summarizes the conclusions and provides some suggestions for the government to guide more enterprises to adopt green technology innovation.

2. Model Assumptions and Construction

With reference to "Guidance on Building a Market-Oriented Green Technology Innovation System," this paper defines green innovation enterprises as those engaged in research and development of new or improved processes, technologies, systems, and products to prevent or reduce environmental damage.

To simplify the problem, this paper assumes that enterprises in the industry are divided into two kinds of scales, enterprise 1 and enterprise 2. The strategy space of enterprises' green technology innovation behaviour can be defined as {adopting green technology innovation (I_1), rejecting green technology innovation (I_2)}. The probability of enterprise 1 adopting green technology innovation is x; then, the probability of rejecting green technology innovation is $1 - x$. The probability of enterprise 2 adopting green technology innovation is y; then, the probability of rejecting green technology innovation is $1 - y$. Each enterprise learns from the strategies of other enterprises, then it integrates its own production and management situations to decide whether to adopt green technology innovation or not. Particularly, they often need to consider the relationship between costs and benefits when deciding to adopt green technology innovation. The green technology innovation market is comprised of each enterprise's stable strategy.

This paper assumes that Q_c is the total objective net benefit of the overall market when all enterprises involved adopt green technology innovation (green technology innovation market, GTI market), Q_n is the total objective net benefit of the overall market when all enterprises reject green technology innovation (traditional market, T market), and Q_h is the total objective net benefit under the mixed market when only a part of enterprises adopt green technology innovation (mixed market, M market). The magnitude of Q_c, Q_h, and Q_n is objective, uncertain, and will not vary with the subjective perception of each enterprise. b_i $(i = 1, 2)$ is the objective portion coefficient of the market benefit obtained by the enterprise i according to its ability and input of resources. Generally speaking, the enterprise with greater competitiveness and more inputs has a larger portion b_i $(i = 1, 2)$. The product of b_i $(i = 1, 2)$ and Q_c, Q_n, or Q_h is the objective net market benefit obtained by enterprise i . For example, $b_1 Q_c$ is the objective net benefit obtained by enterprise 1 when all enterprises adopt green technology innovation.

In addition, this paper assumes that the externalities of green technology innovation for enterprises need to be considered in the M market. That is, enterprises adopting green technology innovation cannot fully get the benefit of green technology innovation because other enterprises can easily share the spill benefits of green technology innovation through imitation and learning in the market. Assume that Z is the total spill benefits of green technology innovation in the M market, and Z is generally smaller than the total net benefits Q_h in the M market. The enterprise i that rejects green technology innovation in the M market can obtain part of the spill benefits $n_i Z$ based on its own capability and inputs; n_i $(i = 1, 2)$ is the ability coefficient of enterprise i to absorb the spill benefit. k_i $(i = 1, 2)$ is the objective spill coefficient after the enterprise i adopts green technology innovation in the M market. Under the M market, the objective net benefits of the enterprise i adopting green technology innovation becomes $(b_i - k_i)Q_h$, and the objective net benefit of the enterprise $j\,(i \neq j)$ rejecting green technology innovation becomes $b_j Q_h + n_j Z$.

According to the prospect theory decision-making framework, enterprises will go through two stages of prospect editing and prospect evaluation when making decisions. During the prospect editing stage, enterprises generally have their own subjective gains and losses that are calculated by comparing the decision maker's subjective net benefit and reference point. Δr is relative value after considering the reference point under different choices. This paper assumes that enterprises use the objective net benefit as the initial reference point. Take the situation that all enterprises adopt green technology innovation as an example; Δr is $(b_i' Q_c' - b_i Q_c)$. Q_c' and b_i $(i = 1, 2)$, respectively, are defined as the subjective total net benefits in the GTI market and the subjective portion coefficient of the market benefit that enterprise i likely to be gained. If enterprise decision makers are optimistic, they will think $Q_c' > Q_c$, and vice versa, they will think $Q_c' < Q_c$. If enterprise decision makers think that they can get more market portion of green technology innovation or can reduce the cost through green technology innovation, they will think $b_i' > b_i$, and vice versa, $b_i' > b_i$. When $(b_i' Q_c' - b_i Q_c) > 0$, it can be assumed that the prospect value of the enterprise is positive. This means that enterprises believe they will get extra gains. On the contrary, enterprises believe that they will face extra losses.

During the prospect evaluation stage, prospect theory suggests that the risk preferences and attitudes of different decision makers may not be the same when confronted with gains or losses. Enterprises will combine their own risk preferences and loss aversion to obtain a value function in green technology innovation. In general, enterprises are risk-averse and are favoured for stable benefit when they face the earnings solutions. However, the prospect theory assumes that they are mostly risk-seeking when they face with loss solutions. Take the situation of all enterprises adopting green technology innovation as an example; $v(\Delta r)$ is the value function, and the value function $v(b_i' Q_c' - b_i Q_c)$ of enterprise i can be expressed as follows.

$$v(b_i' Q_c' - b_i Q_c) = \begin{cases} (b_i' Q_c' - b_i Q_c)^{\gamma}, & (b_i' Q_c' - b_i Q_c > 0) \\ -\lambda\left[-(b_i' Q_c' - b_i Q_c)\right]^{\gamma}, & (b_i' Q_c' - b_i Q_c < 0), \end{cases} \quad (1)$$

γ represents the risk preference degree of enterprise and λ represents the loss aversion degree of enterprise. The values of γ, λ, and $(b_i' Q_c' - b_i Q_c)$ will be influenced by the social responsibility of enterprises, public green consumption preference, the size of the green technology innovation market, and the competitiveness and resources of enterprises. γ and λ may vary across enterprises when they face the same $(b_i' Q_c' - b_i Q_c)$.

Enterprises also have different probabilities p when they choose to adopt green technology innovation during the prospect evaluation stage. The prospect value is $V(\Delta r_1, p_1; \Delta r_2, p_2; \ldots; \Delta r_n, p_n) = \sum_{i=1}^{n} \pi(p_i) v(\Delta r_i)$, where $\pi(p_i)(i = 1, 2)$ is the probabilistic decision function. To simplify the problem, this paper assumes that the enterprises only can choose a behaviour based on the final gains and losses at the prospect evaluation stage. In other words, the two value functions of adopting green technology innovation and rejecting green technology innovation are the prospect values in both cases; that is, $V(\Delta r_i, 1) = V(\Delta r_i) = v(\Delta r_i)$ or $V(\triangle r_i, 0) = 0$.

Then, from the perspective of prospect theory, the market benefit considered by enterprises has changed. In the case of all enterprises adopting green technology innovation, the net benefit of enterprise i is $b_i Q_c + v(b_i' Q_c' - b_i Q_c)$. However, if all enterprises reject green technology innovation, the net benefit of enterprise i is $b_i Q_n$. In the M market scenario, the enterprise i rejects green technology innovation, it still obtains net benefit of $b_i Q_h + n_i Z$; when enterprise $j\,(j \neq i)$ adopts green technology innovation, the net benefit is $(b_j - k_j)Q_h + v[(b_j' - k_j')Q_h' - (b_j - k_j)Q_h]$, $(j \neq i, j = 1, 2)$, where k_j' is the subjective spill coefficient of enterprise j and Q_h' is the subjective total net benefits in the M market.

It should be noted that the government will introduce incentive and punishment policies to encourage enterprises to take the initiative of green technology innovation. These policies have an impact on enterprises' subjective benefits and may influence enterprises' subjective reference points for green technology innovation decisions. These impacts are not necessarily sustainable and can change. However, incentive and punishment policy will guide the decision and development direction of enterprises, when the market for green technology innovation is still in its infancy. This also is why this paper includes policy impacts as a part of the evolutionary game analysis. For example, the government directly gives corresponding subsidies to enterprises through the identification standards of green technology innovation, increases investment in green technology innovation, expands the scope of government green procurement, strengthens green financial support, and so on. These direct incentives can be as S_i for enterprise i. The government can also increase public awareness of green consumption, strengthen the guidance of green technology innovation, improve the green technology innovation transfer mechanism, and protect green technology intellectual property rights. These policies can strengthen the confidence of enterprises in green technology innovation and improve the prospect value judgement $v(\triangle r_i)$.

Of course, some enterprises will choose the traditional non-environmentally friendly areas to innovate, rather than green technology innovation. Even in the case of the same market income, enterprises will adhere to the original production and business model rather than green technology innovation due to path dependence. At this time, the government can impose punishments on enterprises of rejecting green technology innovation by carbon taxes and set pollution emissions standards. The punishments can be as W_i for enterprise i. The interpretation of all parameters is shown in Table 1.

Based on the above assumptions, Table 2 shows the evolutionary game payoff matrix from the perspective of prospect theory about green technology innovation strategy behaviour selection for enterprises.

