# Analysis The Participation of Enterprise In Sustainability Under the ESG Criteria From The Perspective of Game Theory

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**Abstract:** In this paper, I use the evolutionary stable strategy and mixed strategy to construct a game model for both sides from three aspects of ESG and derive the relevant evolutionary stable strategy through a simple replicated dynamic analysis. Then use the Matlab to make a simulation about their evolution of strategy probability. The E-side is a game between the choice of the enterprise's green innovation and governmental responsibility, the S-side is a game between the enterprise's responsibility and employee's loyalty, and the G-side is a game between the enterprise's sustainable internal management and continued investment by investors. The consideration of these aspects of the game is used to construct a game model. The analysis of the mixed and evolutionary stable strategy can be used for the choice of strategy between the two players in different situations, which can be used as a reference when an enterprise is facing the strategy for its management.

**Keywords:** ESG, Evolutionary stable strategy, Sustainable management.

## 1. Background

Environmental problems and sustainability have been hot issues and win a great deal of human attention, which might be the reason why the concept of ESG becomes much more popular and promoted by more people. Rising sea levels, global warming, the shortage of resources on the earth, and so on, all of them always remind the owner and manager of resources that it's necessary for them to make a long-term planning of the usage of resources and govern the business and internal structure reasonably. The ability of an enterprise to stay sustainability and do not make a myopic strategic decision have increasingly become important considerations when investors and the public make the valuation and analysis.

In the process of the enterprise implementing the concept of ESG, considerations from three dimensions will be involved. E, referring to environmental, requires enterprise to considerate thoroughly about its influence on the environment and resources. S, social, is relevant to stakeholders of the enterprise and its social responsibility. G, governance, involves many problems in internal management.

If the enterprise can obtain a high ESG valuation, it suggests that it's more likely to alleviate the problem of environment and resources. The reasonable internal management will support it to grow and develop in the long term, and the enterprise will gain a better reputation. In contrast, a worse evaluation under the standard of ESG will exacerbate the environmental problem and have an adverse impact on its long-term growth and development. The public will complain and enterprise's reputation and evaluation will be badly injured.

Will the enterprise choose to practice the concept of sustainable development? Will it chase a higher evaluation under the standard of ESG? And what's the influence on different people in various aspects caused by these choices of the enterprise? These questions are worthy to be simulated and analysed from the perspective of game theory. During the process of simulation and analysis, we can get the dominant strategy of both sides in the game. Then we can summarize the strategy that contributes to the development and evaluation of the enterprise.

## 2. Literature review

### 2.1 Changes and impacts brought by ESG

The sustainable development of an enterprise is affected by many factors under the standard of ESG principles. The enterprise needs to make a sustainable development planning. However, internal and external factors will play roles when applying and practicing it.

ESG, non-financial evaluation criteria, can influence the financial performance of an enterprise from many aspects. The research of Anton Lisin et al. mentioned not only on the ecological aspects of corporate social responsibility (CSR) but also on the underlying impacts on an enterprise's corporate financial performance (CFP). They concluded that the governing pillar of ESG factors has the highest positive impact on corporations' financial success[1]. Ellen Pei-yi Yu et al. stated that enterprises with greater asset size, better liquidity, higher R&D intensity, fewer inside holdings and well-done past financial performance will be more transparent and perform better in ESG issues[2].

The influence of ESG and people's acknowledge change a lot as some considerable social events happen and society changes. The Covid-19 pandemic has moved ESG investing strategy into the spotlight. Violeta Díaz et al. investigated the importance of ESG ratings in explaining different industry returns during the Covid-19 window by building their ESG factor as the spread in returns between firms in the top ESG quartile and those in the bottom ESG quartile. And their study shows the importance of accounting for ESG factors into investment decisions[3].

### 2.2 The participation of enterprise in sustainability

To some extent, sustainability is involved in the social responsibility of the enterprise. Ans Kolk examined the different conceptualizations of international business and social responsibility illustrated by the articles and showed three sub-themes. Meanwhile, emphasized pivotal developments and implications from a historical perspective[4]. Bob Doherty et al. addressed the social enterprise and its pursuit of the dual mission of financial sustainability and social purpose. They also proposed future study paths for the development of social enterprise and hybrid organization theory by investigating the impact of dual mission and contradictory institutional logic[5].

