Research on the Evolution of Responsible Innovation Behavior of Enterprises Based on Complexity Science

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Abstract: "Responsible innovation" is mostly likely to be another global development concept after "Sustainable development". And it is also the important leading edge and key focus in the field of innovation research both at home and abroad. In order to find the internal regularity in the process of responsible innovation for enterprises effectively, this paper studied the research and practice of responsible innovation theory at home and abroad in recent years, analyzed the process of decision-making evolution of the two objectives--"responsible" and "innovative" in the process of "responsible innovation" in enterprises by evolutionary game theory, sought for the evolutionary stability of the "responsible innovation" strategy and the four possible outcomes of the long-term evolutionary game, dug out deeply how the enterprise managers adjust strategic behavior according to the vested interests of innovation under the premise of limited information. Therefore, this paper enriched the theoretical system of "responsible innovation" development; answered the question of how to realize "responsible innovation" and at the same time, it provides important policy reference for our government to guide the enterprises in our country taking responsible innovation.

1. Introduction

After entering the 20th century, including Internet, Genetic Engineering, Artificial Intelligence and so on, pushing the society development and improving people's life quality, they have caused the public to think and worry about the environmental pollution caused by technological innovation, the negative external of technology and economy, the crisis of moral ethics, and the loss of public legitimacy [1]. In this way, The combination of responsibility and technological innovation has become an inevitable trend. It emphasizes the whole process management and the restraint to the technology innovation practice, adds more responsibility and humanistic ideas to the innovation system [2] and therefore it considers more about the public interest as well as pursues the green and spread of technological innovation results, providing a clearer path for "sustainable development".

In recent years, many enterprises in China have made a lot of efforts to pay attention to social responsibility, protect the ecological environment and promote the healthy and orderly development of technological innovation. However, it still needs further discussion and research about how to guide the overall evolution of the technological innovation of Chinese enterprises in the direction of social satisfaction. In this paper, the author tries to clarify the approach of "responsible" and "innovation" from the perspective of evolutionary game, and answer the question of "how to implement" innovation.

2. Review and Hypothesis

2.1. Review

2.1.1. Responsible Innovation Theory

The ethos of corporate social responsibility began in the United States in the early 20th century. Some scholars believe that corporate social responsibility can be organically integrated into the

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corporate profit maximization strategy. American scholar Clark(1916)first proposed the concept of corporate social responsibility, Frederik(1960),McGuire(1963),Davis(1967)and others discussed corporate social responsibility(see Table 1).

Table 1 Summary of Multi-level Theoretical Framework of Corporate Social Responsibility.

Scholar	Time	Content
Carroll	1979	Corporate social responsibility is divided into four levels, and the corporate social responsibility includes the expectation of the organization in the economic, legal, ethical and voluntary aspects of the organization at a time point, and its weight is in turn 4-3-2-1 [3].
Peter Pratley	1995	The enterprise also accepts the specific moral responsibility, at the lowest level, the enterprise must bear three kinds of responsibilities : (1) To the consumer's concern; (2) Concern for the environment; (3) Care for minimum working conditions. This is the minimum core moral responsibility [4].
Stephen P. Robbins	1997	Social responsibility is a slightly higher concept than social obligation, which advocates three levels of social responsibility: economy, law and morality [5].
Georges Enderle	2002	The scope of corporate responsibility includes three aspects: economic responsibility, social responsibility and environmental responsibility [6].

On the other word, the development of corporate social responsibility is following a logical line of a traceability, from the early understanding that the corporate social responsibility is just like a purely voluntary enterprises or entrepreneurs charity behavior, to the deep agreement that the enterprise need to comment the social responsibility beyond mere profit action in response to both the pressure of “social public opinion and social ideological trend” and the social sustenance to enterprises by expectations of economic, legal, ethical and discretion.

2.1.2. Responsible For Innovation Theory

Von Schomberg (2011) [7] first gives the definition of the responsible innovation. He believed that education was a transparent across participants and recognized different responses to each other. The process of the interaction was designed to deal with the ethical acceptable research, innovation, sustainability and society, making the progress of science and technology properly in the society), at the same time focusing on the way to achieve innovation correctly. In the course of its subsequent development, it has been basically formed by Von Schomberg “correct” view (see Table 2) and represented by Stigoel stakeholders participates in the “common responsibility” views (see Table 3).

Domestic research on responsible innovation still is mainly introduction, and the number of literature is relatively small. Some scholars in our country through the introduction of the concept of “responsible and innovative”, the contact to specific industries or areas of science and technology, the theory fit into the field of the concrete industry to realize the process of outside the theory into practice.

Table 2 Summary of the Concepts of Responsible Innovation's “Common Impact View”.

Scholar	Time	Developing process	Content
Von Schomberg	2011	Clear target	Different participants respond to each other, transparently and interactively, achieve ethical acceptability, sustainability and social satisfaction of research and innovation, and achieve positive impact of innovation [7].
Von Schomberg	2013	Refine target	Promoting innovative design strategies and providing some guidance for realizing social ideal goals; putting forward normative anchors [8].
Stahl et al	2014	Discuss problems	Discussions on all aspects of what can be done to

			achieve positive, socially acceptable and satisfactory results [9].
Hilary Sutcliffe	2014	Clear task	Pay attention to social responsibility and natural ecological responsibility, promote social sustainable development, explore and give priority to the ethical and environmental issues of present and future society [10].
Vincent Blok and Pieter Lemmens	2015	Implementation method	New and innovative approaches that take into account social and ethical impacts and maintain economic, social, cultural and environmental balance [11].

Table 3 Summary of Stakeholder Participation in the View of Joint Responsibility.