3. Replication Dynamic Equations and Local Equilibrium Point Analysis

According to the payoff matrix in Table 2, the expected payoff of enterprise 1 choosing I_1 is $U_{11} = yR_{11} + (1-y)R_{12}$ and the expected payoff of enterprise 1 choosing I_2 is $U_{12} = yR_{13} + (1-y)R_{14}$, so the average expected payoff of enterprise 1 is

$$\overline{U}_1 = xU_{11} + (1-x)U_{12}. \quad (2)$$

The expected payoff of enterprise 2 choosing I_1 is $U_{21} = xR_{21} + (1-x)R_{23}$ and the expected payoff of enterprise 2 choosing I_2 is $U_{22} = xR_{22} + (1-x)R_{24}$. Therefore, the average expected payoff for enterprise 2 is

$$\overline{U}_2 = yU_{21} + (1-y)U_{22}. \quad (3)$$

Enterprises will use historical information to speculate others' strategies for green technology innovation. Based on the replication dynamics analysis approach in evolutionary game theory, the green technology innovation dynamic replication system can be described as follows:

$$\begin{aligned} F(x) = \frac{dx}{dt} &= x\left(U_{11} - \overline{U_1}\right) = x(1-x)\{y\{b_1Q_c - (b_1-k_1)Q_h + v(b_1'Q_c' - b_1Q_c) - v[(b_1'-k_1')Q_h' - (b_1-k_1)Q_h] \\ &\quad - b_1(Q_h - Q_n) - n_1Z\} + (b_1-k_1)Q_h + v[(b_1'-k_1')Q_h' - (b_1-k_1)Q_h] + S_1 - b_1Q_n + W_1\}, \end{aligned} \quad (4)$$

$$\begin{aligned} F(y) = \frac{dy}{dt} &= y\left(U_{21} - \overline{U_2}\right) = y(1-y)\{x\{b_2Q_c - (b_2-k_2)Q_h + v(b_2'Q_c' - b_2Q_c) - v[(b_2'-k_2')Q_h' - (b_2-k_2)Q_h] \\ &\quad - b_2(Q_h - Q_n) - n_2Z\} + (b_2-k_2)Q_h + v[(b_2'-k_2')Q_h' - (b_2-k_2)Q_h] + S_2 - b_2Q_n + W_2\}. \end{aligned} \quad (5)$$

According to Friedman's method of determining the dynamic stability of a system, we find the Jacobi matrix $J = [dF(x)/dx, dF(x)/dy; dF(y)/dx, dF(y)/dy]$ of the green technology innovation system as follows:

$$\begin{aligned} \frac{\mathrm{d}F(x)}{\mathrm{d}x} &= (1-2x)\left\{\begin{array}{c} y\{b_1Q_c - (b_1-k_1)Q_h + v(b_1'Q_c' - b_1Q_c) - v[(b_1'-k_1')Q_h' - (b_1-k_1)Q_h] - b_1(Q_h - Q_n) - n_1Z\} \\ +(b_1-k_1)Q_h + v[(b_1'-k_1')Q_h' - (b_1-k_1)Q_h] + S_1 - b_1Q_n + W_1 \end{array}\right\} \\ &= (1-2x)[y(R_{11} - R_{12} - R_{13} + R_{14}) + R_{12} - R_{14}], \end{aligned} \quad (6)$$

$$\begin{aligned} \frac{\mathrm{d}F(x)}{\mathrm{d}y} &= x(1-x)\{b_1Q_c - (b_1-k_1)Q_h + v(b_1'Q_c' - b_1Q_c) - v[(b_1'-k_1')Q_h' - (b_1-k_1)Q_h] - b_1(Q_h - Q_n) - n_1Z\} \\ &= x(1-x)(R_{11} - R_{12} - R_{13} + R_{14}), \end{aligned} \quad (7)$$

$$\begin{aligned} \frac{\mathrm{d}F(y)}{\mathrm{d}x} &= y(1-y)\{b_2Q_c - (b_2-k_2)Q_h + v(b_2'Q_c' - b_2Q_c) - v[(b_2'-k_2')Q_h' - (b_2-k_2)Q_h] - b_2(Q_h - Q_n) - n_2Z\} \\ &= y(1-y)(R_{21} - R_{23} - R_{22} + R_{24}), \end{aligned} \quad (8)$$

$$\begin{aligned} \frac{\mathrm{d}F(y)}{\mathrm{d}y} &= (1-2y)\left\{\begin{array}{c} x\{b_2Q_c - (b_2-k_2)Q_h + v(b_2'Q_c' - b_2Q_c) - v[(b_2'-k_2')Q_h' - (b_2-k_2)Q_h] - b_2(Q_h - Q_n) - n_2Z\} \\ +(b_2-k_2)Q_h + v[(b_2'-k_2')Q_h' - (b_2-k_2)Q_h] + S_2 - b_2Q_n + W_2 \end{array}\right\} \\ &= (1-2y)[x(R_{21} - R_{23} - R_{22} + R_{24}) + R_{23} - R_{24}]. \end{aligned} \quad (9)$$

The determinant and trace are $De\,t(J) = dF(x)/dx \cdot dF(y)/dy - dF(x)/dy \cdot dF(y)/dx$, $Tr(J) = dF(x)/dx + dF(y)/dy$. The evolutionary stable strategy (ESS) could be obtained when the stable points satisfied both $De\,t(J) > 0$ and $Tr(J) < 0$ [52].

Based on the evolutionary stability strategy definition of evolutionary game, let the equations $(4) = 0$, $(5) = 0$; five local equilibrium points are obtained from the evolutionary dynamic system, respectively, namely, $A(0,0)$, $B(1,0)$, $C(1,1)$, $D(0,1)$, and $E(x^*, y^*)$, where

Table 1: Parameter setting.

	Parameter definition	Range
Q_c	Total objective net benefit of GTI market	$Q_c > 0$
Q_n	Total objective net benefit of T market	$Q_n > 0$
Q_h	Total objective net benefit of M market	$Q_h > 0$
Q_c'	Total subjective net benefit of GTI market	$Q_c' > 0$
Q_h'	Total subjective net benefit of M market	$Q_h' > 0$
b_i	The objective portion coefficient of enterprise $i\,(i = 1, 2)$	$0 < b_i < 1$
b_i'	The subjective portion coefficient of enterprise $i\,(i = 1, 2)$	$0 < b_i' < 1$
k_i	The objective spill coefficient of enterprise $i\,(i = 1, 2)$	$0 < k_i < 1$
k_i'	The subjective spill coefficient of enterprise $i\,(i = 1, 2)$	$0 < k_i' < 1$
Z	The total green technology innovation spill benefit of M market	$1 < Z < Q_h$
n_i	The ability coefficient of enterprise i to absorb the spill benefit $i\,(i = 1, 2)$	$0 < n_i < 1$
S_i	Subsidy obtained by enterprise $i\,(i = 1, 2)$	$S_i > 0$
W_i	Punishment obtained by enterprise $i\,(i = 1, 2)$	$W_i > 0$
γ	Risk preference coefficient of enterprise	$\gamma > 0$
λ	Loss aversion coefficient of enterprise	$\lambda > 1$

Table 2: Evolutionary game payoff matrix from the perspective of prospect theory.

		Enterprise 2	
		I_1: y	I_2: $1-y$
Enterprise 1	I_1: x	(R_{11}, R_{21})	(R_{12}, R_{22})
	I_2: $1-x$	(R_{13}, R_{23})	(R_{14}, R_{24})

$R_{11} = b_1Q_c + v(b_1'Q_c' - b_1Q_c) + S_1$
$R_{21} = b_2Q_c + v(b_2'Q_c' - b_2Q_c) + S_2$
$R_{12} = (b_1 - k_1)Q_h + v[(b_1' - k_1')Q_h' - (b_1 - k_1)Q_h] + S_1$
$R_{22} = b_2Q_h + n_2Z - W_2$
$R_{13} = b_1Q_h + n_1Z - W_1$
$R_{23} = (b_2 - k_2)Q_h + v[(b_2' - k_2')Q_h' - (b_2 - k_2)Q_h] + S_2$
$R_{14} = b_1Q_n - W_1$
$R_{24} = b_2Q_n - W_2$

$$x^* = \frac{(-1)\{(b_2 - k_2)Q_h + v[(b_2' - k_2')Q_h' - (b_2 - k_2)Q_h] + S_2 - b_2Q_n + W_2\}}{b_2Q_c - (b_2 - k_2)Q_h + v(b_2'Q_c' - b_2Q_c) - v[(b_2' - k_2')Q_h' - (b_2 - k_2)Q_h] - b_2(Q_h - Q_n) - n_2Z}, \tag{10}$$

$$y^* = \frac{(-1)\{(b_1 - k_1)Q_h + v[(b_1' - k_1')Q_h' - (b_1 - k_1)Q_h] + S_1 - b_1Q_n + W_1\}}{b_1Q_c - (b_1 - k_1)Q_h + v(b_1'Q_c' - b_1Q_c) - v[(b_1' - k_1')Q_h' - (b_1 - k_1)Q_h] - b_1(Q_h - Q_n) - n_1Z}. \tag{11}$$

When $y = y^*$, there is $F(x) = 0$; enterprise 1 rejects green technology innovation at any time. When $y < y^*$, there are $F(x)'|_{x=1} > 0$ and $F(x)'|_{x=0} > 0$, so $x = 0$ is the equilibrium point of evolution, and enterprise 1 will also reject green technology innovation; when $y > y^*$, there are $F(x)'|_{x=1} \leq 0$ and $F(x)'|_{x=0} > 0$, so $x = 1$ is the equilibrium point of evolution, and enterprise 1 will finally adopt green technology innovation. Similarly, when $x = x^*$, there is $F(y) = 0$, enterprise 2 rejects green technology innovation with changing the time. When $x < x^*$, there are $F(x)'|_{y=1} > 0$ and $F(x)'|_{y=0} < 0$, so $y = 0$ is the equilibrium point of evolution, and enterprise 2 will also reject green technology innovation; when $x > x^*$, there are $F(x)'|_{y=1} < 0$ and $F(x)'|_{y=0} < 0$, so $y = 1$ is the equilibrium point of evolution, and enterprise 2 will adopt green technology innovation in the end.

