

Article

Research on Responsible Innovation Mechanism Based on Prospect Theory

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Abstract: In 2020, the new crown pneumonia COVID-19 epidemic swept the world, and it still has an impact on the production and lifestyle of various countries. Guiding enterprises to implement responsible innovation can enable enterprises to shoulder social responsibilities while innovating, resist the impact of the epidemic, accelerate countries to get out of the haze of the epidemic, and promote high-quality economic development. In this paper, three typical subjects of government, enterprise, and consumer are selected to construct an evolutionary game model, and prospect theory is introduced to explore the strategic choices and influencing factors of the three parties. Through the numerical simulation of MATLAB software, the following conclusions are obtained: in the early stage of policy implementation, the enthusiasm of enterprises to implement responsible innovation is not high; with the implementation of policies and the continuation of time, the enthusiasm of enterprises gradually increases; and the supervision role of the government and consumers gradually decreases. Appropriate government incentives and disincentives will promote enterprises and consumers to participate in responsible innovation. This paper explores the game process of government, enterprises, and consumers from a dynamic perspective, explores the decision-making process of all parties under the prospect theory, reveals the implementation process of responsible innovation and the factors affecting responsible innovation, and provides a theoretical reference for the implementation of responsible innovation model.

Keywords: evolutionary game; prospect theory; responsible innovation; simulation



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1. Introduction

Nowadays, in this era of highly developed science and technology, everyone is surrounded by intelligent electronic devices, and high-tech communication technology can be seen everywhere. With the progress of science and technology, the demand for innovation in science and technology society is becoming more and more intense. However, with the deepening of research and communication on innovation, experts and scholars have gradually found some negative effects of innovation. The development and utilization of nuclear energy has also brought risks to society, the research on genes has led to ethical crises, the development of communication technology has led to the leakage of users' privacy, environmental pollution and ecological damage has been brought by industrialization. The social impact brought by new policies, and a series of social security and ethical issues brought by innovation, have led to the reflection of all sectors of society on social responsibility. There is a general consensus that responsible forms of innovation should be adapted to the needs of society [1]. Therefore, the idea of social responsibility arose from the American public, which demanded that enterprises assume certain social responsibilities to balance their excessive power. After entering the 21st century, some European scholars began to study and discuss the method of implementing responsible innovation, trying to combine innovation with the concept of responsibility, and explore a way to deal with such crises and major hidden dangers, so as to reduce the impact on society.

Von Schomberg has defined responsible innovation as a transparent and interactive process, in which social actors and innovators are responsible for each other, to achieve acceptability, sustainability, and social satisfaction of the innovation process and market products [2]. The characteristic of responsible innovation can be basically summarized as the following four points: First, it is forward-looking. Based on the present and focusing on the future, and guiding innovation to develop in the direction of social values. Second, it requires sharing collective interests and responsibilities. Organizational collective responsibility and innovation trajectories require shared responsibility among stakeholders. Third, it requires social reflexivity. Responsible innovation reflects the state of the current social environment. Forth, it requires continuous evolution and updating. Responsible innovation will make adaptive changes according to the development of society and institutional changes. With the popularity of the term “responsible innovation,” it has been widely used in many aspects of technological innovation, such as sensitive technologies. Responsible innovation is also used in the reflection of traditional innovation and the debate on the negative effects. However, many obstacles need to be overcome to rise from the theoretical height to the practical height. Especially, responsible innovation is related to technological innovation in most cases. Ordinary people have many cognitive obstacles to participate in responsible innovation, and it is very difficult to promote responsible innovation [3]. Since 2020, the COVID-19 epidemic has dealt a serious blow to the economies of various countries; many enterprises have been forced to close down, and many people have also been forced to lose their jobs. Guiding enterprises to innovate while taking social responsibility can fight the impact of the epidemic [4]. For example, mask manufacturers and pharmaceutical companies can reduce the price of masks and drugs to allow more people infected with COVID-19 to be cured, return to normal work and life faster, and promote economic recovery. The difference between responsible innovation and the traditional technological innovation model is that it tries to combine innovation with the concept of responsibility; explores a path for enterprise organizations and society to undertake a series of social responsibilities, such as protecting the ecological environment and ensuring the security of the country and the people while innovating; and is committed to reducing the negative impact on society [5]. Therefore, the implementation of responsible innovation is in line with the current international development environment, and the search for high-quality economic development in the midst of the epidemic is also in urgent need of responsible innovation.

2. Literature Review

In recent years, with the increasing attention of responsible innovation, scholars have carried out a variety of research on responsible innovation and carried out various aspects thereof. Deppeler Joanne and Aikens Kathleen argued that responsible innovation was related to public participation in learning environments for responsible innovation, and constructed a framework analysis to illustrate how to build a learning environment for responsible innovation [6]. John Bessant analyzed the relationship between responsible innovation and citizen health [7]. Burget Mirjam defined the concept of responsible innovation [8]. Van den Hoven believed that responsible innovation was an innovative activity, which guided the extension and coordination of elements of the conceptual world, physical world, and institutional world in the innovation process, so as to expand the cognition and action choices of innovation subjects [9]. Spruit believed that responsible innovation was a process of collective collaboration and inclusion, which shifted the evaluation of the desired goals of the innovation process to the evaluation of the quality of the innovation process [10]. Scholars' theoretical research on responsible innovation mainly focus on the definition of concepts, the construction of frameworks, and the compatibility of responsible innovation with the current society. Since responsible innovation has only emerged in recent years and the development time is relatively short, the current research on responsible innovation by scholars mainly focuses on theory. Of course, there are many scholars who study responsible innovation from a practical perspective. Julia Brebler and Lisa Hegemann conceptualized a responsible

innovation indicator and used it to explore the role of women technologists in implementing responsible innovation [11]. Phil Macnaghten, Richard Owen, and Roland Jackson used their projects in the UK as examples to analyze the intersection of synthetic biology and responsible innovation, construct a framework for responsible innovation in synthetic biology, and address the evolution of synthetic biology from “ethical, legal and social implications” to a responsible innovation framework [12]. With the deepening of the research on responsible innovation, scholars use practical examples to show the application of responsible innovation in some social industries.

The term “stakeholder” first appeared at a conference held at the Stanford Research Institute in 1963 and was defined as: all groups on which an organization depends, and a stakeholder is an individual or group of individuals or groups that may influence or be affected by the achievement of the organization’s goals. Van den Hoven further emphasizes that responsible innovation makes innovation a stakeholder. The ability to understand the knowledge and possible outcomes of innovative actions at an early stage of innovation and to make choices about actions is based on the needs of social development and the ethical acceptability of actions, and Van den Hoven argues that these two criteria should be used as functional guidelines for scientific research design and innovative development actions [13]. In many ways, stakeholder theory demonstrates its role in changing governance, decision-making, action, etc., reflecting the shared aspirations of participants, highlighting the distinction between those with and without rights, and considering the blind spots posed by those who do not have a voice. In the process of responsible innovation, stakeholders can be roughly divided into three categories: innovation experts, policy makers, and social participants [14]. Accountable innovation involves multi-stakeholder subjects, and only by scientifically classifying different stakeholders can different stakeholders be scientifically and reasonably managed in collaboration.