Because of several companies' profit-driven business structures, their long-term sustainability is always at odds with their profitability. They are unable to consider the influence on the environment and society since they are focused on increasing profit and other financial performance. Antony Upward and Peter Jones developed a framework, including certain key assertions and principles, and modeled a successful, long-term business[6].

The enterprise's sustainable innovation plays a significant role in the implementation of sustainability. Sustainable innovation, according to Hilke Elke Jacke Bos-Brouwers, was described as the renewal or enhancement of goods, services, and processes that may produce improved and increased performance in both the short and long term in economic, environmental, and societal aspects[7].

For sure, the enterprise can take full advantage of the information system to get information and make some sustainable progress with the help of rapidly advanced relevant technology. Nigel P. Melville conducted study demonstrating that information systems play a vital role in influencing environmental beliefs, supporting and modifying the organization's sustainable process and practice, and can improve the environment and economic performance[8].

### 2.3 The application of the game theory

There are static games and dynamic games, perfect information games and imperfect information games, simple games and complex games in the game theory development process. The goal of applying game theory to analysis is to predict the game 's result. In a game or competition with more than two players, game theory can help players adopt a dominant strategy. Rationality is a crucial

component of the game theory framework. Each participant must not only optimize their individual return, but also have the capacity to predict the game's payoff[9].

In the allocation of pollution rights, game theory plays a vital role. The distribution of pollution rights has a substantial impact on a region's economic development. By formatting the fuzzy coalitions among numerous producers and relocating the pollution rights, Xiaoyu Huang et al. selected three districts as test cases for this methodology. And the findings suggested that regions with higher production are more inclined to pursue pollution rights, which might create a foundation for an industrial transformation in this region[10].

Many profit-oriented enterprises develop at the cost of environmental destruction. Wei-Min Ma and Xiao-Na Zhang employed various classic models to simulate the game between enterprise and enterprise, as well as enterprise and government. The whole information model has been put up in a static game, and the strategy has been found in the game between enterprise and government[11]. When enterprises are confronted with an environmental issue, they must think carefully and seriously about the game they are playing with their competitors, the government, or the general public.

## 3. Method

### 3.1 Evolutionary stable strategy (ESS)

ESS states that game players alter their strategies through trial and error, as well as choice in learning and imitation, until they find their evolutionary stable strategy[12]. We can create a payoff matrix to analyze the equilibrium and players' expected payoff utilizing evolutionary stable strategy and mixed strategy.

### 3.2 Mixed strategy

When participants can only pick one dominant strategy with the assistance of the available information in a complete information game, we refer to this strategy as pure strategy. If players can pick more than one strategy with different probability and find a Nash equilibrium under the given information, that strategy is a mixed strategy. The payoff of a pure strategy can be represented by utility, whereas the payoff of a mixed strategy can only be described as expected utility.

### 3.3 Replication dynamics

Replication dynamics is a mechanism that describes the dynamic strategic adjustment of a limited rationality game party with only the ability to simply imitate the dominant strategy. It focuses on the fact that the successful strategies in the group are adopted by progressively more individuals, using either a dynamic differential equation or a set of differential equations.

## 4. The establishment of the model

Before to build a model, we assume that in a "natural" environment where no other constraints are taken into account, both players of the game, as actors, are finite rational individuals with the ability to learn and have their own behavioral options and power.

### 4.1 Evolutionary game model of enterprise sustainable innovation and governmental supervision and support[12]

The environmental aspect is considered from the perspective of whether the enterprise is innovating environmental friendly, and whether the government is fulfilling its regulatory role. This scenario is modeled and discussed in a paper by Le Xu et al. Below is the payoff matrix that they made.

Both the enterprise and the government have two strategies. The probability that the enterprise chooses green innovation is $x$, and the probability that the government chooses to fulfill its

responsibility is $y$. The enterprise's profit when it chooses to produce in its original mode of operation is $P$. $\Delta P$ is the increased profit from choosing green innovation, and its innovation cost is $C$. $P_g$ and $S_g$ are the profit and loss of green environment gained by the government, respectively. $\alpha A$, $\beta J$, $\gamma K$ are the costs consumed by the government in terms of environmental propaganda, incentives for technological innovation and the imposition of pollution taxes and fees, respectively.