4. Evolutionary Stabilization Strategies Analysis of Typical Scenarios

Due to the long industry life cycle, the game of green technology innovation among enterprises is a continuous process. On the basis of the actual background of current enterprise green technology innovation in China, the following four representative scenarios are selected for stability strategy analysis:

Scenario 1: when the prospect benefits from the adoption of green technology innovation for enterprise 1 and enterprise 2 on M market are lower than the prospect benefits from the rejection of green technology innovation for the corresponding enterprise on T market, the prospect benefits from the adoption of green technology innovation for enterprise 1 or enterprise 2 on GTI market are lower than the prospect benefits from the rejection of green technology innovation for corresponding enterprises on M market. That is, $R_{12} < R_{14}$, $R_{23} < R_{24}$, $R_{11} < R_{13}$, or $R_{11} < R_{13}$.

In this scenario, the government's incentives and punishment measures are all ineffective due to path dependence or the influence of traditional production methods. The stability strategy of the green technology innovation game between enterprise 1 and enterprise 2 is $A(0,0)$, both enterprise 1 and enterprise 2 reject green technology innovation. The evolutionary paths are presented in Figure 1(a).

Scenario 2: when the prospect benefits from the adoption of green technology innovation for enterprise 1 and enterprise 2 on GTI market are lower than the prospect benefits from the rejection of green technology innovation for the corresponding enterprises on M market, the prospect benefits from the adoption of green technology innovation for enterprise 1 and enterprise 2 on M market are greater than the prospect benefits from the rejection of green technology innovation for corresponding enterprise on T market. That is, $R_{11} < R_{13}$, $R_{21} < R_{22}$, $R_{12} > R_{14}$, and $R_{23} > R_{24}$; the stabilization strategy for enterprise is $B(1,0)$ or $D(0,1)$, and Figure 1(b) presents the evolutionary paths.

In this scenario, there is greater uncertainty in enterprises' decisions about green technology innovation. Enterprise i obtains government support and a greater market portion by adopting green technology innovations first. The market portion obtained may be reduced at a later stage when other enterprises have gradually adopted green technology innovation. Therefore, enterprises need to make their own decisions according to the behaviour of other enterprises, and they need to continuously pursue innovations to maintain their competitive advantage or give up the green technology to reduce the cost. The enterprise's behaviour of every stage may depend more on its social responsibility and the change of public green consumption habits. However, in this situation of equilibrium, the production methods of some enterprises that reject green technology innovation can cause greater pollution to the environment and can inhibit the incentive for other enterprises that are truly adopting green technology innovation. This equilibrium is detrimental to overall social development.

Scenario 3: when the prospect benefits from the adoption of green technology innovation for enterprise 1 and enterprise 2 on GTI market are greater than the prospect benefits from the rejection of green technology innovation for the corresponding enterprise on M market, the prospect benefits from the adoption of green technology innovation for enterprise 1 or enterprise 2 on M market are greater than the prospect benefits from the rejection of green technology innovation for corresponding enterprise on T market. That is, $R_{11} > R_{13}$, $R_{21} > R_{22}$, $R_{12} > R_{14}$, or $R_{23} > R_{24}$.

In this scenario, the market for green technology innovation is growing in size, enterprises believe that regardless of what behaviour other enterprises take, their own commitment to green technology innovation brings greater benefits. ESS of the green technology innovation game among enterprises will transfer to $C(1,1)$. The system's evolutionary paths are described in Figure 1(c). This is the most perfect situation, but the preconditions are stricter. Given the uncertainty about industry development environment, the existence of risks associated with green technology innovation cannot be ignored by enterprises.

Regarding the current stage in China, green technology innovation market development is gradually. Unless the government provides greater and more precise support, enterprises will not be able to take advantage of the benefits from large-scale green technology innovation. The majority of enterprises cannot also identify conceptually with the development perspectives of green technology innovation.

Scenario 4: similar to scenario 3, when the prospect benefits from the adoption of green technology innovation for enterprise 1 and enterprise 2 on GTI market are greater than the prospect benefits from the rejection of green technology innovation for the corresponding enterprises on M market, but the prospect benefits from the adoption of green technology innovation for enterprise 1 and enterprise 2 on M market are lower than the prospect benefits from the rejection of green technology innovation for corresponding enterprise on T market. That is, $R_{11} > R_{13}$, $R_{21} > R_{22}$, $R_{12} < R_{14}$, and $R_{23} < R_{24}$.

The enterprises in scenario 4 are closely connected and highly aggregated, so the interaction between different enterprises is very strong. However, even assuming that the market for green technology innovation is expanding and government support is increasing at this time, enterprises are uncertain about the future of green technology innovation. There is a general crisis of confidence problems and competition among enterprises, it is possible that no one is willing to risk being the first to break out of the corporate ecosystem and actively adopt green technology innovation. ESS of the

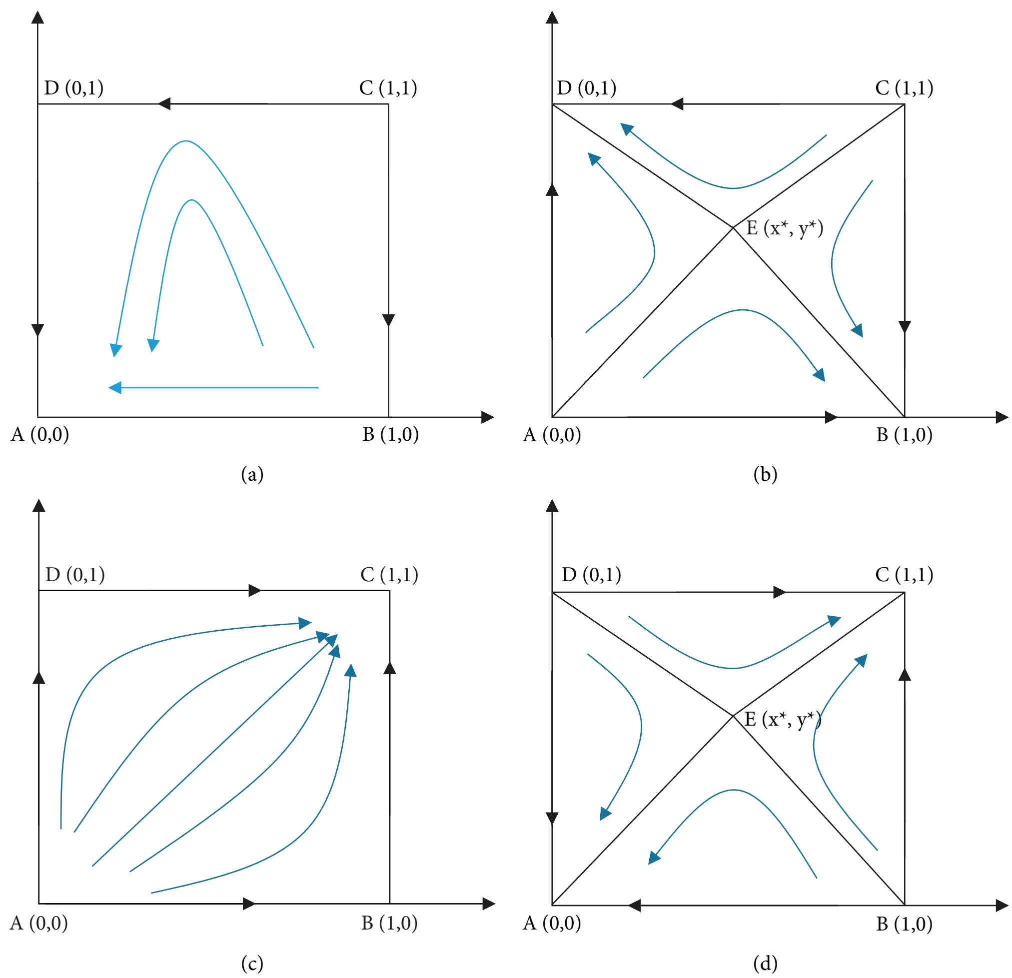

FIGURE 1: Phase diagram of the evolution of enterprises green innovation decisions. (a) Evolution path of $A(0,0)$. (b) Evolution path of $B(1,0)$ or $D(0,1)$. (c) Evolution path of $C(1,1)$. (d) Evolution path of $A(0,0)$ or $C(1,1)$.

green technology innovation game among enterprises will finally be $A(0,0)$ or $C(1,1)$. Figure 1(d) shows the evolutionary paths.