In summary, the research and discussion of responsible innovation shows that the current academic research on responsible innovation is mainly in the concept, connotation, advantages and shortcomings, and framework construction of responsible innovation, and some scholars’ research on some specific cases also involves the theory of responsible innovation. Responsible innovation has slowly become the benchmark for enterprise innovation, and has widely triggered the discussion and research of responsible innovation participants. According to current research on responsible innovation, there are still the following two shortcomings. First of all, most of the academic research on responsible innovation is at the theoretical level, and few scholars discuss the mechanism of responsible innovation by establishing specific models. Second, unlike the traditional rational person discussion, prospect theory and evolutionary game are discussed under the premise of bounded rationality, and the introduction of prospect theory can more directly see the changes in the strategic choices of enterprises, governments, and consumers, and few scholars have introduced prospect theory into the discussion of responsible innovation. Studying the responsible innovation mechanism with the participation of multiple stakeholders can better play the function and social value of responsible innovation, and can promote the implementation of responsible innovation in society faster. Prospect theory selects the appropriate strategy by calculating the prospect value of each scheme, which is very similar to the decision-making of corporate strategy in responsible innovation, so the introduction of prospect theory can more intuitively explore the selection law of the strategy of the participating entity. The market is mainly composed of government, enterprise, and consumer. This paper selects three typical subjects, which are enterprise, government and consumer, uses evolutionary game method, constructs a tripartite evolutionary game model, introduces prospect theory to explore the interaction mechanism of three-party responsible innovation, and, finally, obtains the evolutionary game stability strategy, analyzes the impact of some important parameters on the strategy choice of the tripartite subject, and puts forward relevant policies and suggestions.

3. Model Assumptions and Description

Each stakeholder in the responsible innovation ecosystem must play its own role and assume corresponding responsibilities in order to make the innovation system work. Among the government, enterprises, and consumers in responsible innovation, if enterprises do not implement responsible innovation, they will face the risk of being punished by the government and complained about by the public. If the government does not actively implement responsible innovation, it will face the risk of public complaints. If the public does not actively participate in responsible innovation and supervise the implementation of responsible innovation, the public will face the risk of damage to its own interests. For enterprises, the implementation of responsible innovation needs to invest additional production and research costs, but if enterprises do not implement responsible innovation, they will face the risk of fines. Whether enterprises choose to implement responsible innovation or not has a significant relationship with the size of these two costs.

In this paper, the three-party strategy selection is understood as follows: enterprises pay more attention to the protection of ecological environment, social ethics, and user privacy, and pay more attention to social value and influence when implementing responsible innovation. Government measures to actively promote responsible innovation include: the government will issue policy documents on the implementation of responsible innovation, and the government will actively supervise the implementation of responsible innovation by enterprises; enterprises that take the initiative to implement responsible innovation will be appropriately rewarded, and those that do not will be fined. The measures for enterprises to implement responsible innovation include: on the basis of innovation behavior, enterprises should pay attention to ecological environment protection and social ethical value, realize the economic benefits of innovation, and shoulder the social responsibility without delay. The measures for consumers to participate in responsible innovation include: consumers believe that enterprises should take social responsibility, implement responsible innovation, and supervise whether enterprises implement responsible innovation.

3.1. Model Assumptions

- (1) The evolutionary game model is established under the premise that the government, enterprises, and consumers are all bounded rationality. The acquisition and processing of relevant information of the three parties are not perfect when selecting strategies. The strategies chosen by the three parties are all aimed at maximizing their own interests, and there is some imperfection [15].
- (2) This paper is based on the fact that enterprises, consumers and the government form a closed system. Without considering the influence of the external environment on this system, innovative knowledge and information will not flow into and out of this system [16].
- (3) When enterprises do not implement responsible innovation, they can still gain benefits from normal innovation activities, but the government and consumers cannot gain benefits; Companies implementing responsible innovation will bring value to society, and both consumers and governments will benefit from it. When the government carries out the policy of passive responsible innovation, it will not fine the enterprises that do not carry out responsible innovation, nor will it reward the enterprises that carry out responsible innovation. Non-responsible innovation will bring a series of risks to the society, such as ecological environment destruction, user privacy disclosure, and ethical crises. When the government actively promotes responsible innovation, it will manage the risks brought by non-responsible innovation. When consumers do not participate in responsible innovation, they will not complain about enterprises that do not implement responsible innovation and governments that passively promote responsible innovation. In order to encourage enterprises and consumers to participate in responsible innovation, the government's subsidies and fines to enterprises must be greater than the participation costs of enterprises, and the government's subsidies to consumers must be greater than the participation costs of consumers.

- (4) In the evolutionary game model, there are two alternative strategies for all participants: enterprises choose to implement or not to implement responsible innovation; consumers choose to participate or not to participate in responsible innovation; and governments choose to actively implement responsible innovation policies or negatively implement responsible innovation policies. The risk preference of players in the game is also uncertain, and it is difficult for players to reach the complete information condition when choosing game strategies. Their strategy choices are not based on direct profit and loss, but on their own subjective feelings to make decisions on the value of strategies, which cannot be estimated according to the expected utility theory [17]. In this paper, the prospect theory is used to analyze the change of three-party strategy selection with time.

3.2. Model Description

In the tripartite game model, it is assumed that the decision probability of enterprises implementing responsible innovation is x , the decision probability of consumers participating in responsible innovation is y , and the decision probability of governments actively implementing responsible innovation is z .

- (1) The revenue of responsible innovation is Re , the cost is Ce , and Se is the government subsidy for responsible innovation. If an enterprise does not implement responsible innovation, it will face the risk of consumer complaints and be fined by the government. Fe is used to represent government fines. The revenue and the cost of an enterprise that does not implement responsible innovation is Rn and Cn . Consumer participation in responsible innovation will bring additional benefits V to enterprise.
- (2) Consumer participation in responsible innovation requires labor cost, which is represented by Cp . Sp is government subsidies to consumers participating in responsible innovation. If an enterprise implements responsible innovation, it will bring additional external benefits to consumers, which is represented by Rp . If an enterprise does not implement responsible innovation, it will not generate additional external benefits to consumers.
- (3) The cost of the government's active implementation of responsible innovation is represented by Cg . The implementation of responsible innovation will bring social value. The governance value and reputation for the government is represented by Rg . If the government chooses to passively implement responsible innovation policies, it will face public complaints and suffer losses Fg . If enterprises do not implement responsible innovation, the government needs to pay extra governance cost K to control the risks and hazards that may be brought by enterprise's non-responsible innovation.

4. Model Establishment and Solution

4.1. Model Establishment

- (1) The expected revenue of enterprise

When the government chooses an active policy for implementing responsible innovation, and consumers participate in the responsible innovation, the expected return of enterprise implementing responsible innovation is $Re - Ce + Se$, and the expected return of enterprise not implementing responsible innovation is $Rn - Cn - Fe$. When the government chooses an active policy for implementing responsible innovation, and consumers do not participate in responsible innovation, the expected return of enterprise implementing responsible innovation is $Re - Ce + Se$, and the expected return of enterprise not implementing responsible innovation is $Rn - Cn - Fe$.