Scholar	Time	Theme	Content
Owen et al	2012	common responsibility	Concern about Joint Responsibility and Change the Path of Innovation [12].
Stilgoe et al	2013		Exploring the Future through Collective Management of Existing Science and Innovation [13].
Stahl et al	2013		Higher level of meta-responsibility [14].
Michael Davis and KellyLaas	2014		Relevant actors (such as researchers, innovators and other social actors) integrate into a transparent and interactive process of mutual responsibility [15].
Setiawan and Singh	2015		Ensuring innovation participants' sense of responsibility through anticipation, reflection, response, deliberation and participation in innovation adoption [16].
Spruit et al	2015		Collective Inclusive Process, Achieving the Change from Evaluating the Advisability of Innovation Process Result to Evaluating the Quality of Innovation Process [17].
Wilford	2015	Personal responsibility	Creating a way to change, those engaged in research and innovation should consider the impact of what they do [18].

Now it seems “responsible innovation” is most likely to become another global development concept after “sustainable development”, but as a popular concept, when scholars talk about “responsible innovation”, they mostly avoid the motive behind the implementation of innovation strategy. Most of the motives are value choice, and the essence of value choice is benefit choice. The association that “Responsible innovation” with the inherent interests is an important factor that cannot be ignored in research process. Especially for enterprises, the pursuit of profit is the primary innovation motivation. And it is hypercorrection to see responsibility or environment the priority rather than getting profit. If the benefits behind the innovation of enterprise are ignored, the “responsible innovation” will be shelved.

2.1.3. The Evolutionary Game and Bounded Rationality Theory

With the rise of the theory of behavioral decision-making in the 1980s, scholars began to study the decision-making model of describing the actual decision-making behavior with the premise of bounded rationality [19]. The evolutionary game theory combines the classical game theory with the ecological theory [20], studies and analyzes the behavioral characteristics, the adjustment process and the evolution system of the participants with bounded rationality from the viewpoint of system theory. That is to say, the game participants usually do not find the optimal strategy from the beginning, but through continuous learning and trial and error they will find a better or more satisfactory strategy [21].

Through the review and reflection of literature above, this paper boldly proposes that whether we can embed evolutionary game methodology in the research of “responsible innovation”, which provides a new perspective for “responsible innovation” research.

2.2. Hypothesis

2.2.1. Objects

2.2.1.1. Classification of Technological Innovation in Enterprises

The enterprise resource school believes that corporate profits come from the company's unique scarce resources, and there is constant internal power to generate such resources. To maintain sustainable competitiveness, companies must have continuous asymmetries in the resources and capabilities of manufacturers in the same industry. The conditions for companies to have competitive advantages over their competitors are to have valuable profitable resources, and the resources are obtained at a price lower than their value [22]. Based on this, we can divide technological innovation into three categories: leading innovation, follow-up innovation, and survival innovation according to innovation motives (see Table 4).

Table 4 Pyramid Explanation of Enterprise Technological Innovation Activities.

Level	Connotation
leading Innovation	This kind of innovation is to obtain higher excess profits and construct higher barriers to competition in order to gain lasting competitive advantage in the market and become the leader of technological innovation.
Following-up Innovation	After the first round of innovation is completed by the pioneer enterprises, this kind of innovation is a micro-innovation and simulation innovation, adopted to share the technology premium in order to obtain low-risk benefits.
Living Innovation	This kind of innovation is facing the dilemma of business performance. In order to alleviate the survival crisis, we should adopt the innovation of technology purchase and introduction with small risk, short investment cycle and quick effect.

2.2.1.2. Classification of “Responsible” Behavior of Enterprises

After sorting out the previous references, it is not difficult to find that domestic and international corporate ethics have initially formed a complete research framework after years of development, and as an important part of the corporate ethics research system, although a broad consensus of corporate social responsibility has been reached, “ what is the social responsibility that companies should assume ” experienced a changing understanding process to gradually mature. Among them, Carroll’s corporate social responsibility “four-level theory” and “corporate social responsibility pyramid” models are the most representative. They sort out the mechanism for the evolution of the company’s responsibility from being “bigger and stronger” to “promoting social prosperity and progress”. It is believed that the emphasis on basic, compliance, ethics, and public welfare is the

Table 5 Pyramid Description of “Responsible” Behavior of Enterprises.

Level	Connotation
Full Responsibility	1. Affected by the ethical norms of self-needs and social expectations, enterprises implement dedication ethics. 2. Enterprises aim at respecting and safeguarding human rights and promoting social well-being.
Ethical Responsibility	1. Comply with social norms, norms and values to avoid being condemned by public opinion. 2. Decision-making conforms to the basic social ethics and does justice and fairness. 3. The change of ethical responsibility often leads to the formation of legal responsibility.
Basic Responsibility	1. As the main body of market economy, to provide high-quality products and services for the society. 2. To carry out business activities within the framework of law and abide by government policies and regulations in order to avoid being punished by the government and the market. 3. Maintain the survival and development of enterprises by fulfilling the obligations promised to the government and the public.

basic path for corporate social responsibility [23]. Based on this, we can divide the “responsible” behavior of the company into three levels: full responsibility, ethical responsibility, and basic responsibility according to the development path, and form a “responsible” behavioral pyramid. (See Table 5).

2.2.1.3. Research Object and Explanation

The object of this article is to discuss how the company's responsible innovation behaviors are played and realized. However, it is worth noting that only in “Leading Innovation”, companies as technological leaders and pioneers can perform their tasks in accordance with their strategic goals and strengths in a full range of responsibilities and access to excess profits, build market advantages, and achieve sustainable development goals. It is in accordance with the perspective of our research that we completely choose and choose ourselves, in order to achieve a balance between the two, so the essence of the research object is the question of how the company assumes full responsibility in leading innovations.

2.2.2. Hypothesis

Tanking the combination of “leading innovation” and “all-round responsibility that has the bottom line and without limits” that has clarified above as the object of research, it uses the basic concepts of evolutionary stabilization strategy, emphasizes the dynamic process of the game, and which equilibrium can ultimately be achieved in multiple balance depends on the initial conditions and paths of evolution.