**Table 1.** The payoff matrix of enterprise and government

| | Fulfill Responsibilities ($y$) | | Default Responsibilities ($1-y$) | |
|---|---|---|---|---|
| | Government | Enterprise | Government | Enterprise |
| Green Innovation ($x$) | $P_g-\alpha A-\beta J$ | $P+\Delta P+\beta J-C$ | $P_g$ | $P+\Delta P-C$ |
| No Innovation ($1-x$) | $\gamma K-\alpha A-S_g$ | $P-\gamma K$ | $-S_g$ | $P$ |

They got the conclusion that when the government and enterprise are the two players, whether the government will fulfill its responsibilities mainly depends on the relative magnitude of the imposition of pollution taxes and fees, $\gamma K$, and the expenditure of environmental propaganda, $\alpha A$. Meanwhile, whether the enterprise will innovate environmental friendly will depend on the relative magnitude of the profit, $\Delta P$, and the cost, $C$. This conclusion is in line with reality. The decision of an enterprise to innovate green will depend on its consideration of the costs and benefits of green innovation, and the government's investment in environmental taxes and green publicity will influence the firm's decision to innovate green.

### 4.2 Evolutionary game model of enterprise's social responsibility and employee's loyalty

In terms of social responsibility, the model considers whether the company has a sense of corporate and social responsibility and the loyalty of its employees - whether they have a high willingness, or a negative willingness to work or even quit the job. If a company takes an active role in its responsibility, the welfare of its employees will be enhanced. While if it does not, this will be the detriment of employees' interests and welfare. Meanwhile, a high level of employee loyalty will bring additional benefits to the company, while a low level of employee loyalty will cause additional staff turnover costs to the enterprise.

#### 4.2.1 Separate analysis of the enterprise and employee in the game

**Table 2.** The payoff matrix of enterprise and employee

| | High loyalty ($y$) | | Lower loyalty ($1-y$) | |
|---|---|---|---|---|
| | Enterprise | Employee | Enterprise | Employee |
| Responsible ($x$) | $P+\Delta P+\Delta M-C$ | $M+\alpha\Delta M+\beta\Delta P$ | $P+\Delta P-C-\lambda C$ | $M+\beta\Delta P$ |
| Irresponsible ($1-x$) | $P+\Delta M$ | $M+\alpha\Delta M-\Delta C$ | $P$ | $M$ |

For the enterprise, the present revenue is $P$. Taking responsibility will bring the enterprise additional benefits, $\Delta P$. And the cost of taking responsibility will be $C$. If the employees are highly loyal, they will be efficient and productive. It will make an additional benefits of $\Delta M$. Conversely, if its employees are disloyal when the enterprise takes responsibility and pays more to give more welfare to their employees, the loss caused by low efficiency and loyalty of employees to the enterprise will be $\lambda C$. So we can get:

Expected benefits of enterprise when taking responsibility:

$$E_r = y(P + \Delta P + \Delta M - C) + (1-y)(P + \Delta P - C - \lambda C) \tag{1}$$

Expected benefits of enterprise when not taking responsibility:

$$E_i = y(P + \Delta M) + (1-y)P \tag{2}$$

Average earnings of enterprise:

$$\overline{E} = xE_r + (1-x)E_i = x(\Delta P - C - \lambda C) + y(x\lambda C + \Delta M) + P \tag{3}$$

Replicated dynamic equation:

$$F_1(x) = \frac{dx}{dt} = x(E_r - \overline{E}) = x(1-x)(y\lambda C + \Delta P - C - \lambda C) \tag{4}$$

Using the equations above, we can analysis the formula (4) and divide the discussion into the following three situations:

When $y = \frac{C + \lambda C - \Delta P}{\lambda C}$, $x \in [0,1]$ is the evolutionary stable strategy of the enterprise. That is to say that in this case, all values of $x$ are the ESS of enterprise. When $y < \frac{C + \lambda C - \Delta P}{\lambda C}$, $x$=0 is the ESS of the enterprise. It means that the enterprise will choose to be irresponsible if the total cost of taking responsibility and the loss may caused by low efficiency and loyalty of employees when the enterprise takes responsibility are higher than the additional profits, $\Delta P < C + (1-y)\lambda C$. When $y > \frac{C + \lambda C - \Delta P}{\lambda C}$, $x$=1 is the evolutionary stable strategy of the enterprise. When $\Delta P > C + (1-y)\lambda C$, enterprise will choose to be responsible.