When the government chooses a negative policy for implementing responsible innovation, and consumers participate in responsible innovation, the expected return of enterprise implementing responsible innovation is $Re - Ce + V$, and the expected return of enterprise not implementing responsible innovation is $Rn - Cn - Fe$. When the government chooses a negative policy for implementing responsible innovation, and consumers do

not participate in responsible innovation, the expected return of enterprise implementing responsible innovation is $Re - Ce$, and the expected return of enterprise not implementing the responsible innovation is $Rn - Cn$.

(2) The expected revenue of consumer

When the government chooses an active policy for implementing responsible innovation and enterprises implement responsible innovation, the expected return of consumers participating in responsible innovation is $Rp - Cp + Sp$, and the expected return of consumers not participating in responsible innovation is Rp . When the government chooses an active policy for implementing responsible innovation, and enterprises do not implement responsible innovation, the expected return of consumers participating in responsible innovation is $Sp - Cp$, and the expected return of consumers not participating in responsible innovation is 0.

When the government chooses a negative policy for promoting responsible innovation, and the enterprise implements responsible innovation, the return of consumers participating in the responsible innovation is $Rp - Cp$, and the return of consumers not participating in the responsible innovation is Rp . When the government chooses a negative policy for promoting responsible innovation, and enterprises do not implement responsible innovation, the return of consumers participating in responsible innovation is $-Cp$, and the return of consumers not participating in responsible innovation is 0.

(3) The expected revenue of government

When consumers participate in responsible innovation and enterprises actively implement responsible innovation, the return of a government which chooses an active policy for implementing responsible innovation is $Rg - Cg - Sp - Se$, and the return of a government which chooses a negative policy for implementing responsible innovation is $Rg - Fg$. When consumers do not participate in responsible innovation and enterprises neglect to implement it, the return of a government which chooses an active policy for implementing responsible innovation is $Fe - Cg - Sp - K$, while the return of a government which chooses a negative policy for implementing responsible innovation is $-K - Fg$.

When consumers do not participate in responsible innovation, and enterprises implement responsible innovation, the return of a government which chooses an active policy for implementing responsible innovation is $Rg - Cg - Se$, while the return of a government which chooses a negative policy for implementing responsible innovation is Rg . When consumers do not participate in responsible innovation and enterprises do not implement responsible innovation, the return of a government which chooses an active policy for implementing responsible innovation is $Fe - Cg - K$, while the return of a government which chooses a negative policy for implementing responsible innovation is $-K$. The final strategy choices and returns of enterprises, consumers, and government are shown in Table 1.

Table 1. The choices and returns of responsible innovation strategy by enterprises, consumers and government.

Choice of Strategy		Government	
		Actively Promote (z)	Negatively Promote (1-z)
Enterprises implement (x)	Consumers engage (y)	$Re - Ce + Se$	$Re - Ce + V$
		$Rp - Cp + Sp$	$Rp - Cp$
		$Rg - Cg - Sp - Se$	$Rg - Fg$
	Consumers do not engage (1-y)	$Re - Ce + Se$ Rp $Rg - Cg - Se$	$Re - Ce$ Rp Rg
Enterprises do not implement (1-x)	Consumers engage (y)	$Rn - Cn - Fe$	$Rn - Cn - Fe$
		$Sp - Cp$	$-Cp$
		$Fe - Cg - Sp - K$	$-K - Fg$
	Consumers do not engage (1-y)	$Rn - Cn - Fe$ 0 $Fe - Cg - K$	$Rn - Cn$ 0 $-K$

4.2. Model Solving

4.2.1. Construction of Replication Dynamic Equation

According to Table 1 and the model constructed, the average returns of enterprises, consumers and government can be calculated. The expected return of enterprise implementing responsible innovation is Ex , and the expected return of enterprise not implementing responsible innovation is E_{1-x} , then the average return of enterprise is: $\bar{Ex} = xEx + (1-x)E_{1-x}$. The expected return Ex of enterprise choosing to implement responsible innovation is

$$Ex = yz(Re - Ce + Se) + y(1-z)(Re - Ce + V) + (1-y)z(Re - Ce + Se) + (1-y)(1-z)(Re - Ce)$$

The expected return E_{1-x} of an enterprise choosing not to implement responsible innovation is:

$$E_{1-x} = yz(Rn - Cn - Fe) + y(1-z)(Rn - Cn - Fe) + (1-y)z(Rn - Cn - Fe) + (1-y)(1-z)(Rn - Cn)$$

The average expected revenue of enterprise $\bar{Ex}$ is:

$$\bar{Ex} = xEx + (1-x)E_{1-x} = xy(1-z)V + xzSe + xRe - xCe + (xy - y - xyz - z + xz + yz)Fe + (1-x)(Rn + Cn)$$

According to the Malthusian dynamic equation, the replication dynamic equation of the enterprise can be obtained as follows:

$$F(x) = \frac{dx}{dt} = x(Ex - \bar{Ex}) = x[(y - yz - xy + xyz)V + (z - xz)Se + (1-x)Re + (x-1)Ce + (y - xy + z - xz - yz + xyz)Fe + (x-1)Rn + (1-x)Cn] \quad (1)$$

The return of consumers who implement responsible innovation is Ey , and the return of consumers who do not implement responsible innovation is E_{1-y} , then the average return of consumers is $\bar{Ey} = yEy + (1-y)E_{1-y}$;

The expected revenue Ey of consumers choosing to participate in responsible innovation is as follows:

$$Ey = xz(Rp - Cp + Sp) + x(1-z)(Rp - Cp) + (1-x)z(Sp - Cp) + (1-x)(1-z)(-Cp)$$

The expected revenue of consumers choosing not to participate in responsible innovation are as follows:

$$E_{1-y} = xz(Rp) + x(1-z)(Rp) + (1-x)z * 0 + (1-x)(1-z) * 0$$

The average expected revenue of consumers is:

$$\bar{Ey} = yEy + (1-y)E_{1-y} = xRp - yCp + yzSp$$

According to the Malthusian dynamic equation, the replicated dynamic equation of consumers can be written as:

$$F(y) = dy/dt = y(Ey - \bar{Ey}) = y(y-1)(Cp - zSp) \quad (2)$$

If government chooses an active policy for implementing responsible innovation, the revenue is Ez , and if government chooses a negative policy for implementing responsible innovation, the revenue is E_{1-z} . The average revenue of the government is: $\bar{Ez} = zEz + (1-z)E_{1-z}$;

The expected revenue Ez of the government which chooses an active policy for implementing responsible innovation is:

$$Ez = xy(Rg - Cg - Sp - Se) + x(1-y)(Rg - Cg - Se) + (1-x)y(Fe - Cg - Sp - K) + (1-x)(1-y)(Fe - Cg - K)$$

The expected revenue E_{1-z} of the government which chooses a negative policy for implementing responsible innovation is:

$$E_{1-z} = yz(Rg - Fg) + x(1-y)(Rg) + (1-x)y(-K - Fg) + (1-x)(1-y)(-K)$$

The average expected return of the government $\bar{Ez}$:

$$\bar{Ez} = zEz + (1-z)E_{1-z} = xRg - xzSe - xySp + zFe - zFg - xzFe - yFg - K + xK + yzFg$$