3. Research Design

3.1. Model Hypotheses

Hypothesis 1: enterprises participate in game have bounded rationality, which means they have differences and possibilities of errors while choosing strategies in responsibility and innovation. Usually, it is not to find the optimal strategy at the beginning, but to continuously obtain information and gradually seek the optimal strategy in the process of game playing [24].

Hypothesis 2: “being responsible” and “innovation” mentioned below means the effect that enterprises got by putting extra efforts when their basic survival and development are ensured. R is benchmark profit of game participating enterprises; ΔR_1 is the premium profit of game participating enterprises who take responsible strategies; ΔR_2 is the premium profit of game participating enterprises who take innovation strategies; ΔR_3 is the premium profit of game participating enterprises who take responsible and innovation strategies; C is the total investment of innovation and being responsible beyond the benchmark investigation, in which α is the proportion of responsible strategies’ investigation and 1-α is proportion of innovation strategies.

Hypothesis 3: R_4 is the reward from government after enterprises being responsible; R_5 is the reward from government after enterprises being innovative; αc_1 is the punishment from government when enterprises being irresponsible. That is to say, after making the above-mentioned decision, enterprises pay less attention to the original innovation activities and may cause various losses.; αc_2 is the punishment from market when enterprises being irresponsible. In order not to lose generality, all parameter values mentioned above are positive.

Hypothesis 4: for enterprises, we assume that the responsible strategies have two choices-being responsible or irresponsible while the innovation strategies also have two choices--being innovative or non-innovative. Therefore, the choices of behavior strategy are (both being responsible and innovative; being responsible but not innovative; being innovative but not responsible; being not responsible or innovative). Meanwhile, we assume that at the beginning of the game, the probability for enterprises choosing being responsible is x while the probability of being not responsible is 1-x, the probability for enterprises choosing being innovative is y while the probability of being not innovative is 1-y(see Table 6);

Table 6 profit matrix of enterprises responsible innovation.

		being responsible or not	
being innovative or not		responsible	irresponsible
	innovative	$R+R_4+R_5+\Delta R_3-C$	$R+R_5+\Delta R_2-(1-\alpha)C-\theta c_1-\theta c_2$
	not innovative	$R+R_4+\Delta R_1-\alpha C$	$R-\theta c_1-\theta c_2$

3.2. Evolutionary Game Model

According to the profit matrix of enterprise responsible and innovation evolutionary game model, the expected profit of game participating enterprises is:

$$u_{11}=y(R+R_4+R_5+\Delta R_3-C)+(1-y)(R+R_4+\Delta R_1-\alpha C) \quad (1)$$

The expected profit of game nonparticipating enterprises is:

$$u_{12}=y[R+R_5+\Delta R_2-(1-\alpha)C-\theta c_1-\theta c_2]+(1-y)(R-\theta c_1-\theta c_2) \quad (2)$$

The average expected profit of game participating enterprises taking responsibility and irresponsibility strategies:

$$\begin{aligned}\overline{u_1}&=x[y(R+R_4+R_5+\Delta R_3-C)+(1-y)(R+R_4+\Delta R_1-\alpha C)]\\&+(1-x)[y[R+R_5+\Delta R_2-(1-\alpha)C-\theta c_1-\theta c_2]+(1-y)(R-\theta c_1-\theta c_2)]\end{aligned} \quad (3)$$

The replicator dynamics equation for game participating enterprises taking responsibility and irresponsibility strategies:

$$\frac{dx}{dt}=x(u_{11}-\overline{u_1})=x(1-x)[y(\Delta R_3-\Delta R_1-\Delta R_2)+R_4+\Delta R_1+\theta c_1+\theta c_2-\alpha C] \quad (4)$$

In the equation, $\frac{dx}{dt}$ means the time related probability changing rate of bounded rationality enterprises' strategy choices on whether being responsible. When it is positive, as time going by, the probability of choosing responsible strategies is increasing. When it is negative, as time going by, the probability of choosing responsible strategies is decreasing. As we can see from equation (4), that the probabilistic changing rate of bounded rationality enterprises' strategy choices on whether being responsible is not only proportional to the probability of last time's choice of taking responsible strategies, but also proportional to the expected profit and average expected profit while choosing strategies. When taking responsible strategies, game participating enterprises' profits are not only higher than that when taking irresponsible strategies but also higher than the average expected profit of taking responsible and irresponsible strategies. In that case, taking responsible strategies is benefit to enterprises. As long as the enterprises can do certain calculating and judgment, they will find out the differences of profit in the game process, and polish their strategies similar to the top level. In the similar way, the expected profit of taking innovation strategies or not and the average expected profit of it are:

$$u_{21}=x(R+R_4+R_5+\Delta R_3-C)+(1-X)[R+R_5+\Delta R_2-(1-\alpha)C-\theta c_1-\theta c_2] \quad (5)$$

$$u_{22}=x(R+R_4+\Delta R_1-\alpha C)+(1-x)(R-\theta c_1-\theta c_2) \quad (6)$$

$$\begin{aligned}\overline{u_2}&=y[x(R+R_4+R_5+\Delta R_3-C)+(1-X)[R+R_5+\Delta R_2-(1-\alpha)C-\theta c_1-\theta c_2]]+\\&(1-y)[x(R+R_4+\Delta R_1-\alpha C)+(1-x)(R-\theta c_1-\theta c_2)]\end{aligned} \quad (7)$$

Replicator dynamics equation for game participating enterprises taking innovation and non-innovation strategies:

$$\frac{dy}{dt}=y(u_{21}-\overline{u_2})=y(1-y)[x(\Delta R_3-\Delta R_1-\Delta R_2)+R_5+\Delta R_2-(1-\alpha)C] \quad (8)$$