The $Det(J)$ and $Tr(J)$ judgement of each stability strategy are shown in Table 3.

5. Simulation Analysis Results

Some enterprises are already innovating green technology or adopting green production. For example, Tread Sneakers uses natural lighting and solar energy to reduce energy consumption, the use of electricity, and fresh water in the production of leather. Bosideng of China has standardized the safe, effective, and harmless disposal of its industrial solid waste by taking a stake in an environmental protection company. UNIQLO has launched a clothing recycling program that collects unwanted clothing from customers and then processes and transforms them. Therefore, the current state of green technology innovation in the market is more similar to the M market. But many enterprises still use traditional production methods that are more polluting to the environment. This paper prefers all enterprises to adopt green technology innovation, which is $C(1,1)$ state. However, the conditions of scenario 3 are too harsh, and scenario 4 is more suitable for discussion of $C(1,1)$ or $A(0,0)$ states in the simulation. Therefore, scenario 4 is selected as the environment for numerical simulation.

In Figure1(d), if we hope that the equilibrium state between the enterprise tends to $C(1,1)$, the area of S_{ABED} should become smaller. According to $S_{ABED} = x^* \cdot y^* \, (0 < x^* < 1, 0 < y^* < 1)$ and equations (10)and (11), we can find that spill benefit Z, ability coefficient n_i to absorb spill benefit, government support S_i, and government punishments W_i have relatively clear impacts on the evolution of green technology innovation system.

However, the total subjective net benefits Q_c' of GTI market, the total subjective net benefits Q_h' of M market, the subjective portion coefficient b_i' , the subjective spill coefficient k_i' , risk preference coefficient γ, loss aversion coefficient λ, and the reference point have uncertainty effects on

Table 3: Stability analysis of equilibrium points for four types of scenarios.

Equilibrium points	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	$De\ t(J)$	$Tr(J)$	Stability	$De\ t(J)$	$Tr(J)$	Stability	$De\ t(J)$	$Tr(J)$	Stability	$De\ t(J)$	$Tr(J)$	Stability
$A(0,0)$	+	−	ESS	+	+	Unstable	+	+	Unstable	+	−	ESS
$B(1,0)$	−	×	Saddle	+	−	ESS	−	×	Saddle	+	+	Unstable
$C(1,1)$	+	×	Saddle	+	−	ESS	−	×	Saddle	+	+	Unstable
$D(0,1)$	+	+	Unstable	+	+	Unstable	+	−	ESS	+	−	ESS
$E(x^*,y^*)$	−	0	Saddle	−	0	Saddle	−	0	Saddle	−	0	Saddle

Note. × indicates that $Tr(J)$ cannot be determined.

Table 4: Parameters' impact on green technology innovation evolution system.

Parameter	Q_c'	Q_h'	b_i'	k_i'	Z	n_i	S_i	W_i	γ	λ
	−	−	−	−	↓	↓	↓	↓	−	−
$S_{ABE\ D}$	−	−	−	−	↓	↓	↑	↑	−	−

Note. − indicates that this parameter has uncertainty effects on the strategy choice of green technology innovation for each enterprise.

the strategy choice of green technology innovation for each enterprise. Impacts of each parameter that can change have been shown in Table 4.

Therefore, this paper uses Hu and Rao's [53] analytical approach and MATLAB software to simulate the scenario 4 environment and the uncertain influence of factors. Referring to Chen et al.'s model [22], we make a distinction among benefits from the various markets. We assume that the initial value of the total objective net benefit of GTI market $Q_c = 95$ is greater than the total objective net benefit of M market $Q_h = 85$, which is also greater than the total objective net benefit of the T market $Q_n = 80$. And the total spill benefit $Z = 15$ is smaller than the total net benefits Q_h. Enterprise 1 is assumed as the dominant enterprise, which can occupy a larger market portion and government support than enterprise 2, so there are $b_1 = 0.23$, $b_2 = 0.21$; $S_1 = 2.5$, $S_2 = 2$. Besides, dominant enterprise 1 is more visible to consumers and competitors in the marketplace, the green innovations they develop are more likely to spread, which create opportunities for other competitors to share the spill benefits, so we assume that $k_1 = 0.1$, $k_2 = 0.08$; $n_1 = 0.15$, $n_2 = 0.1$. The government has introduced clear punishment for various types of pollution, and the final penalties will be determined by the severity of the pollution and the scale of production of the enterprise within the specified penalty amount, so we can assume that $W_1 = 1.8$, $W_2 = 1.6$. This is also consistent with the analysis of heterogeneous enterprises of literature [34, 36, 54].

According to the model assumptions of this paper, the initial values of the enterprises' subjective parameters are set as follows: $Q_c' = 85$, $Q_h' = 75$; $b_1' = 0.25$, $b_2' = 0.24$; and $k_1' = 0.12, k_2' = 0.1$. Based on Tversky's assumptions [55], the risk preference coefficient $\gamma = 0.88$ and loss aversion coefficient $\lambda = 2.25$.

In the process of numerical simulation, only one parameter is adjusted at a time and the remaining parameters are kept constant. The initial point (x_0, y_0) of the system evolution is set to $(0.5, 0.5)$.

5.1. Differences in the Impact of Whether Prospect Theory is Used on Enterprises' Green Technology Innovation Behaviour.

According to Figure 2, when Q_c is set to 95, the ESS of green technology innovation is $C(1,1)$; enterprise 1 and enterprise 2 gradually choose to adopt green technology innovation. As Q_c is set separately to 100, 105, and 110, the direction of evolution does not change.

In Figure 3, when Q_c is set to 95, 100, and 105, the enterprises still reject green technology innovation and trend to $A(0,0)$; only if Q_c is up to 110, the ESS of green technology innovation will evolve to $C(1,1)$. The results of evolution considering prospect theory are a little different from the situation without considering prospects. It shows that the decision makers who have their own judgement of the gains, losses, and risk in the framework of prospect theory will be more cautious about the green technology innovation decision.

5.2. Prospect Editing Stage

(1) *The Impact of Reference Points on the Evolutionary Game Analysis of Green Technology Innovation Behaviour*

To explore the influence of reference points individually on green technology innovation, a reference point adjustment factor e is introduced into system so that the reference points become eb_iQ_c and $e(b_i - k_i)Q_h$. We set the reference point adjustment factor $e = (1, 0.99, 0.98, 0.97)$. When $e = (1, 0.99)$, the value functions $v(b_i'Q_c' - eb_iQ_c)$ and $v((b_i' - k_i')Q_h' - e(b_i - k_i)Q_h)$ are still losses or small benefit, so enterprise 1 and enterprise 2 will reject green technology innovation from the results of Figures 4 and 5. When $e = (0.98, 0.97)$, enterprises' reference point is more lower, $v(b_i'Q_c' - eb_iQ_c)$ and $v((b_i' - k_i')Q_h' - e(b_i - k_i)Q_h)$ become larger and change to gain, and enterprises will eventually evolve toward $C(1,1)$.

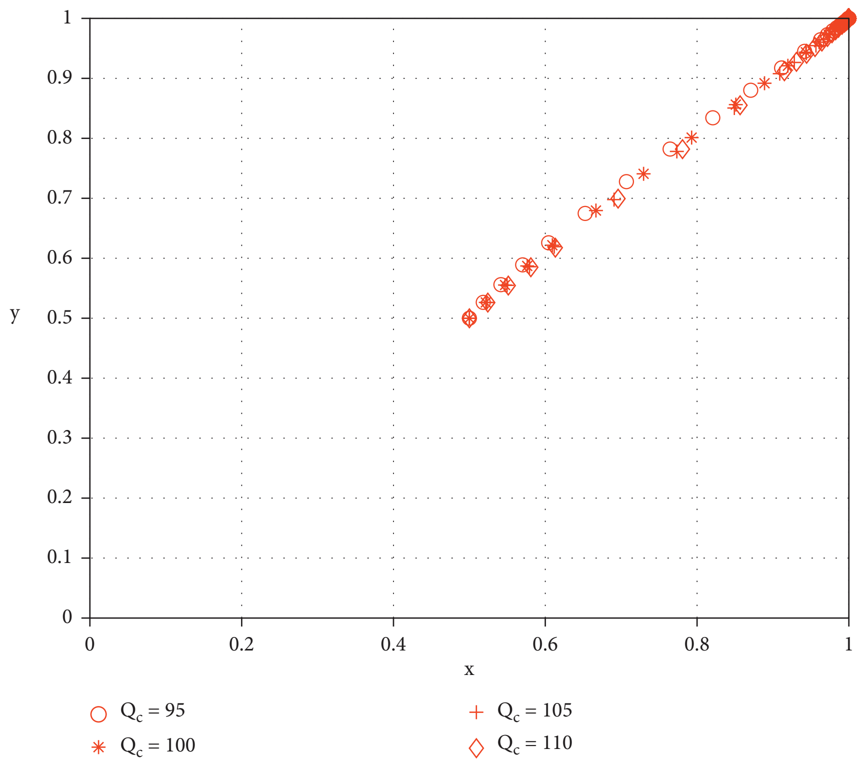

Figure 2: Evolution of enterprises without considering the prospects.