According to the Malthusian dynamic equation, the government's replication dynamic equation can be written as:

$$F(z) = dz/dt = z(Ez - \bar{Ez}) = z[(x-1)(z-1)Fe + (y+z-yz)Fg + x(z-1)Se + y(x-1)Sp - Cg] \quad (3)$$

4.2.2. Equilibrium Solution of Equation

The process of evolutionary game is a dynamic one, in which enterprises, consumers, and government reach a balance. In other words, it takes a certain time for the three stakeholders to reach a state of equilibrium. According to the characteristics of the differential equation, when the three dynamic equations are all 0, the differential equation reaches a stable state, namely:

$$\begin{cases} F(x) = \frac{dx}{dt} = x(Ex - \bar{Ex}) = x[(y - yz - xy + xyz)V + (z - xz + xyz)Se + (1-x)Re + (x-1+xyz)Ce + (y - xy + z - xz - yz + xyz)Fe + (x-1)Rn + (1-x)Cn] = 0 \\ F(y) = \frac{dy}{dt} = y(Ey - \bar{Ey}) = y(y-1)(Cp - zSp) = 0 \\ F(z) = \frac{dz}{dt} = z[(x-1)(z-1)Fe + (y+z-yz)Fg + x(z-1)Se + y(x-1)Sp - Cg] = 0 \end{cases}$$

According to the above equation, the equilibrium solution of the evolutionary game model can be calculated. There must be eight special equilibrium points: (0,0,0), (0,0,1), (0,1,0), (0,1,1), (1,0,0), (1,0,1), (1,1,0), and (1,1,1) [18]. Depending on the value of the parameter, the equation may also have a ninth equilibrium point, (x^*, y^*, z^*) , $0 \leq [x^*, y^*, z^*] \leq 1$. This equilibrium point falls inside the model, but according to the assumptions and realities of the model, the strategic choices of the three parties are only 1 or 0, that is, enterprises choose to implement or not to implement responsible innovation, consumers choose to participate or not to participate in responsible innovation, and government chooses an active policy for implementing responsible innovation or a negative policy for implementing responsible innovation. Therefore, there are only eight special equilibrium points to consider [19].

4.2.3. Stable Strategy of Evolutionary Game

According to the conclusion of Friedman's research, the stability of the eight special equilibrium points can be achieved only when all the eigenvalues of the Jacobian matrix of the system are negative. The Jacobian matrix is as follows:

$$J = \begin{pmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{pmatrix} = \begin{pmatrix} F11 & F12 & F13 \\ F21 & F22 & F23 \\ F31 & F32 & F33 \end{pmatrix}$$

Among them, $F11 = (y - yz - 2xy + 2xyz)V + (z - 2xz)Se + (1 - 2x)Re + (2x - 1)Ce + (y + z - 2xy - 2xz - yz + 2xyz)Fe + (2x - 1)Rn + (1 - 2x)Cn$

$$F12 = x(1 - z - x + xz)(V + Fe)$$

$$F13 = x[(xy - y)V + (1 - x)Se + (1 - x - y + xy)Fe]$$

$$F21 = 0$$

$$F22 = (2y - 1)(Cp - zSp)$$

$$F23 = -y(y - 1)Sp$$

$$F31 = z(z - 1)(Fe + Se) + yzSp$$

$$F32 = z(1 - z)Fg + z(x - 1)Sp$$

$$F33 = (x - 1)(2z - 1)Fe + (y + 2z - 2yz)Fg + x(2z - 1)Se + y(x - 1)Sp - Cg$$

Eight special equilibrium points are put into the Jacobian determinant, and their corresponding eigenvalues are calculated respectively in Table 2.

Table 2. Eight special equilibrium points and their eigenvalues.

Point of Equilibrium	Eigenvalue		
	α_1	α_2	α_3
(0,0,0)	$Fe - Cg$	$-Cp$	$Cn - Ce + Re - Rn$
(0,0,1)	$Cg - Fe$	$Sp - Cp$	$Cn - Ce + Fe + Re - Rn + Se$
(0,1,0)	Cp	$Fe - Cg + Fg - Sp$	$Cn - Ce + Fe + Re - Rn + V$
(0,1,1)	$Cp - Sp$	$Cg - Fe - Fg + Sp$	$Cn - Ce + Fe + Re - Rn + Se$
(1,0,0)	$-Cp$	$-Cg - Se$	$Ce - Cn - Re + Rn$
(1,0,1)	$Sp - Cp$	$Cg + Se$	$Ce - Cn - Fe - Re + Rn - Se$
(1,1,0)	Cp	$Fg - Cg - Se - Sp$	$Ce - Cn - Fe - Re + Rn - V$
(1,1,1)	$Cp - Sp$	$Cg - Fg + Se + Sp$	$Ce - Cn - Fe - Re + Rn - Se$

For the point (0,0,0), according to the premise assumptions of the model, it can be known that government subsidies and fines are greater than the participation costs of each participant, so $Fe - Cg > 0$, eigenvalue α_1 does not satisfy the condition of stability point of evolutionary game.

For the point (0,0,1), according to the premise assumptions of the model, the government subsidies and fines are greater than the participation costs of all parties, so $Sp - Cp > 0$, eigenvalue α_2 does not satisfy the condition of stability point of evolutionary game.

For the point (0,1,0), $Cp > 0$, eigenvalue α_1 does not satisfy the condition of stability point of evolutionary game.

For the point (0,1,1), $Cp - Sp < 0$, when $Cg - Fe - Fg + Sp < 0$ and $Cn - Ce + Fe + Re - Rn + Se < 0$, (0,1,1) is a stable point of evolutionary game.

For the point (1,0,0), $-Cp < 0$, $-Cg - Se < 0$, when $Ce - Cn - Re + Rn < 0$, (1,0,0) is a stable point of evolutionary game.

For the point (1,0,1), $Sp - Cp > 0$, (1,0,1) is not a stable point of evolutionary game.

For the point (1,1,0), $Cp > 0$, (1,1,0) is not a stable point of evolutionary game.

For the point (1,1,1), $Cp - Sp < 0$, $Cg - Fg + Se + Sp < 0$ and $Ce - Cn - Fe - Re + Rn - Se < 0$, (1,1,1) is a stable point of evolutionary game.

According to the above analysis, the possible stable points of the evolutionary game are: (0,1,1), (1,0,0), and (1,1,1). Consumers and governments make the same decisions, and both participate or do not participate in responsible innovation. From the perspective of the full life cycle theory of responsible innovation, different roles played by the government in each stage of the life cycle of responsible innovation are analyzed below [20]. The policy of responsible innovation can be roughly summarized into three stages from the proposal to maturity. In the early stage of the policy, the public consumers as the beneficiaries of the policy and the government as the implementer of the policy will actively participate in the responsible innovation. In order to implement responsible innovation, enterprises need to invest extra research and development costs. Due to the consideration of revenue, enterprises have low enthusiasm to implement responsible innovation, and the initial stage of the policy corresponds to the stable point of evolutionary game (0,1,1). In the medium term of policy proposal, government and consumers should play a supervisory role, and enterprises should pay more attention to social ecological ethics and development

prospects, and actively implement responsible innovation. In the medium term, the policy corresponds to the stable point of evolutionary game (1,1,1). In the late stage of policy implementation, even without the supervision of government and consumers, enterprises will actively implement responsible innovation, which corresponds to the stable point of evolutionary game (1,0,0).