Now the problem to be solved is: when t tends to infinity, what are enterprises' choices of responsible innovation strategies? That is the evolutionary game stability problem for enterprises'

being responsible and innovative. As to a dynamical system described by differential equation, the equilibrium point's stability can be analyzed by the stability theorem of differential equation and the character of evolutionary stability strategies [25]. A stable state becomes evolutionary stability strategies only when it has robustness to small perturbations. That is to say, if we suppose that x* is the equilibrium point of evolutionary stability strategies, it has to have those character other than being equilibrium itself ($\frac{dx}{dt}$ at that point is zero)-the replicator dynamics still will be back to x* if some players' accidental mistakes made it deviate. In mathematics, it is equivalent to that we assume the interference is ∂x (∂x is minimum), when $x = x^* - \partial x$, $\frac{dx}{dt}$ has to be bigger than zero; when $x = x^* + \partial x$, $\frac{dx}{dt}$ has to be smaller than zero. Therefore, when $\frac{dx}{dt}$ at x* is zero, the derivative has to be smaller than zero [26].

4. The Stability Analysis of Game Evolution

4.1. The Evolutionary Stability Analysis of Responsible or Irresponsible Strategies Choices for Game Participating Enterprises

Suppose $f(x) = dx/dt$

So $$f(x) = x(1-x)[y(\Delta R_3 - \Delta R_1 - \Delta R_2) + R_4 + \Delta R_1 + \theta c_1 + \theta c_2 - \alpha C] \quad (9)$$

If $\frac{dx}{dt}$ at x* is zero, there might be equilibrium points x=0 or x=1

Take the derivative of $f(x)$

$$f'(x) = (1-2x)[y(\Delta R_3 - \Delta R_1 - \Delta R_2) + R_4 + \Delta R_1 + \theta c_1 + \theta c_2 - \alpha C] \quad (10)$$

Suppose $$l_y = \frac{-(R_4 + \Delta R_1 + \theta c_1 + \theta c_2 - \alpha C)}{\Delta R_3 - \Delta R_1 - \Delta R_2} \quad (11)$$

When $\Delta R_3 < \Delta R_1 + \Delta R_2$, which usually happens at the primary stage of market development when the policies and regulations are not sound and the income distribution is unreasonable, which results in the premium profits from being responsible and innovative are lower than the sum of premium profit from being only responsible and only innovative.

Under the circumstance mentioned above, if $R_4 + \Delta R_1 + \theta c_1 + \theta c_2 < \alpha C$, $f'(0) < 0$ and $f'(1) > 0$ are always true no matter what value y is, then x=0 is the evolutionary stability strategy. That is to say, bounded rationality enterprises will choose the irresponsible strategies in the end whether game participating enterprises choose innovation strategies or non-innovation strategies. Phase image is shown as (a) in the figure 1.

If $R_4 + \Delta R_1 + \theta c_1 + \theta c_2 > \alpha C$, when $y < l_y$, $f'(0) > 0$ and $f'(1) < 0$, then x=1 is the evolutionary stability strategy; when $y > l_y$, $f'(0) < 0$ and $f'(1) > 0$, then x=0 is the evolutionary stability strategy; when $y = l_y$, then all x are evolutionary stability strategies. As the conclusion indicates, if the probability of choosing innovation strategy is smaller than the threshold value l_y, bounded rationality enterprises are bound to choose responsible strategy; if the probability of choosing innovation strategy is bigger than this threshold value, bounded rationality enterprises are bound to choose irresponsible strategy; if the probability of choosing innovation strategy is equal to this threshold value, it is uncertain that bounded rationality enterprises will choose responsible or

irresponsible strategy. The threshold value $l_y = \frac{-(R_4 + \Delta R_1 + \theta c_1 + \theta c_2 - \alpha C)}{\Delta R_3 - \Delta R_1 - \Delta R_2}$ mainly depends on two factors: (1) the premium profit for enterprise taking responsible and innovation strategy is more than the sum of premium profit from taking only responsible strategy and only innovation strategy; (2) The enterprises are not responsible for the game between the government and the market, the reward of the government and the pure and responsible premium net income. Phase image is shown as (b) in the figure 1.

When $\Delta R_3 > \Delta R_1 + \Delta R_2$, which usually happens at the mature stage of market development when the policies and regulations are sound and the income distribution is reasonable, which results in the premium profits from being responsible and innovative are higher than the sum of premium profit from being only responsible and only innovative.

Under the circumstance mentioned above, when $R_4 + \Delta R_1 + \theta c_1 + \theta c_2 < \alpha C$, if $y < l_y$, then $f'(0) < 0$ and $f'(1) > 0$,so x=0 is evolutionary stability strategy; if $y > l_y$, then $f'(0) > 0$ and $f'(1) < 0$,so x=1 is evolutionary stability strategy; if $y = l_y$, every x is evolutionary stability strategy. Phase image is shown as (c) in the figure 1.

Under the circumstance mentioned above,if $R_4 + \Delta R_1 + \theta c_1 + \theta c_2 > \alpha C$, then $f'(0) > 0$ and $f'(1) < 0$are always true no matter what value y is, and x=1 is the evolutionary stability strategy. That is to say, bounded rationality enterprises will choose to take responsible strategy whether game participating enterprises choose innovation strategies or non-innovation strategies. Phase image is shown as (d) in the figure1.