To sum up, enterprise's choice will be weighed against the benefits and costs of taking responsibility.

For the employee, the present welfare and wage is $M$. Their high level of loyalty, which keeps them highly motivated and enthusiastic at work and contributes to a more efficient workforce, will bring them additional benefits, $\alpha\Delta M$. If the company is not responsible when their employees work with great enthusiasm and loyalty, employees will be demotivated and, to some extent, do not being paid what they deserve. Therefore, there will cause a loss to the employee, and it will be $\Delta C$. Additional welfare benefits, $\beta\Delta P$, for employee if the company is responsible. So we can get:

Expected benefits of employee when loyalty is high:

$$E_h = x(M + \alpha\Delta\mathrm{M} + \beta\Delta\mathrm{P}) + (1-x)(M + \alpha\Delta M - \Delta C) \tag{5}$$

Expected benefits of employee when loyalty is low:

$$E_l = x(M - \varepsilon C + \beta\Delta P) + (1-x)(M - \varepsilon C - \Delta C) \tag{6}$$

Average earnings of employee:

$$\overline{E} = yE_h + (1-y)E_l = xy\Delta C + x\beta\Delta P + y(\alpha\Delta M - \Delta C) + M \tag{7}$$

Replicated dynamic equation:

$$F_1(y) = \frac{dy}{dt} = y(E_h - \overline{E}) = y(1-y)(x\Delta C + \alpha\Delta M - \Delta C) \tag{8}$$

Using the equations above, we can analysis the formula (8) and divide the discussion into the following three situations:

When $x = \frac{\Delta C - \alpha \Delta M}{\Delta C}$, $y \in [0,1]$ is the ESS. When $x < \frac{\Delta C - \alpha \Delta M}{\Delta C}$, y=0 is the ESS of the employee. When $x > \frac{\Delta C - \alpha \Delta M}{\Delta C}$, y=1 is the ESS of the employee.

In a conclusion, employee's choice will be made after considering the sum value of the additional benefits of being highly loyal and the loss caused by enterprise's irresponsible behaviour when the employee is highly loyal, $\alpha \Delta M - (1-x)\Delta C$.

### 4.2.2 Evolutionary equilibrium analysis of the both sides

In order to analyze and study the evolutionary equilibrium of the two sides of the game, joint replicated dynamic equations of the enterprise and employee, (4) and (8). We can get five equilibrium points, $A(0,0)$, $B(1,0)$, $C(0,1)$, $D(1,1)$, $E(\frac{\Delta C - \alpha \Delta M}{\Delta C}, \frac{C + \lambda C - \Delta P}{\lambda C})$. By means of the equilibrium points, we can obtain the Jacobi matrix. The determinant of the matrix is $\det(J)$, and the trace is $tr(J)$:

$$\begin{bmatrix} \frac{\partial F_1(x)}{\partial x} & \frac{\partial F_1(x)}{\partial y} \\ \frac{\partial F_1(y)}{\partial x} & \frac{\partial F_1(y)}{\partial y} \end{bmatrix} = \begin{bmatrix} a_1 & a_2 \\ a_3 & a_4 \end{bmatrix} \tag{9}$$

$$\det(J) = a_1 a_4 - a_2 a_3 \tag{10}$$

$$tr(J) = a_1 + a_4 \tag{11}$$

When it is the evolutionary stable strategy, the determinant of the matrix must be positive, $\det(J) > 0$, and its trace needs to be negative, $tr(J) < 0$. These two conditions must be met simultaneously.

There was a comprehensive literature review on ESG in 2015, which concluded from a summary of over 2,000 studies that the majority of studies, both qualitative and quantitative, showed a positive correlation between ESG indicators and performance[13]. While this positive correlation still needs to be discussed on a case-by-case basis, we can make an assumption that the additional profit to the enterprise or employee is much higher than the loss or the cost that they think of, $\Delta P - C - \lambda C > 0$, $\alpha \Delta M - \Delta C > 0$. Therefore, it's certain that $\Delta P - C > 0$. In this hypothetical scenario, we can get the equilibrium result in some equilibrium points.

However, the positive and negative signs in some equilibrium points cannot be judged by the assumptions we have made so far. But since the two conditions must be met at the same time and one of them can already be judged, we can temporarily replace the result with a slash. We found the ESS is that the enterprise will choose to take responsibilities and employee will choose to be highly loyal simultaneously.