4.2.4. Evolutionary Game Analysis Based on Prospect Theory

Prospect theory is a decision-making theory under uncertain conditions. It is based on the bounded rationality of game players, who care about loss value rather than profit value [21]. According to prospect theory, the return of enterprises that do not implement responsible innovation activities are taken as the benchmark. Before the implementation of responsible innovation policies, enterprises do not implement responsible innovation, and government and consumers do not participate in responsible innovation. The expected return of enterprises are the return of enterprises that do not implement responsible innovation, and there is no loss or additional earnings. The prospect value of enterprise is $V_0 = 0$.

In the early stage of policy implementation, enterprises do not implement responsible innovation, and government and consumers participate in responsible innovation. Under the supervision of government and consumers, the behavior of enterprises that do not implement responsible innovation will be punished and the reputation of enterprises will be damaged; the total loss value is h_1 . At this time, the prospect value of enterprise is: $V_1 = V_0 - h_1$, and the stable point of evolutionary game is (0,1,1).

According to prospect theory, enterprises are loss-averse and will try to implement responsible innovation [22], which will pay extra cost h_2 and gain extra income p_1 . Consumers will bring additional benefits to enterprise that implements responsible innovation, and government will reward the enterprise that implements responsible innovation, and the enterprise's reputation will also be improved. The total additional benefits brought by government and consumers to the enterprise that implements responsible innovation is p_2 , and the prospect value of enterprise is $V_2 = V_1 - h_2 + p_1 + p_2$; the stable point of evolutionary game is (1,1,1).

When an enterprise implements responsible innovation, but consumers and government do not participate in responsible innovation, the additional revenue p_2 brought by consumers and government to the enterprise does not exist. At this time, the prospect value of enterprise is $V_3 = V_1 - h_2 + p_1$, corresponding to the stable point of evolutionary game (1,0,0). In prospect theory, enterprises, consumers, and government are loss-averse, therefore, $V_1 < V_0$ and $V_0 < V_2$ will encourage responsible innovation. $V_0 < V_3$ will encourage enterprises to implement responsible innovation all the time. According to their own return, enterprises, consumers, and government choose different strategies to fight against losses in the middle and late stages of policy implementation [23], and finally reach a stable strategy: enterprises implement responsible innovation, consumers do not participate in responsible innovation, and government passively promotes responsible innovation [24].

5. Numerical Simulation Analysis

The stable points of the evolutionary game are obtained through the previous analysis and calculation. In order to more clearly and intuitively understand the evolutionary trajectory of enterprises, consumers, and government, and the sensitivity of some important parameters, this section will use MATLAB software to carry out relevant numerical simulation and parameter analysis of these stable points and some important parameters of evolutionary game.

5.1. Parameter Simulation of Stability Point

For the equilibrium point (0,1,1) at the initial stage of policy implementation, it should be satisfied $Cg - Fe - Fg + Sp < 0$ and when $Cn - Ce + Fe + Re - Rn + Se < 0$, (0,1,1) is the evolutionary game stability point. In order to meet the condition of becoming a stable point, assume that the value of the parameter is: $V = 2$, $Re = 8$, $Ce = 4$, $Rn = 18$, $Cn = 3$, $Cp = 1$,

$Cg = 4, Se = 5, Fe = 5, Sp = 2, Fg = 8$. Parametric simulation with MATLAB is shown in Figure 1. According to the prospect theory, at the end of policy implementation, when the benefits of participating in responsible innovation by the three decision-making parties are greater than the benefits of not participating in responsible innovation, the decision-makers will tend to participate in responsible innovation. According to the evolutionary trajectory, with the extension of the implementation time of the responsible innovation policy, the probability of enterprises implementing responsible innovation will increase, the probability of consumers participating in responsible innovation will increase, and the probability of the government implementing the active implementation of responsible innovation policy will decrease, so at the end of the policy implementation, the benefits of enterprises and consumers participating in responsible innovation are greater than the benefits of not participating in responsible innovation, and the benefits of government not participating in responsible innovation are greater than the benefits of participating in responsible innovation. The optimal game strategies of the three parties are: enterprises implement responsible innovation, consumers participate in responsible innovation, and the government chooses to passively implement responsible innovation strategy. Also at the end of the period, the reason why the government chooses passive responsible innovation policy is: as enterprises implement responsible innovation and consumer participation in responsible innovation, the purpose of the government's implementation of responsible innovation policy has been achieved, the government can no longer vigorously promote responsible innovation policy, and finally the government can save costs by passively implementing responsible innovation policy.

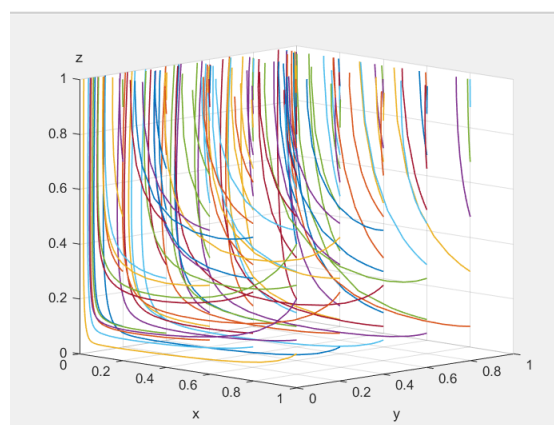


Figure 1. MATLAB parameter simulation of stable point (0,1,1). Each line in the figure represents the evolution of enterprises (x), consumers (y), and government (z) in different states.

For the stable point (1,1,1), when $Cg - Fg + Se + Sp < 0$ and $Ce - Cn - Fe - Re + Rn - Se < 0$, (1,1,1) is the stable point of evolutionary game. In order to meet the condition of becoming a stable point, assume that the value of the parameter is: $V = 6, Re = 8, Ce = 3, Rn = 8, Cn = 6, Cp = 3, Cg = 3, Se = 3, Fe = 8, Sp = 5, Fg = 12$. Parameter simulation is shown in Figure 2. With the implementation of policy, the probability of government actively implementing responsible innovation decreases rapidly to 0. The probability of enterprises implementing responsible innovation gradually decreases. The reason is that the lack of government supervision on enterprises reduces the willingness of enterprises to implement responsible innovation, and the total return of enterprises to implement responsible innovation is less than that of non-responsible innovation, and enterprises are more inclined to not implement responsible innovation.