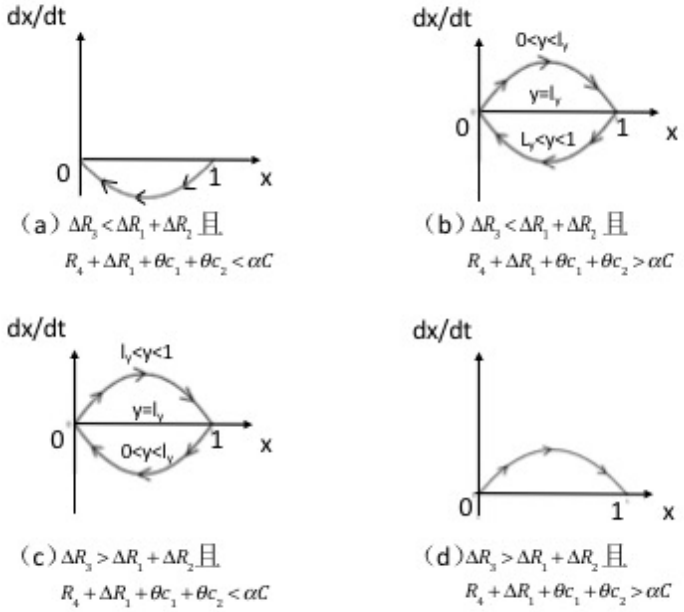


Figure 1 the replicator dynamics phase image of enterprises choosing responsible or irresponsible strategy.

4.2. The Evolutionary Stability Analysis of Innovation or Non-innovation Strategy Choices for Game Participating Enterprises

Suppose $g(y) = dy/dt$

So $g'(y) = y(1-y)[x(\Delta R_3 - \Delta R_1 - \Delta R_2) + R_5 + \Delta R_2 - (1-\alpha)C]$ (12)

Take the derivative of (12)

$$g'(y)=(1-2y)[x(\Delta R_3-\Delta R_1-\Delta R_2)+R_5+\Delta R_2-(1-\alpha)C] \quad (13)$$

Suppose $l_x=\dfrac{-[R_5+\Delta R_2-(1-\alpha)C]}{\Delta R_3-\Delta R_1-\Delta R_2}$ (14)

When $\Delta R_3<\Delta R_1+\Delta R_2$:

If $R_5+\Delta R_2<(1-\alpha)C$, so $g'(0)<0$ and $g'(1)>0$ are always true no matter what value x is, then y=0 is the evolutionary stability strategy. That is to say, bounded rationality enterprises will choose to take non-innovation strategy whether game participating enterprises choose responsible strategies or irresponsible strategies. Phase image is shown as (a) in the figure 2.

If $R_5+\Delta R_2>(1-\alpha)C$, when $x<l_x$, so $g'(0)>0$ and $g'(1)<0$, then y=1 is the evolutionary stability strategy; that is to say, if the probability of choosing responsible strategy is smaller than the threshold value l_x, bounded rationality enterprises are bound to choose innovation strategy; when $x>l_x$, so $g'(0)<0$ and $g'(1)>0$, then y=0 is the evolutionary stability strategy; that is to say, if the probability of choosing responsible strategy is bigger than the threshold value l_x, bounded rationality enterprises are bound to choose non-innovation strategy. When $x=l_x$, then every y is evolutionary stability strategy, that is to say, if the probability of choosing responsible strategy is equal with the threshold value l_x, it is uncertain that bounded rationality enterprises will choose innovation or non-innovation strategy. The threshold value $l_x=\dfrac{-[R_5+\Delta R_2-(1-\alpha)C]}{\Delta R_3-\Delta R_1-\Delta R_2}$ mainly depends on two factors: (1) the premium profit for enterprise taking responsible and innovation strategy is more than the sum of premium profit from taking only responsible strategy and only innovation strategy; (2) the comparison between the reward of government for innovation and the premium net profit of only taking innovation.

Phase image is shown as (b) in the figure 2.

When $\Delta R_3>\Delta R_1+\Delta R_2$

If $R_5+\Delta R_2<(1-\alpha)C$, when $x<l_x$, so $g'(0)<0$ and $g'(1)>0$, then y=0 is the evolutionary stability strategy; that is to say, if the probability of choosing responsible strategy is smaller than the threshold value l_x, bounded rationality enterprises are bound to choose non-innovation strategy; when $x>l_x$, then $g'(0)>0$ and $g'(1)<0$, then y=1 is the evolutionary stability strategy; that is to say, if the probability of choosing responsible strategy is bigger than the threshold value l_x, bounded rationality enterprises are bound to choose innovation strategy; when $x=l_x$, then every y is evolutionary stability strategy, that is to say, it is uncertain that bounded rationality enterprises will choose innovation or non-innovation strategy. Phase image is shown as (c) in the figure 2.

If $R_5+\Delta R_2>(1-\alpha)C$, $g'(0)>0$ and $g'(1)<0$ are always true no matter what value x is, then y=1 is the evolutionary stability strategy. That is to say, bounded rationality enterprises will choose to take innovation strategy whether game participating enterprises choose responsible strategies or irresponsible strategies. Phase image is shown as (d) in the figure 2.

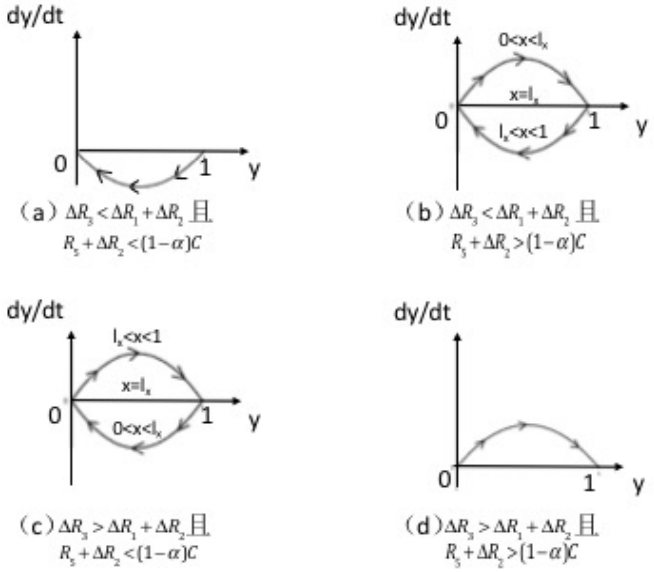


Figure 2 the replicator dynamics phase image of enterprise choosing innovation or non-innovation strategy.