**Table 3.** Evolutionary stable points for both sides of the game and expression for the value of the equilibrium point

| Equilibrium Point | $\det(J)$ And Its Symbol | $tr(J)$ And Its Symbol | Equilibrium Result |
|---|---|---|---|
| $A(0,0)$ | $(\Delta P - C - \lambda C)(\alpha\Delta M - \Delta C)$ ( + ) | $\Delta P - C - \lambda C + \alpha\Delta M - \Delta C$ ( + ) | Unstable point |
| $B(1,0)$ | $\alpha\Delta M\,(C + \lambda C - \Delta P)$ ( - ) | $C + \lambda C - \Delta P + \alpha\Delta M$ ( \ ) | Unstable point |
| $C(0,1)$ | $(C - \Delta P)(\alpha\Delta M - \Delta C)$ ( - ) | $\Delta P - C - \alpha\Delta M + \Delta C$ ( \ ) | Unstable point |
| $D(1,1)$ | $\alpha\Delta M\,(\Delta P - C)$ ( + ) | $C - \Delta P - \alpha\Delta M$ ( - ) | ESS |
| $E(\frac{\Delta C - \alpha\Delta M}{\Delta C}, \frac{C + \lambda C - \Delta P}{\lambda C})$ | $\frac{(\alpha\Delta M)^2(\Delta P - C)^2(\Delta C - \alpha\Delta M)(\Delta P - \lambda C - C)}{(\Delta C)^2(\lambda C)^2}$ ( - ) | 0 | Saddle Point |

Here, use the Matlab numerical simulation to visualize the trajectory of the game players evolving from different initial values towards the equilibrium point. Remember we supposed here that $\Delta P - C - \lambda C > 0$, $\alpha\Delta M - \Delta C > 0$. The additional benefits are much higher than the cost. So we can get the figure below.

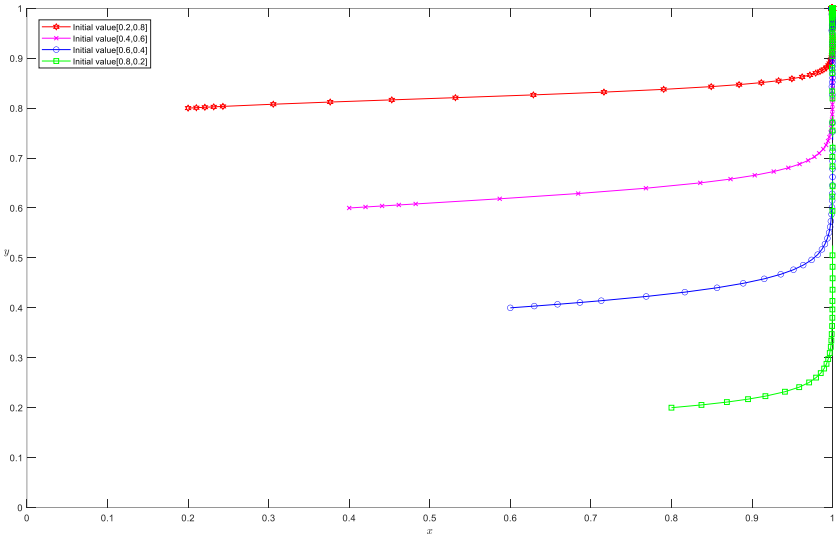


**Figure 1.** Dynamic evolutionary process between the enterprise and employee

when the gap between additional benefits and costs is large

The image shows a visual representation that over time, the evolution in this case tends towards $x = 1$ and $y = 1$. This corresponds to the equilibrium point, the ESS, which we argued above, $D(1,1)$. We can also see that a small change in $y$ corresponds to a large change in $x$, and that $x$ evolves to a value of $1$ before $y$.

This shows that in the process of evolution, regardless of the initial value, enterprise evolves more quickly to take responsibility and employee gradually evolves and finally chooses to remain highly loyal. It seems like a win-win strategy.