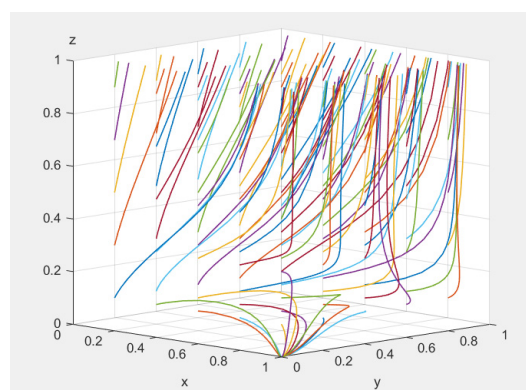


Figure 2. MATLAB parameter simulation of stable point (1,1,1). Each line in the figure represents the evolution of enterprises (x), consumers (y), and government (z) in different states.

For the stable point (1,0,0), when $Ce - Cn - Re + Rn < 0$, (1,0,0) is the stable point of evolutionary game. In order to meet the condition of becoming a stable point, assume that the value of the parameter is: $V = 2$, $Re = 10$, $Ce = 4$, $Rn = 8$, $Cn = 3$, $Cp = 1$, $Cg = 4$, $Se = 5$, $Fe = 5$, $Sp = 2$, $Fg = 6$. Parameter simulation is shown in Figure 3. With the extension of policy implementation time, the probability of enterprises implementing responsible innovation will decrease, while the probability of consumers participating in responsible innovation will increase. The probability that governments will actively pursue responsible innovation policies will increase. Therefore, the optimal game strategies of the three parties are: enterprises do not implement responsible innovation, consumers participate in responsible innovation, and government chooses active strategy to promote responsible innovation.

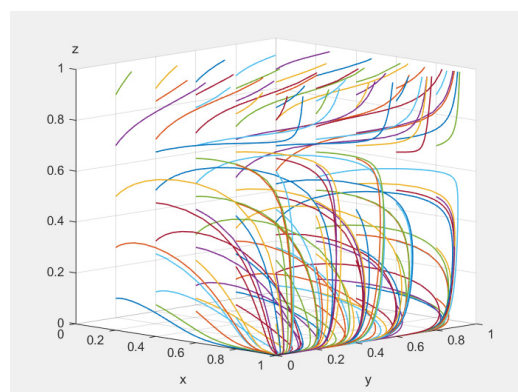


Figure 3. MATLAB parameter simulation of stable point (1,0,0). Each line in the figure represents the evolution of enterprises (x), consumers (y), and government (z) in different states.

5.2. Simulation of Some Important Parameters

Among these stable points for the implementation of responsible innovation policies, (1,1,1) is the most important point. It means that enterprises implement responsible innovation, consumers participate in responsible innovation, and government adopts proactive policies to promote responsible innovation. The implementation of a policy cannot be separated from the participation and efforts of all parties, and the participation of all games in responsible innovation is a necessary stage in the process of policy implementation. Therefore, this part is to analyze the sensitivity of some important parameters in the stable point of evolutionary game (1,1,1). Figures 4–8 shows the impact of five important factors on the participation of enterprises or consumers in responsible innovation. The abscissa axis $x(y)$ axis in Figures 4–8 represents the probability of enterprises (consumers) implementing (participating in) responsible innovation, which can also be explained as the proportion of all enterprises (consumers) participating in responsible innovation, and the three lines

represent the impact of changes in one parameter on the probability of enterprises (consumers) participating in responsible innovation (the number of enterprises or consumers participating in responsible innovation) when other parameters remain unchanged. The faster the graph line approaches one, the greater the probability of enterprises (consumers) implementing responsible innovation (the number of enterprises or consumers participating in responsible innovation), and the slower the graph line is closer to one, indicating that the probability of enterprises (consumers) implementing responsible innovation (the number of enterprises or consumers participating in responsible innovation) is smaller.

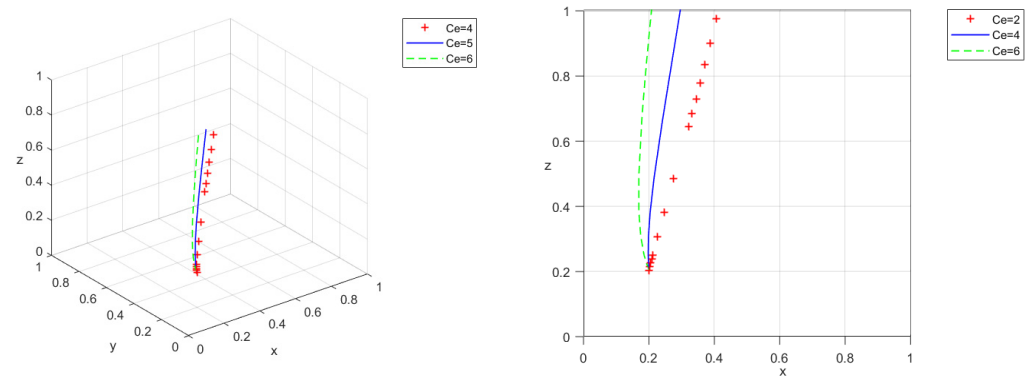


Figure 4. The impact of cost C_e on enterprises which implement responsible innovation.

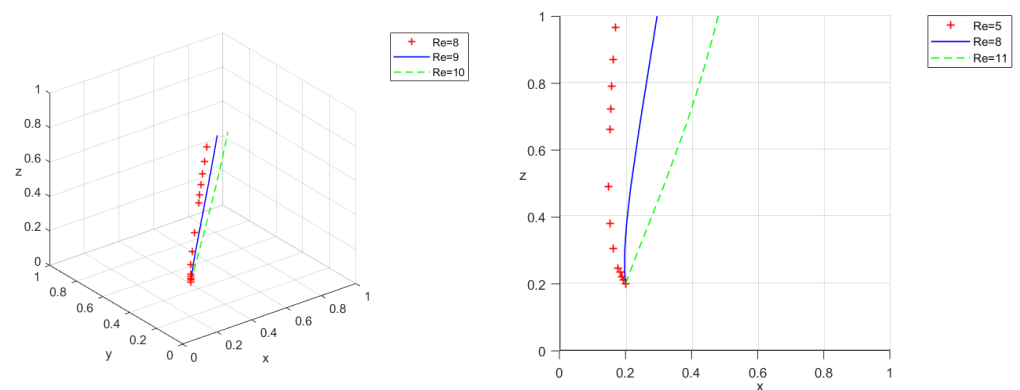


Figure 5. The impact of revenue R_e on enterprises which implement responsible innovation.

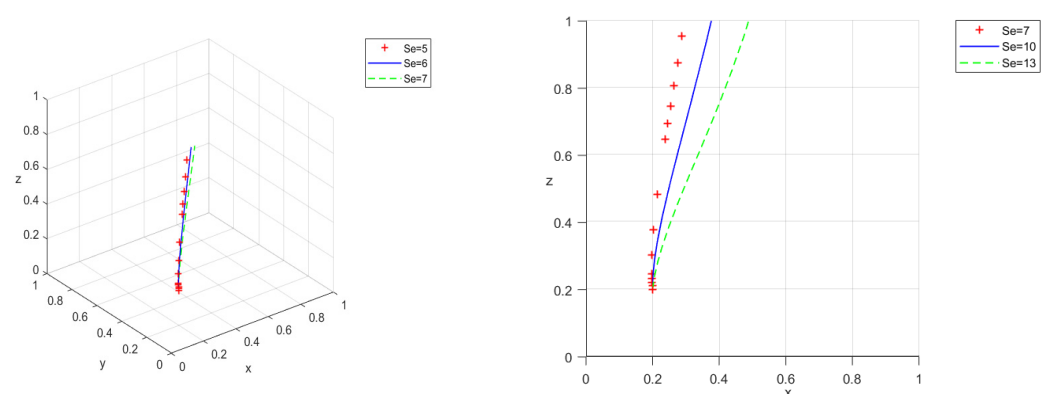


Figure 6. The impact of subsidy S_e given by government on enterprises which implement responsible innovation.