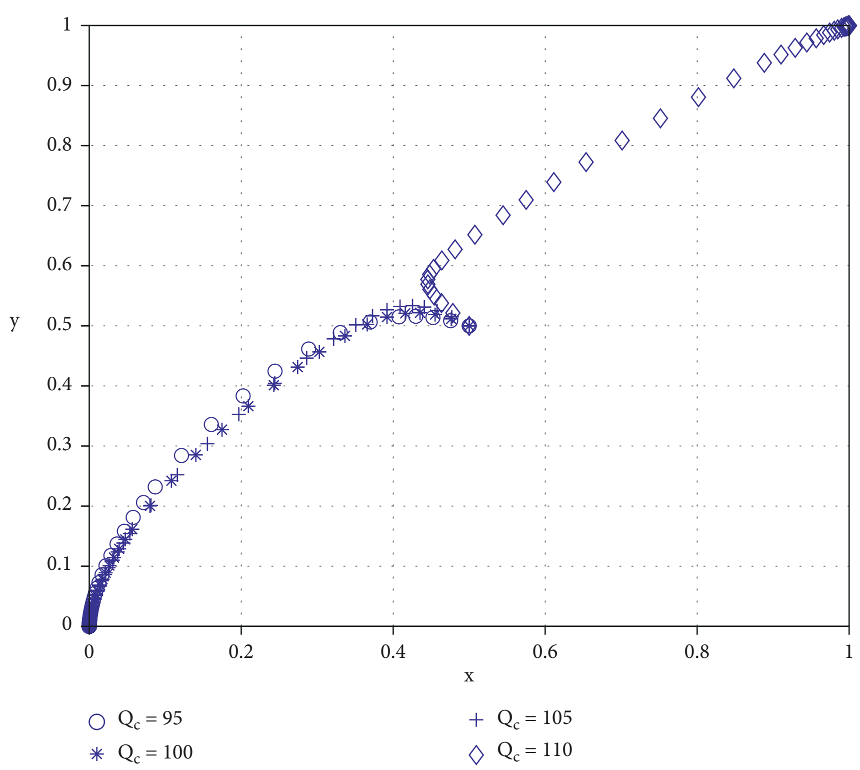

Figure 3: Evolution of enterprises with considering the prospects.

Enterprises have the habit of reference dependence when making decisions and do not just make direct judgments based on the magnitude of objective values. The smaller the reference point set by the enterprises, the greater the enterprises' sense of entitlement for the same benefits, thus motivating

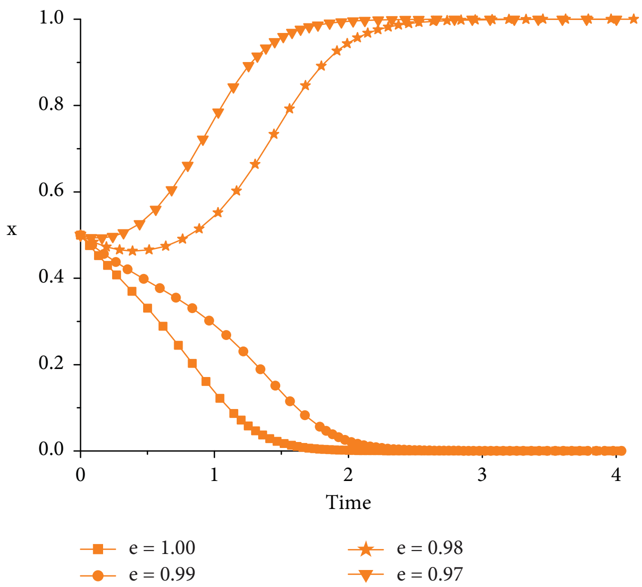

Figure 4: Impact of reference points on enterprise 1.

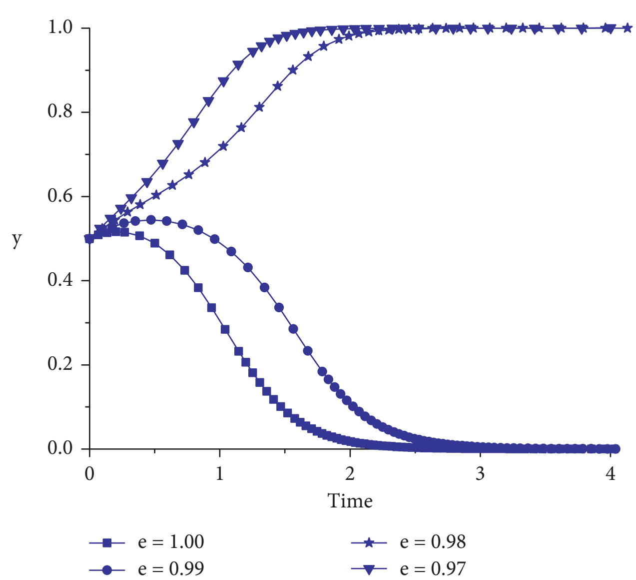

Figure 5: Impact of reference points on enterprise 2.

the enterprises to adopt green technology innovation. Besides, enterprise 2 is slightly more sensitive to the change of reference point by comparing Figures 4 and 5. This means that lower reference points due to other external factors, including government policies, will be more favourable to inferior enterprises to adopt green technology innovation behaviours.

(2) *The Impact of Total Subjective Net Benefits on the Evolutionary Game Analysis of Green Technology Innovation Behaviour*

Changing the total subjective net benefits, $Q_c' = (85, 90, 95, 100)$, and the evolutions of the decision path of enterprise 1 and enterprise 2 are shown in Figures 6 and 7. When we first set $Q_c' = 85$,

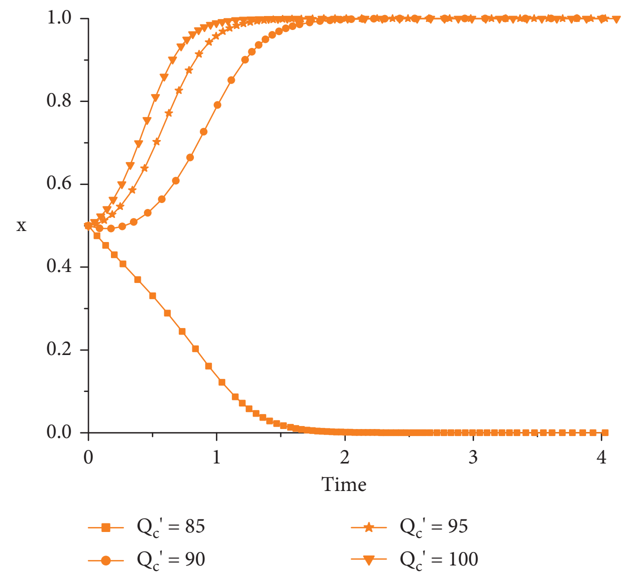

Figure 6: Impact of total subjective net benefits Q_c' on enterprise 1.

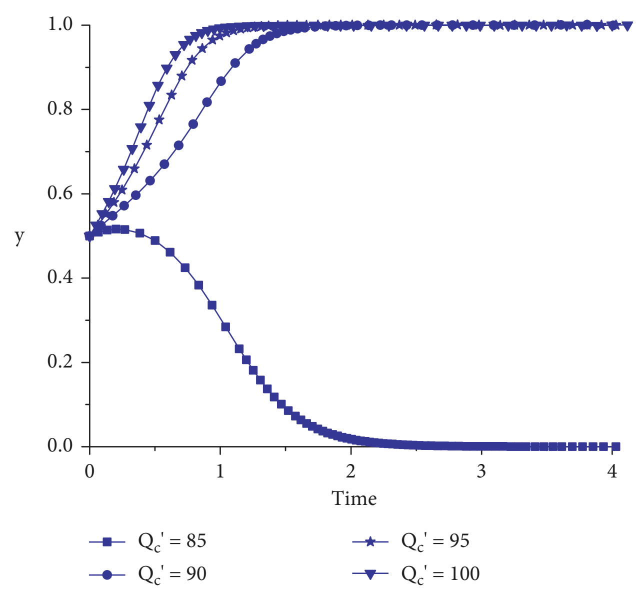

Figure 7: Impact of total subjective net benefits Q_c' on enterprise 2.

the benefits of enterprises in different situations are as follows: $R_{11} > R_{13} > R_{14} > R_{12}$, $R_{21} > R_{22} > R_{24} > R_{23}$; it shows that enterprises will gain the biggest benefit if they are fully rational and adopt green technology innovation. However, it can be seen that all enterprises with limited rationality actually reject green technology innovation in Figures 6 and 7. Enterprises feel that the high risks of green technology innovation strategies at this time are not offset by the benefits gained, and they prefer the deterministic traditional benefits to avoid risks. As Q_c' increases, the market of green technology innovation is growing. When Q_c' is set to 90, enterprises