4.3. The Evolutionary Path of Responsible and Innovation Strategy

According to analysis above, the responsible innovation evolutionary game strategy can be divided three types below:

Conclusion1: when responsible or irresponsible strategy and innovation or non-innovation strategy do not affect each other, there are two possible evolutionary paths: first, the game participating enterprises do not take responsible strategy or innovation strategy. Second, the game participating enterprises take both responsible strategy and innovation strategy. We can learn from the analysis of figure 7, when the premium profit of choosing responsible innovation strategy is higher than the premium profit sum of choosing only responsible strategy and only innovation strategy for enterprises, and the sum of premium profit from taking responsible strategy, the reward from government, the punishment avoided from government and market is higher than the input of taking responsible strategy, and the sum of premium profit from taking innovation strategy and the reward from government are higher than the input of taking innovation strategy, the bounded rationality enterprises are bound to take the responsible innovation strategy; if on the contrary, the bounded rationality enterprises are bound to take irresponsible and non-innovation strategy.

There are 4 combinations of the dynamic evolutionary path where only one side of the strategy is affected by the other: when the premium profit ΔR_3brought by responsible innovation is less than the sum of premium profit $\Delta R_1 + \Delta R_2$brought by only being responsible and only innovative, which is $\Delta R_3 < \Delta R_1 + \Delta R_2$, then $R_4 + \Delta R_1 + \theta c_1 + \theta c_2 < \alpha C$ is true is true when the game participating enterprises are choosing responsible or irresponsible strategy, and $R_5 + \Delta R_2 > (1-\alpha)C$ is also true when the game participating enterprises are choosing innovation or non-innovation strategy; or $R_4 + \Delta R_1 + \theta c_1 + \theta c_2 > \alpha C$ is true is true when the game participating enterprises are choosing responsible or irresponsible strategy, and $R_5 + \Delta R_2 < (1-\alpha)C$ is also true when the game participating enterprises are choosing innovation or non-innovation strategy. When the profit ΔR_3 brought by responsible innovation is higher than the sum of premium profit $\Delta R_1 + \Delta R_2$brought by

only being responsible and only innovative, which is $\Delta R_3 > \Delta R_1 + \Delta R_2$, then $R_4 + \Delta R_1 + \theta c_1 + \theta c_2 > \alpha C$ is true is true when the game participating enterprises are choosing responsible or irresponsible strategy, and $R_5 + \Delta R_2 < (1-\alpha)C$ is also true when the game participating enterprises are choosing innovation or non-innovation strategy; or $R_4 + \Delta R_1 + \theta c_1 + \theta c_2 < \alpha C$ is true is true when the game participating enterprises are choosing responsible or irresponsible strategy, and $R_5 + \Delta R_2 > (1-\alpha)C$ is also true when the game participating enterprises are choosing innovation or non-innovation strategy. The specific evolutionary path is shown in figure 3.

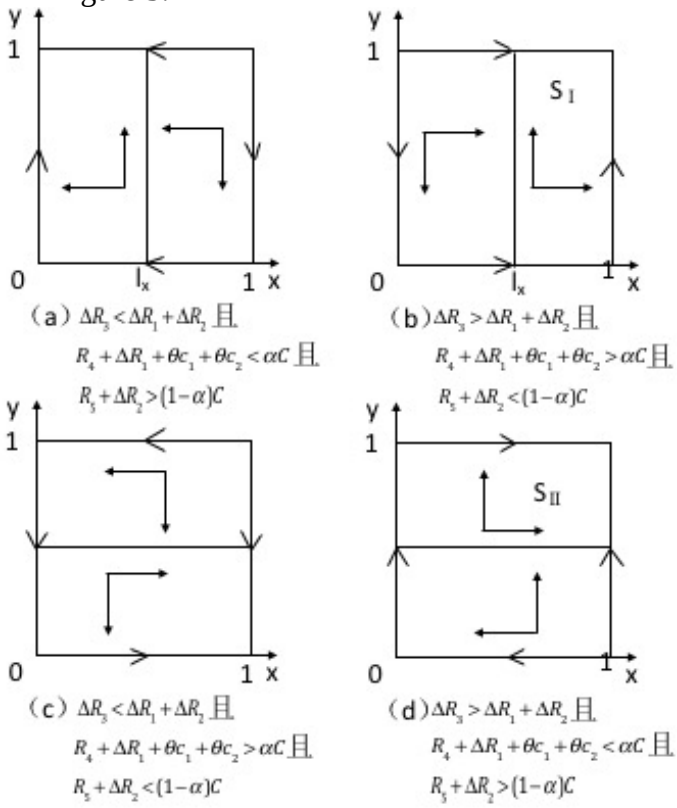
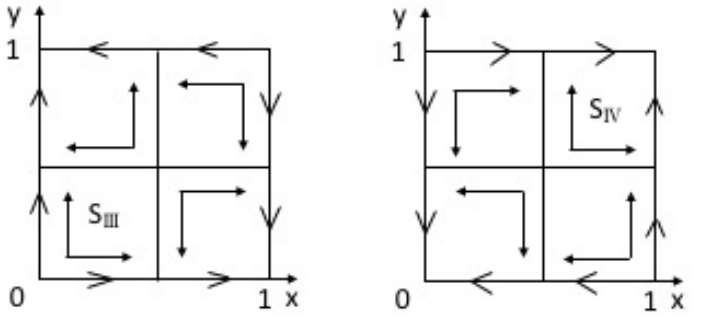


Figure 3 the dynamic evolutionary path where only one side of the strategy is affected by the other.