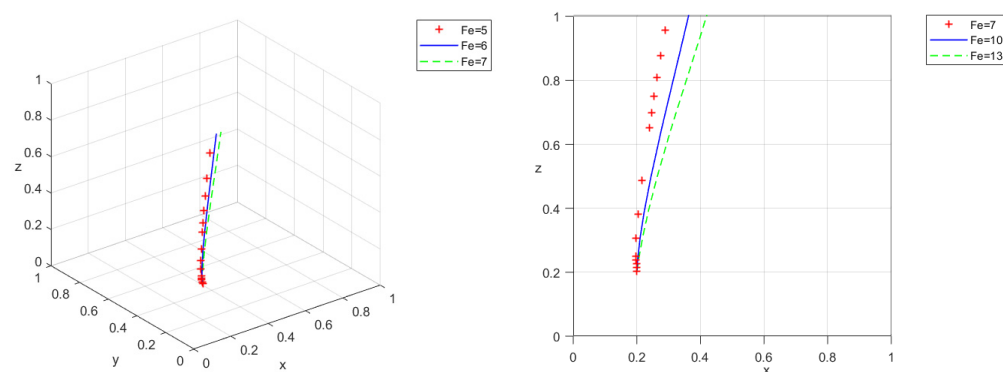


Figure 7. The impact of government penalty Fe on enterprises not implementing responsible innovation.

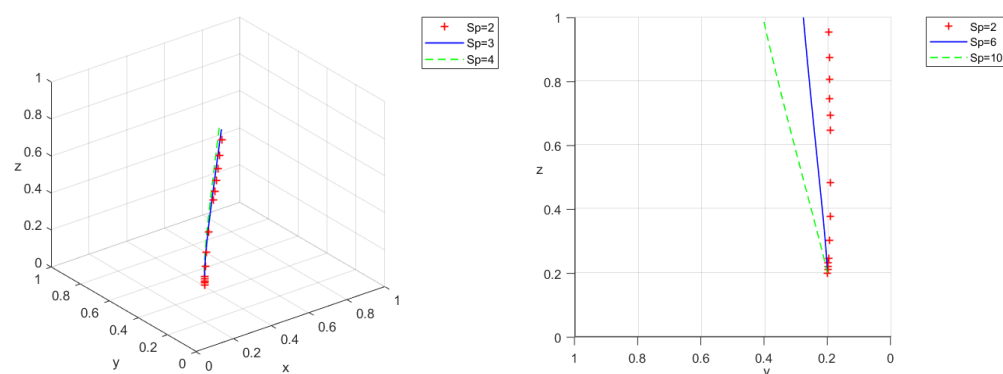


Figure 8. The impact of government subsidies Sp on consumer participating responsible innovation.

5.2.1. Sensitivity Analysis of Cost Ce for Enterprises Which Implement Responsible Innovation

When $Cg - Fg + Se + Sp < 0$ and $Ce - Cn - Fe - Re + Rn - Se < 0$, (1,1,1) is the stable point of evolutionary game, and cost Ce of enterprise's implementing of responsible innovation is set as 2, 4, and 6 respectively, as shown in Figure 4. With the increase of implementation cost of responsible innovation, the probability of enterprise's implementation of responsible innovation decreases. The increase of implementation cost of responsible innovation will reduce the enthusiasm of enterprises to implement responsible innovation.

5.2.2. Sensitivity Analysis of Revenue Re for Enterprises Which Implement Responsible Innovation

When $Cg - Fg + Se + Sp < 0$ and $Ce - Cn - Fe - Re + Rn - Se < 0$, (1,1,1) is the stable point of evolutionary game, revenue Re of enterprise implementing responsible innovation is set as 5, 8, and 11 respectively, as shown in Figure 5. With the increase of the enterprise's revenue from the implementation of responsible innovation, the probability of enterprises implementing responsible innovation also increases, and the improvement of the implementation revenue of responsible innovation will improve the enthusiasm of enterprises.

5.2.3. Sensitivity Analysis of Subsidy Se for Enterprises which Implement Responsible Innovation

When $Cg - Fg + Se + Sp < 0$ and $Ce - Cn - Fe - Re + Rn - Se < 0$, (1,1,1) is the stable point of evolutionary game, and the government's subsidy Se for enterprises which implement responsible innovation is set as 7, 10, and 13, as shown in Figure 6. With the increase of the government's subsidy for the implementation of responsible innovation for enterprises, the probability of enterprises implementing responsible innovation strategy increases, and the increase of government subsidies for enterprises implementing responsible innovation will increase the enthusiasm of enterprises to implement it. However, by comparing Figures 5 and 6, it can be seen that the revenue Re of enterprises implementing

responsible innovation has a greater impact on enterprises' enthusiasm than government subsidy Se .

5.2.4. Sensitivity Analysis of Penalty Fe on Enterprises Not Implementing Responsible Innovation

When $Cg - Fg + Se + Sp < 0$ and $Ce - Cn - Fe - Re + Rn - Se < 0$, (1,1,1) is the stable point of evolutionary game. The government's penalty Fe for non-implementation of responsible innovation is set as 7, 10, and 13 respectively, as shown in Figure 7. As the government's penalty for non-implementation of responsible innovation increases, the probability of enterprises implementing responsible innovation strategy increases, the increase of government's punishment on enterprises implementing responsible innovation strategy will promote the implementation of responsible innovation. However, by comparing Figures 5 and 7, it can be seen that the revenue Re of enterprises implementing responsible innovation has a greater impact on enterprises' implementation enthusiasm than the penalty Fe .

5.2.5. Sensitivity Analysis of Rewards Sp for Consumers Participating in Responsible Innovation

When $Cg - Fg + Se + Sp < 0$ and $Ce - Cn - Fe - Re + Rn - Se < 0$, (1,1,1) is the stable point of evolutionary game, and government's reward Sp for consumers participating in responsible innovation is set as 2, 6, and 10 respectively, as shown in Figure 8. As the government's reward for consumers participating in responsible innovation increases, the probability of consumers participating in responsible innovation increases, and the increase of the government's reward to consumers participating in responsible innovation will promote consumers to participate in responsible innovation.