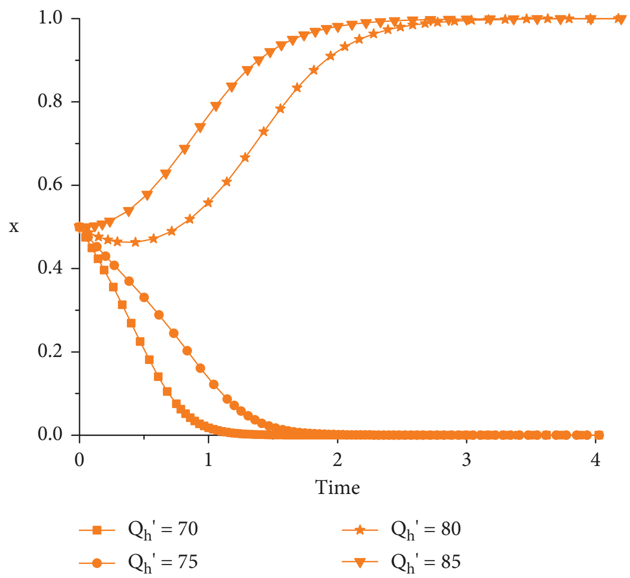

FIGURE 8: Impact of total subjective net benefits Q_h' on enterprise 1.

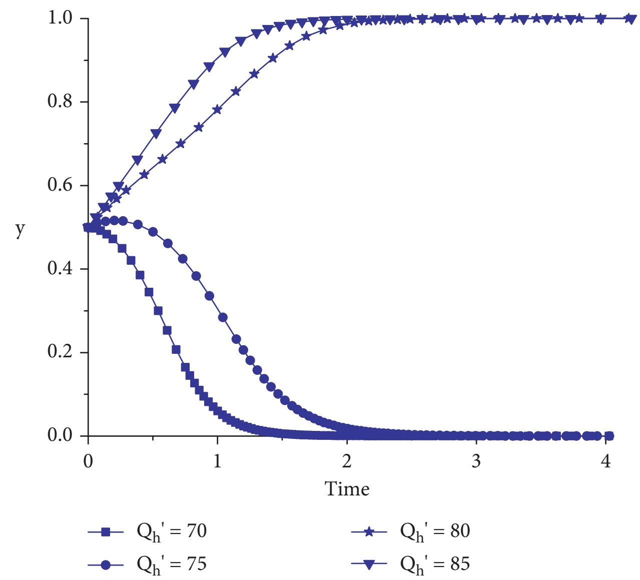

FIGURE 9: Impact of total subjective net benefits Q_h' on enterprise 2.

shift their attitude and both of them will evolve to 1 under the attraction of market expansion trend.

The subjective total net benefits Q_h' of M market is set as $(70, 75, 80, 85)$. And both enterprise 1 and enterprise 2 will evolve to 1 when $Q_h' = (80, 85)$, as it can be shown in Figures 8 and 9. There is a similar positive impact of Q_c' and Q_h' on the evolutionary direction of green technology innovation in enterprises, but there are differences in the degree of influence.

(3) *The Impact of Subjective Portion Coefficients on the Evolutionary Game Analysis of Green Technology Innovation Behaviours*

When enterprises have different scales of green technology investment and product marketing based on their own preferences and perceptions, they will change their judgments about the subjective portion coefficient b_i'. The subjective portion coefficients are set to $b_1' = (0.25, 0.26, 0.27, 0.28)$, $b_2' = (0.23, 0.24, 0.25, 0.26)$, the evolution results are shown in Figures 10 and 11. When b_1' is up to 0.26 and b_2' is up to 0.25, both enterprise 1 and enterprise 2 will approach 1.

Comparing the behaviour of enterprise 1 and enterprise 2, enterprise 1 shows a stronger preference for green innovation with the b_i' increase in the same degree, and enterprise 1 evolves to 1 faster than enterprise 2. These show that dominant enterprises are paying more attention to the market portion when they make decisions about adopting green technology innovation.

(4) *The Impact of Subjective Spill Coefficients on the Evolutionary Game Analysis of Green Technology Innovation Behaviours*

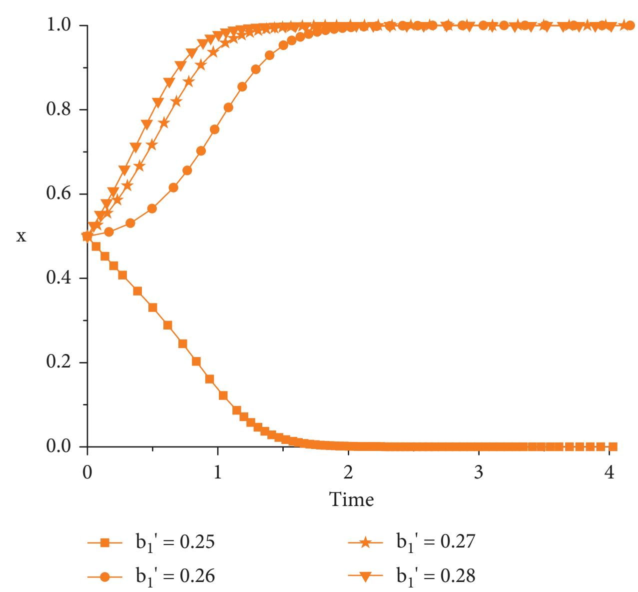

FIGURE 10: Impact of subjective portion coefficient b_1' on enterprise 1.

The enterprises adopting green technology innovation have the risk of spill losses due to the negligence of intellectual property protection. To observe the influence of the subjective spill coefficient k_1' for enterprises behaviour, k_i' is set to $(0.13, 0.12, 0.11, 0.1)$; k_2' is set to $(0.11, 0.10, 0.09, 0.08)$. The results are shown in Figures 12 and 13. When $k_1' = (0.13, 0.12, 0.11)$, $k_2' = (0.11, 0.10)$, the spill losses caused by enterprises adopting green technology innovation are much larger compared to the government punishment of rejecting green

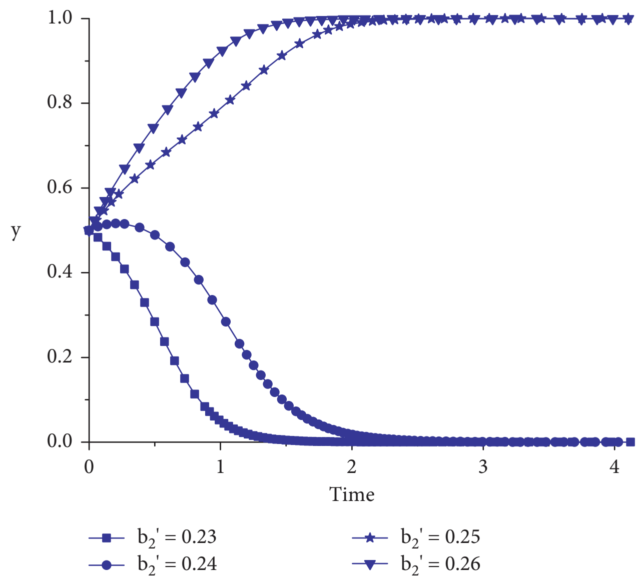

Figure 11: Impact of subjective portion coefficient b_2' on enterprise 2.

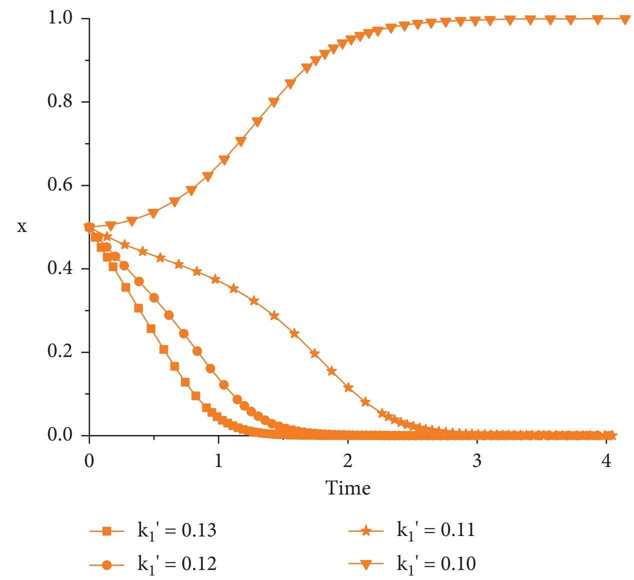

Figure 12: Impact of subjective spill coefficient k_1' on enterprise 1.

technology innovation. Loss-averse enterprise decision makers usually choose to reject green technology innovation to seek a lower amount of loss; that is, they will evolve to the direction of 0. Only when $k_1' = 0.1$, the stable strategy of enterprise 1 is adopting green innovation. The same trend as enterprise 2 is shown in Figure 13; as $k_2' = (0.09, 0.08)$, enterprise 2 will gradually evolve to 1. At this point, it may be that the reduction of spill losses makes the amount of benefits of green technology innovation and the amount of innovation subsidies more tempting to enterprises, who turn to seek higher benefits at the risk of losses.