Conclution2: when only one side of the strategy is affected by the other, there are 4 possible evolutionary paths. But only under the premise that the premium profit of being both responsible and innovative is higher than the premium profit sum of being only responsible and only innovative for enterprises, when the sum of premium profit from taking responsible strategy, the reward from government, the punishment avoided from government and market is higher than the input of taking responsible strategy, even though the premium profit of taking only innovation strategy and the reward from government are less than the input of taking innovation strategy, as long as the probability of taking responsible strategy for enterprises is bigger than certain threshold value, enterprises are bound to choose the responsible innovation strategy in the end. Under the same premise, when the sum of premium profit from taking innovation strategy and the reward from government are higher than the input of taking innovation strategy, even though the sum of premium profit from taking responsible strategy, the reward from government, the punishment avoided from government and market is less than the input of taking responsible strategy, as long as the probability of taking innovation strategy for enterprises is bigger than certain threshold value, enterprises are also bound to choose the responsible innovation strategy in the end.

There are 2 combinations of the dynamic evolutionary path where responsible or irresponsible strategy and innovation or non-innovation strategy affect each other: first, when the premium brought by responsible innovation $\Delta R_3$is less than the sum of premium $\Delta R_1 + \Delta R_2$brought by being only responsible and only innovative, which is $\Delta R_3 < \Delta R_1 + \Delta R_2$. Then $R_4 + \Delta R_1 + \theta c_1 + \theta c_2 > \alpha C$ is true when the game participating enterprises are choosing responsible or irresponsible strategy, and $R_5 + \Delta R_2 > (1-\alpha)C$ is also true when the game participating enterprises are choosing innovation or non-innovation strategy. Second, when the premium brought by responsible innovation $\Delta R_3$is more than the sum of premium $\Delta R_1 + \Delta R_2$brought by being only responsible and only innovative, which is $\Delta R_3 > \Delta R_1 + \Delta R_2$. Then $R_4 + \Delta R_1 + \theta c_1 + \theta c_2 < \alpha C$ is true when the game participating enterprises are choosing responsible or irresponsible strategy, and $R_5 + \Delta R_2 < (1-\alpha)C$ is also true when the game participating enterprises are choosing innovation or non-innovation strategy. The specific evolutionary path is shown in figure 4.



(a) $\Delta R_3 < \Delta R_1 + \Delta R_2$ 且 $R_4 + \Delta R_1 + \theta c_1 + \theta c_2 > \alpha C$ 且 $R_5 + \Delta R_2 > (1-\alpha)C$

(b) $\Delta R_3 > \Delta R_1 + \Delta R_2$ 且 $R_4 + \Delta R_1 + \theta c_1 + \theta c_2 < \alpha C$ 且 $R_5 + \Delta R_2 < (1-\alpha)C$

Figure 4 the dynamic evolutionary path where responsible or irresponsible strategy and innovation or non-innovation strategy affect each other.

Conclusion3: when responsible or irresponsible strategy and innovation or non-innovation strategy affect each other, there are two possible evolutionary paths. First, if the premium profit of being responsible and innovative is lower than the premium profit sum of being only responsible and only innovative, as long as the sum of premium profit from taking responsible strategy, the reward from government, the punishment avoided from government and market is higher than the input of taking responsible strategy, and the premium profit of taking only innovation strategy and the reward from government are higher than the input of taking innovation strategy, and the probabilities of choosing responsible strategy and innovation strategy are both lower than certain threshold value, then the bounded rationality enterprises are bound to choose responsible innovation strategy in the end. Second, if the premium profit of being responsible and innovative is higher than the premium profit sum of being only responsible and only innovative, but the sum of premium profit from taking responsible strategy, the reward from government, the punishment avoided from government and market is lower than the input of taking responsible strategy, and at the same time, the premium profit of taking only innovation strategy and the reward from government are less than the input of taking innovation strategy, as long as the probabilities of choosing responsible strategy and innovation strategy are both higher than certain threshold value, then the bounded rationality enterprises are also bound to choose responsible innovation strategy in the end.

5. Further Analysis of Game Results

From the above conclusions, there are 4 possible results of long-term evolutionary game for enterprise responsible innovation,--(irresponsible, non-innovation), (responsible, non-innovation), (irresponsible, innovation), (responsible, innovation), and the four strategies combination are all stability strategy, and the direction of the evolution depends mainly on the parameters of the income game matrix of the enterprise responsible innovation and the initial state of the system. What we care about is the condition that may evolve to a stable point (responsible, innovation).

From Fig. 3 (b) and (d), it can be seen whether the enterprises will take responsible innovation strategy in those two circumstances depends on the area of areas I and II respectively

$$S_{\text{I}} = 1 - \frac{-[R_5 + \Delta R_2 - (1-\alpha)C]}{\Delta R_3 - \Delta R_1 - \Delta R_2} \tag{15}$$

$$S_{\text{II}} = 1 - \frac{-(R_4 + \Delta R_1 + \theta c_1 + \theta c_2 - \alpha C)}{\Delta R_3 - \Delta R_1 - \Delta R_2} \tag{16}$$

From Fig. 4 (a) and (b), it can be seen whether the enterprises will take responsible innovation strategy in those two circumstances depends on the area of areas III and IV respectively

$$S_{\text{III}} = \frac{-[R_5 + \Delta R_2 - (1-\alpha)C]}{\Delta R_3 - \Delta R_1 - \Delta R_2} \bullet \frac{-(R_4 + \Delta R_1 + \theta c_1 + \theta c_2 - \alpha C)}{\Delta R_3 - \Delta R_1 - \Delta R_2} \tag{17}$$

$$S_{\text{IV}} = [1 - \frac{-[R_5 + \Delta R_2 - (1-\alpha)C]}{\Delta R_3 - \Delta R_1 - \Delta R_2}] \bullet [1 - \frac{-(R_4 + \Delta R_1 + \theta c_1 + \theta c_2 - \alpha C)}{\Delta R_3 - \Delta R_1 - \Delta R_2}] \tag{18}$$

Taking the partial respect of SI to $R_5, \Delta R_2, \alpha, C, \Delta R_3, \Delta R_1$ respectively, we can learn how SI changes with these influence factors. Similarly, we can learn how SII,SIII,SIV change with these influence factors. See Table 7 for details.