5.3. Summary

This paper is dedicated to studying the implementation process of responsible innovation, exploring the influencing factors affecting the participation of enterprises, governments and consumers in responsible innovation, and putting forward some policy suggestions for enterprises in various countries to implement responsible innovation in the future. The contributions of this paper are as follows: Firstly, constructing a tripartite evolutionary game model of responsible innovation. Previous studies mainly made in-depth analysis on the concept connotation and theoretical framework of responsible innovation, but rarely explored the mechanism design and future evolution process of multi-stakeholder collaborative decision-making. Responsible innovation is a collaborative decision-making involving multiple stakeholders. In this paper, the interaction mechanism of key stakeholders is discussed from the perspective of dynamic process, the behavioral characteristics of key stakeholders in responsible innovation are described, and the governance mode in which multiple stakeholders form the resultant force to implement responsible innovation is revealed, so as to provide reference for the decision-making behaviors of multiple stakeholders. Secondly, quantitative analysis of stable strategies of government, enterprise and consumer in responsible innovation. Existing studies on the role of government in responsible innovation are mostly qualitative descriptions of science and technology policy orientation, lacking the support of quantitative policy theory. Based on prospect theory and evolutionary game method, this paper quantitatively analyzes how the government guides the stakeholders to assume their responsibilities with a positive attitude through policies. This paper analyzes how enterprises balance the pursuit of economic benefits and bear the social responsibility of innovation. In order to explore the evolution path and stable strategy of multi-agent interaction in responsible innovation, this paper analyzes the relationship between consumers' vital interests and the costs of participating in innovation policy formulation and bearing innovation risks.

6. Research Conclusions and Prospects

6.1. Research Conclusions and Implications

This paper studies the mechanism of responsible innovation by establishing a tripartite evolutionary game model of enterprises, consumers, and governments, introduces prospect theory, analyzes the change of prospect value of future enterprises and consumers participating in responsible innovation in combination with prospect theory, obtains the process of future enterprises and consumers participating in responsible innovation, and proposes better policy measures to increase the number of enterprises and consumers participating in responsible innovation. Some important parameters in the evolutionary game model are numerically simulated and analyzed, and the important parameter indicators affecting the game side are obtained. Combined with the prospect theory, the revenue increase or decrease of the game side is judged, which may affect the strategy selection of the game side, and can also reflect the strategy changes of the parties in the process of implementing the responsible innovation. According to the final evolution results, the following conclusions can be drawn: First, at the initial stage of policy implementation, enterprises are not highly motivated to implement responsible innovation, while consumers and the government are highly motivated to participate, and consumers and the government play a strong role in supervising enterprises. With the implementation of the policy, the enthusiasm of enterprises to implement responsible innovation is gradually increased, and the supervisory role of consumers and government on enterprises is gradually reduced. Second, the increase of the cost of responsible innovation will reduce the enthusiasm of enterprises to implement it. The increase of the income of enterprises to implement responsible innovation, and the increase of the government's subsidies and penalties will increase the enthusiasm of enterprises to implement it, and the effect of reducing the cost and improving the income is more obvious than the government's subsidies and penalties. With the increase of government incentives for participating consumers, the enthusiasm of consumers to participate increases. Third, the strategy choice of enterprises, consumers, and government will change with the implementation of policies and the continuation of time. The three parties will choose appropriate strategies according to their own income changes. The final strategy is: enterprises actively implement responsible innovation, consumers do not participate in responsible innovation, and the government passively promotes responsible innovation.

According to the conclusions of the research, the following enlightenments and suggestions are obtained: First, at the initial stage of policy implementation, consumers and the government can appropriately improve the supervisory role of enterprises to promote enterprises to actively implement responsible innovation. Second, with the implementation of the policy, consumers and the government can appropriately reduce the supervisory role of enterprises. At the initial stage of policy implementation, the government can issue corresponding policy documents or set up special supervisory organizations to promote the implementation of responsible innovation by enterprises, and consumers can give positive feedback on the situation of responsible innovation by enterprises. With the implementation of policies and the active implementation of responsible innovation by enterprises, the government and consumers can appropriately reduce the supervision of enterprises to save resource costs. For example, the government can open relevant departments and platforms to subsidize innovation funds for enterprises that implement responsible innovation, impose fines on enterprises that do not implement responsible innovation, and increase the cost of pollution control. The government can also increase publicity for enterprises that implement responsible innovation to increase the visibility of the enterprise and increase the enthusiasm of enterprises to implement responsible innovation. The three parties will choose different strategies at different times of policy implementation to cope with the losses caused by the policy and improve their own benefits; this process is consistent with the decision-making process of the decision-making agent in the prospect theory. The application of prospect theory considers the behavioral characteristics of a single participant under the condition of limited rationality, improves and expands the dynamic evolutionary game model of the interaction among the government, enterprises, and consumers, and

the use of the evolutionary game model can also more clearly show the decision-making process of the decision-making subject under the prospect theory. This paper discusses the interaction mechanism of three stakeholders from the perspective of dynamic process, describes the behavior characteristics of key stakeholders in responsible innovation, reveals the governance model of multi-stakeholder formation of responsible innovation implementation, and fills the gap in the research on the evolution process of multi-stakeholder collaborative decision-making in responsible innovation, so as to provide reference for the decision-making behavior of multiple stakeholders. The key factor to improve the enthusiasm of enterprises to implement responsible innovation is to reduce the cost of implementing responsible innovation and increase the benefits of enterprises, appropriate increases in subsidies and penalties will promote enterprises and consumers to participate in responsible innovation, but the incentive and punishment measures to improve the enthusiasm of enterprises and consumers is limited. Enterprises will choose whether to implement responsible innovation according to their own conditions and research and development capabilities, and the change of income is also part of the company's consideration of the implementation of responsible innovation strategy. Third, the government needs to appropriately adjust the implementation policy according to the changes in the strategy of enterprises and consumers, and in the early stage of policy implementation, the concept and advantages of responsible innovation can be popularized to improve the awareness of responsible innovation among enterprises and consumers, which is more conducive to the implementation of policies. In the process of policy implementation, the supervision mechanism, reward and punishment mechanism, and scientific and technological innovation mechanism can be continuously improved according to the implementation status, so as to achieve the purpose of policy implementation in a shorter time and promote the implementation and dissemination of responsible innovation.

6.2. Research Deficiencies and Prospects

Based on the prospect theory, this paper uses the evolutionary game method and numerical simulation to draw relevant research conclusions and policy recommendations. However, for the convenience of the research, this paper only uses the typical subjects of responsible innovation, such as enterprises, consumers, and government, and does not consider the inflow and outflow of innovation in the system, nor the influence of academia and the cooperation between enterprises and academia. Future research on responsible innovation will focus on the following three directions: (1) Develop new research methods. This paper attempts to analyze the strategy choices of game players in the case of asymmetric information through modeling methods such as differential game and signal game, and selects policy simulation methods based on system dynamics to calculate the consumer response under different strategies, so as to optimize the proposal of policy recommendations [25]. (2) Deepen the research content. A combination of "quantitative and qualitative" research methods, such as questionnaire surveys and empirical analysis, can be adopted to make the conclusion more convincing. (3) Expand the research scenario. For example, the privacy security issues and intelligent decision-making of the contemporary internet can be studied in the future. The evolution process of internet responsible innovation and policy realization, and the solution of Internet privacy security issues, can be promoted.

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