However, the speed of enterprise 2 evolving to 1 is faster than enterprise 1 when the subjective spill coefficient k_i' changes at the same relative value reference to the corresponding initial values. It indicates that decreasing the subjective spill losses will be more effective for inferior enterprises.

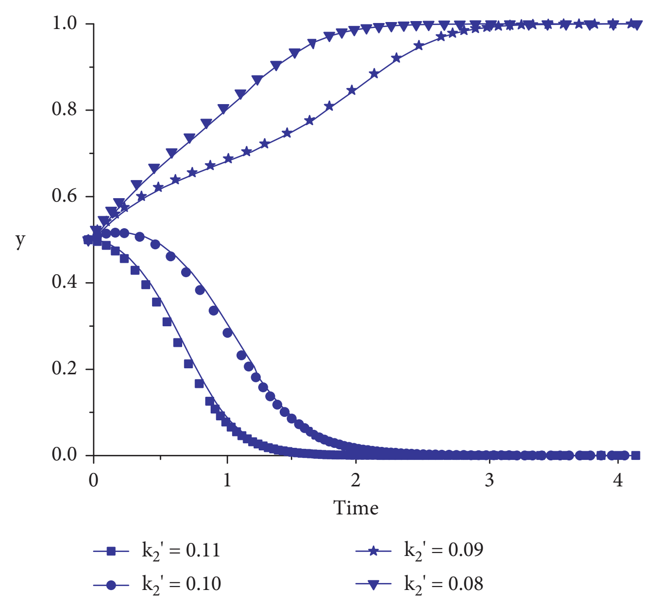

Figure 13: Impact of subjective spill coefficient k_2' on enterprise 2.

5.3. Prospect Evaluation Stage

(1) *The Impact of Risk Preference Coefficient on the Evolutionary Game Analysis of Green Technology Innovation Behaviour*

The risk preference coefficient γ is set into $0.4, 0.6, 0.88, 1.00$. The enterprises' green technology innovation behaviours are shown in Figures 14 and 15. As the policy and market environment of green technology innovation is more suitable for enterprises, and decision makers will be favourable for taking the risk, and their risk preference coefficient will increase. Only when $\gamma = 1$, both enterprise 1 and enterprise 2 finally trend to 1 and adopt green technology innovation.

Comparing the evolution slope in Figures 14 and 15, we find that enterprise 2 is more risk-seeking than enterprise 1 at the same value of γ. This is probably because enterprise 1 in dominant position gets more benefit and wants to gain an advantage with a more stable probability, so it shows a slower transformation. However, faced with stricter punishment from the government or unsatisfied benefits in the market, enterprise 2 in inferior position will be more risk-seeking, so its speed of evolving to 1 is faster.

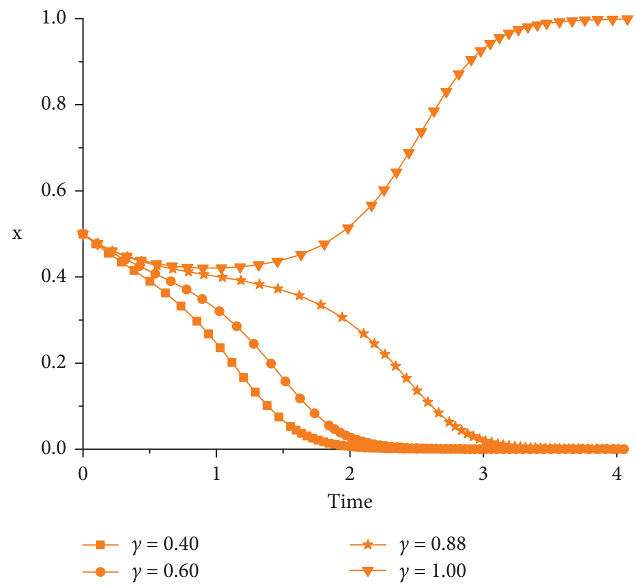

Figure 14: Impact of risk preference coefficient on enterprise 1.

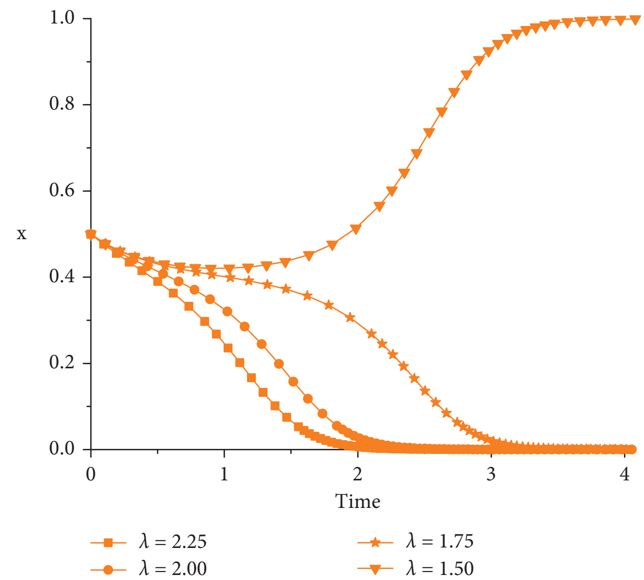

Figure 16: Impact of loss aversion coefficient on enterprise 1.

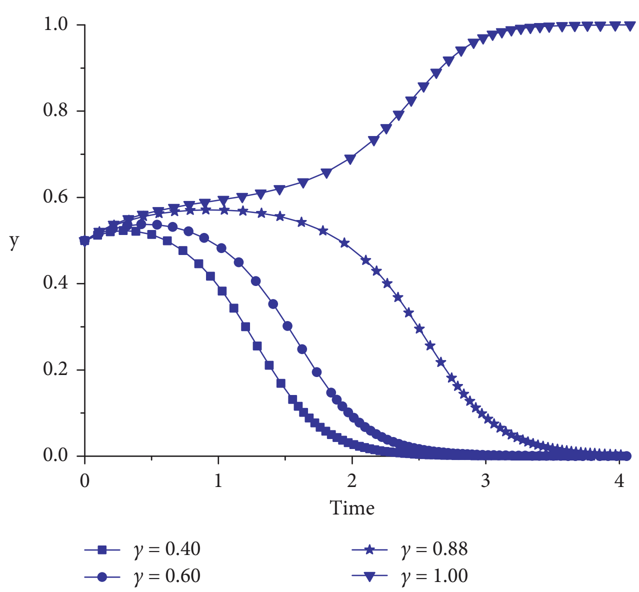

Figure 15: Impact of risk preference coefficient on enterprise 2.

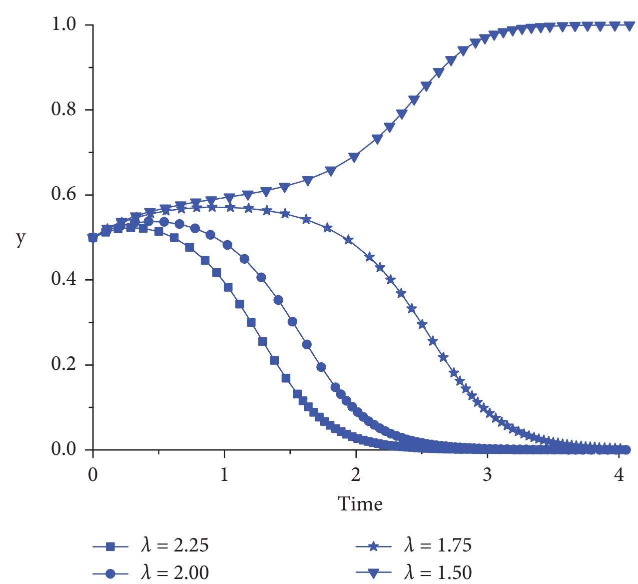

Figure 17: Impact of loss aversion coefficient on enterprise 2.

(2) *The Impact of Loss Aversion Coefficient on the Evolutionary Game Analysis of Green Technology Innovation Behaviour*

The loss aversion coefficient λ is set to $(2.25, 2, 1.75, 1.5)$, and the behaviours' evolutions of enterprise 1 and enterprise 2 are respectively shown in Figures 16 and 17. As $\lambda = 1.5$ according to Figures 16 and 17, both enterprise 1 and enterprise 2 are evolving to 1. It seems that the lower the loss aversion coefficient λ is, enterprises will adopt green technology in a bigger possibility. Although enterprise 2 is more sensitive to the change of λ, the evolution direction of enterprise 1 and enterprise 2 is very similar.

6. Discussion

This study takes enterprises as subjects and simulates the effects of parameter changes on the enterprises' behaviour in green technology innovation based on prospect theory and game theory framework. Many enterprises around the world still hesitate to develop or adopt green innovations due to the associated high R&D spending and production costs [28]. Even with government subsidies and punishments, enterprises still feel they are not benefiting from the mixed market for green technology innovation, but rather are enduring the high cost [56] and the spill risks [22], especially in manufacturing industry.