Table 7 the influence factor analysis of responsible innovation evolutionary game for enterprises.

Influence factors	S Ⅰ	S Ⅱ	SⅢ	SⅣ
C	↓	↓	-	-
α	↑	↓	-	-
ΔR_1	↓	↑	↓	↓
ΔR_2	↑	↓	↓	↓
ΔR_3	↑	↑	↑	↑
R_4	✘	↑	↑	↑
R_5	↑	✘	↑	↑
θc_1	✘	↑	↑	↑
θc_2	✘	↑	↑	↑

(notice：✘means no influence, and–-means the changing process is not certain)

6. Conclusions and Enlightenment

Under the premise that the game participants have bounded rationality, this paper uses evolutionary game theory to analyze the decision-making evolution process of responsible and innovative in the process of enterprise responsible innovation, and we find out the 4 possible results of long-term evolutionary game for enterprise responsible innovation based on the evolutionary stability of enterprise responsible innovation, that is (responsible, innovation) (irresponsible, non-innovation), (responsible, non-innovation), (irresponsible, innovation), and the four strategies

combination are all stability strategy, and the direction of the evolution depends mainly on the parameters of the evolutionary game matrix of the enterprise responsible innovation and the initial state of the system. At the same time, we investigate the responsible innovation behavior of enterprises and the factors influencing it, the suggestions below can be put forward based on the investigation conclusion.

6.1. Establish a Reasonable Proportion of Responsible Innovation Inputs; Stimulate the Responsible Innovation Energy

According to the analysis result of Table 2, the total input beyond criterion input of responsible innovation for enterprises has negative impact on the responsible innovation behavior of enterprises. But the impacts of input proportion for enterprise responsible strategy α and innovation strategy $1-\alpha$ on area SI,SII,SIII,SIV are not only in one direction. That is to say, the model of this paper is unable to be certain what the specific values of the input proportion α of responsible strategy for enterprises and the input proportion $1-\alpha$ of responsible strategy for enterprises. Game participating enterprises are independent business entities, which aim to maximize their own interests. Therefore, if we want them to evaluate to the behavior of being responsible and innovative, on one hand, we need to reduce the input proportion of being responsible innovative for enterprises so as to make the game participating enterprises gain the maximum profit from responsible innovation and the responsible innovation will be motivated.

6.2. Establish an Effective Responsible Innovation Reward and Punishment Mechanism; Standardize the Responsible Innovative Behavior of Enterprises

From the view point of influencing factors of responsible innovation evolutionary game for enterprises, the reward R_4, R_5 given to enterprises from government for the responsible and innovative behavior and the ∂c_1, ∂c_2 punishment from government and market for irresponsible behavior increase, the possibility of choosing responsible innovation strategy for enterprises will increase. Therefore, on one hand, rather than merely just encourage enterprises to innovate and ignore the reward for responsible innovation, the government should give material and spiritual rewards to the enterprises for responsible innovation trough establishing an effective comprehensive mechanism of reward and punishment. And at the same time, severe penalties should be given to enterprises for irresponsible behaviors. In that way, they can mobilize the enthusiasm of enterprises and stimulate the enthusiasm of responsible innovation, so as to improve the success rate of responsible innovation activities. On the other hand, the government should formulate and improve market related policies and regulations, in case enterprises get away from irresponsible innovative behavior, and have fluke mind. In that way, the responsible innovation behavior of enterprises can be standardized.

6.3. Improve the Premium Business Value of Responsible Innovation, Culminate Responsible Innovation Concept in Enterprises

In the evolutionary model of responsible innovation for enterprises, ΔR_3 has positive effect on the responsible innovation behavior of enterprises, but ΔR_1 and ΔR_2 have negative effect on the responsible innovation behavior of enterprises. That is to say, the premium profit ΔR_3 of enterprises brought by responsible innovation, the premium profit ΔR_1 of enterprises brought only by being responsible and the premium profit ΔR_2 of enterprises brought only by being innovative are all key factors in deciding the enterprise to evolve towards the four behaviors. Therefore, if we want

enterprises to evolve towards the behavior of being both responsible and innovative, the premium profit of enterprises brought by responsible innovation is to be increased to be higher than the premium profit brought by being only responsible or innovative. First, the premium profit of enterprises brought by responsible innovation is usually decided by the development stage of market competition. So when the market competition is not fierce, the government can use methods like public consumption allowance to make the enterprises that are innovative enjoy the maximum premium profit, so as to cultivate the management theory of enterprise responsible innovation. Second, enterprises should know without a doubt about responsible and innovative, and think from the long-term strategic planning when taking responsible innovation. The synergistic effect aroused by it can help enterprises establish a good reputation and image in the market.

6.4. Use the Concerted Mechanism of the Government and the Market, to Create a Responsible and Innovative Social Environment

In this process, first, the government should strengthen the publicity of significance meaning and function of responsible innovation, increase the publicity and recognition of success enterprises in responsible innovation to let them play a leading role, so that enterprises and stakeholders will establish a responsible innovation consciousness. And second, in the fields where the market mechanism is relatively effective, the government should go with the flow, break industry monopolies, cancel unnecessary trade restraint, insist on letting the market help enterprises to choose the path and direction of responsible innovation, and build a fair and well-organized market environment to form a new mechanism of responsible innovation which the government and society support and the enterprises happily take part in. In the end, the government should build an environment promoting responsible innovation. For some new industry forms and business model innovation, efforts should be made to improve the quality, environment and other related certification and evaluation systems for enterprises responsible for innovation, improve the level of government public services, and guarantee the legitimate rights and competition order of responsible innovation for enterprises.

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