Compared with the traditional evolutionary game framework, our study finds that the behaviour of enterprise choosing green technology innovation under the prospect theory framework shows a more conservative attitude. This is probably because the study assumes that the decision makers are limited rationality with independent subjective judgement and loss aversion, so uncertainty and risk will significantly discourage decision makers' judgement on green technology innovation. The importance of subjective perceptions has been addressed in some earlier works [50].

In the prospect editing stage, when the reference point becomes smaller, enterprises will adopt green technology innovation. This is because the gap between the enterprise subjective gain and reference point is increasing according to the prospect theory. Green technology innovation behaviour can be promoted when the subjective reference point is slightly lower than the objective benefits of the enterprise [39], so the goal of promoting green technology innovation behaviour through lowering the reference point can be achieved by practical measures, such as increasing enterprise social responsibility and government subsidies.

When we assume that the total benefit of green industry is a little higher than that of traditional industry by adjusting the subjective total net benefit value in the GTI market, enterprises still reject green technology innovation. Unlike Ma et al.'s conclusion that enterprises always determine the behaviour through a trade-off on absolute product sales' benefits and innovation costs [9], decision makers will be influenced by their perception of market size and industry maturity [54]. And the benefits of green innovation are risky and may not be very attractive at the early stage of development of the industry. Therefore, enterprises prefer the deterministic traditional benefits to avoid risks. As the green technology innovation industry gradually develops, the stability and positive trends in the industry will encourage enterprises to adopt green technology innovation. Similar to the total net benefit value in GTI market, the increase of subjective portion coefficient has a positive impact on promoting enterprises green technology innovation. An increase in the subjective portion coefficient indicates that enterprises remain optimistic about the green technology market, and the optimistic one will have a higher incentive to innovate green technology [30]. It is also in line with Han et al.'s research that the optimal profitability of building material manufacturers and retailers is increasing as consumers' green preferences increase [31]. The subjective spill coefficient as a loss has a reverse disincentive effect on enterprises' green technology innovation behaviour. Enterprises cannot accept that part of the output is shared by other social agents without compensation. However, it is difficult to control the size of spill losses by relying solely on the enterprise's own strength. Government subsidies and regulation of illegitimate behaviour will play an important role in reducing the spill losses at that time [57].

In the prospect evaluation stage, enterprise will adopt green technology innovation when the risk preference is increasing and the loss aversion of decision maker is decreasing. Risk preference and loss aversion are not only related to individual preferences [58], but also to the environment and information to which an individual is exposed. Therefore, it is important to guide decision makers to a proper understanding of risk. And it is necessary for government to enhance information transparency [33] and improve enterprises' information gathering capabilities.

In addition, our study finds that subjective perceptions also vary between enterprises; different sizes and market shares of enterprises also treat the risks differently. Unless the dominant enterprise has confidence in its market share of green technology, it will prefer traditional production methods because it has a larger market share under the traditional market. Samuelson and Zeckhauser also argue that players have a bias to maintain a favourable status quo [59]. Unlike Sun and Zhang's [36] study, which argues that government penalties have an equal impact on the green behaviour of advantaged and disadvantaged enterprises without considering decision makers' risk preference and loss aversion, we find that a disadvantaged enterprise exhibits a more risk-taking spirit when they face risk and loss. This may be because they cannot stand out in traditional markets and have to look for new areas to open up markets. In reality, small- and medium-sized enterprises develop many green products, while large enterprises are better able to commercialise green product innovations [8]. This is also consistent with previous research findings that large enterprises tend to be less ambitious in their environmental objectives, and they have a wider influence due to their established market advantages.

Though evolutionary game analysis is an appropriate method to analyse enterprise green technology innovation, the green technology innovation system is a complicated and dynamic system. It can be disturbed by many factors, both internal and external. Various factors influence the green technology evolution system, and the influence of each factor on the costs and benefits to different enterprises is quite different. The environment for green technology innovation is also different for every industry and can involve many other stakeholders. The probability and proportion of enterprises adopting in green technology innovation also vary in each industry. Therefore, a change in a particular influencing factor or in an enterprise's strategy will cause the system to fluctuate and then reach a new equilibrium state. Our study gives some more general scenarios and patterns, and we also hope to attract the attention of enterprise decision makers and policy makers.

7. Conclusions, Policy Implications, and Future Work

7.1. Conclusions. In this study, the evolutionary games and prospect theory are used to study the green technology innovation behaviour of enterprises. And we demonstrate the stable equilibrium states and the impact of key factors through scenario analysis and numerical simulation. The main findings of this paper are as follows:

(1) When enterprises think that the benefits of T market are the greatest, they will trend to $A(0,0)$ as scenario 1. And if the prospect benefits for enterprise 1 and enterprise 2 on GTI market are the greatest, enterprises equilibrium point is $C(1,1)$ as scenario 3. The benefit of adopting green technology innovation is always greater than that of rejecting green technology innovation, but it is unclear whether the prospective benefits are greater under the GTI market or under the M market, enterprises equilibrium point is $B(1,0)$ or $D(0,1)$ as scenario 2. The system will tend to $A(0,0)$ or $C(1,1)$ as scenario 4 when the sum of benefits is the smallest for all enterprises in the M market; however, it is not possible to determine whether the sum of benefit is greater in the GIT market or in the T market.

(2) In the case of scenario 4, enterprises in the framework of prospect theory adopt a more cautious and conservative attitude towards green technology innovation behaviour compared to the traditional models. In the prospect editing stage, decision makers facing the benefits of green technology innovation are usually loss-averse and choose traditional production strategies with stable benefits. Influencing decision makers' perceptions by adjusting other key factors, such as expanding market gains, lowering reference points, and reducing the spill of green technology innovation, will facilitate enterprises' green technology innovation to a greater extent. Based on the heterogeneity of enterprises, we also find that the inferior enterprise is more sensitive to the change of reference point and subjective spill coefficient. Increase of subjective net benefits and subjective portion coefficient is easier to motivate dominant enterprises to adopt green innovation decisions.

(3) In the prospect evaluation stage, enterprises have subjective risk preference and loss aversion. Higher risk preference and lower loss aversion will increase the initiative of enterprise green technology innovation and promote them to evolve to $C(1,1)$.

7.2. Policy Implications. Based on the analysis results of this study, it is necessary to formulate a combined and differentiated policy system. Government should also consider subjective factors, such as their risk preference and loss aversion. Government support policies can be adjusted according to the different stages and different levels of maturity of green innovation in the industry. For example, more policies' instruments, such as environmental regulation, transfer payment, and tax credit, can be implemented to compensate for the innovation cost in the developing market. In the mature market, government should improve green technology financial instruments and tax tools [30] to accelerate the market-oriented application and use market power to promote the innovative behaviour of enterprises' green technology. The development of photovoltaic industry and new energy vehicle in China is a typical example.

The government should standardize the green technology innovation acquisition system and guide enterprises to establish reference points. It is also important to raise consumer awareness of green products and cultivate their green consumption habits to expand the market need and increase enterprises' subjective benefit portion in GTI market. Another way to improve the enterprises social responsibility is preaching and education.

A stable and predictable policy environment can reduce the subjective risk of enterprises. Government can reduce the spill loss of enterprises by cracking down on "greenwashing" and other unfair competition tactics. The government needs to issue relevant laws and regulations to regulate intellectual property licensing and trading channels and promotes the legal and compliant dissemination. Take full advantage of the role of consumers, nongovernmental organizations (NGOs), and certification bodies in the supervision of the green product market.

Policy makers must create the proper external conditions for enterprises to develop new green technology while simultaneously improving their financial performance. If enterprises are conscious that society values their green outputs, they will attempt to improve their effort of green technology innovation. Besides, if the green innovation technology can bring economic performance to enterprises, it will attract others through continuous learning and adjustment development strategy. The entire industry will progressively evolve from traditional innovation to green technology innovation.

The government also should enhance the strength of green technology innovation in dominant enterprises. Small- and medium-sized enterprises can control the cost of innovation and increase their risk-taking capacity. Support of enterprise management commitment is essential for the development and implementation of green technology innovation. Managers also can focus on identifying opportunities and integrating socially and green responsible policies into the overall strategy.

7.3. Future Work. We explore the green technology innovation stable equilibrium states of competing enterprises under uncertainty environment and simulate the key factors in scenario 4 to observe the impact on the evolution of enterprises green technology innovation. The above discussion provides some valuable insights on how to promote enterprises to adopt green technology innovation. However, this paper also has its limitations; we can discuss more initial point (x_0, y_0) in different situations and set simulation parameters based on a more suitable actual case in the future work. We also could hypothesize that uncertainty arises from specific scenarios to better help enterprise decision makers obtain the benefits of green technology innovation. Finally, this paper focuses more on the issue of whether competing enterprises in the same industry enter the market of green technology innovation under the influence of subjective psychological factors. Analysis can continue on how the government creates market environment to help green technology innovation enterprises develop and grow throughout cooperation and alliance in the future.

Data Availability

The data used to support the findings of the study can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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