When the value of the cost is very close to but lower than the additional benefits:

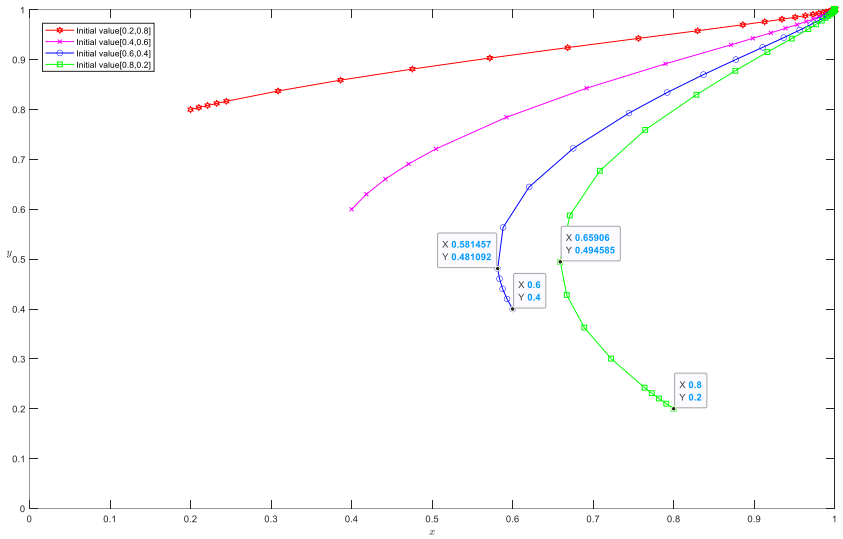


**Figure 2.** Dynamic evolutionary process between the enterprise and employee when the gap between additional benefits and costs is small

This shows that when the gap between additional benefits and costs is small and the probability of the strategy that maintaining a high loyalty is initially low, the firm will gradually choose to reduce the probability of choosing to take responsibility. Then gradually increase this probability, and finally both tend to choose to take responsibility and maintain high loyalty. And the lower the probability that the employee chooses to remain highly loyal at the beginning, the greater the variation in the enterprise's probability of choosing to take responsibility. This is also in line with the reality that enterprise adjusts its strategic choices as it evolves, thus optimizing its business performance.

### 4.3 Evolutionary game model of sustainable management of enterprise and investment of investor

The governmental dimension considers whether the enterprise is managed sustainably and whether the investor will make additional investment in the business. If a company consciously manages its internal business sustainably, it will increase its long-term returns. But if not, the valuation of the company will decrease in the long term. Investors will also increase their investment according to ESG criteria, because a company with a high ESG assessment will provide more returns to investors while the lower one will result in some reduction in investment returns. The actual return on investment may not necessarily outweigh the opportunity cost, but there will have a loss if the enterprise doesn't manage sustainably or the investment is not made.

#### 4.3.1 Separate analysis of the enterprise and investor in the game

**Table 4.** The payoff matrix of enterprise and investor

| | Invest in( $y$ ) | | Don't invest in $(1-y)$ | |
|---|---|---|---|---|
| | Enterprise | Investor | Enterprise | Investor |
| Sustainable( $x$ ) | $P+\Delta P+\Delta I-C$ | $I+\beta\Delta P+\alpha\Delta I$ | $P+\Delta P-C-\lambda C$ | $I+\beta\Delta P$ |
| Unsustainable $(1-x)$ | $P+\Delta I$ | $I-\Delta C$ | $P$ | $I$ |

For the enterprise, the present revenue is $P$. Making sustainable management will bring the enterprise additional benefits, $\Delta P$. And the cost of making sustainable management will be $C$. If the investors invest more, the enterprise will have more money to operate and the revenue will

increase $\Delta I$. Conversely, if the enterprise makes sustainable management but the investors don't want to invest more, the loss to enterprise will be $\lambda C$. So we can get:

Expected benefits to enterprise when making sustainable management:

$$E_S = y(P + \Delta P + \Delta I - C) + (1 - y)(P + \Delta P - C - \lambda C) \tag{12}$$

Expected benefits to enterprise when making unsustainable management:

$$E_U = y(P + \Delta I) + (1 - y)(P - \lambda C) \tag{13}$$

Average earnings of enterprise:

$$\overline{E} = xE_S + (1 - x)E_U = xy\lambda C + x(\Delta P - C - \lambda C) + y\Delta I + P \tag{14}$$

Replicated dynamic equation:

$$F_2(x) = \frac{dx}{dt} = x(E_S - \overline{E}) = x(1 - x)(y\lambda C + \Delta P - C - \lambda C) \tag{15}$$

Using equations above, we can analysis the formula (15) and divide the discussion into the following three situations:

When $y = \frac{C + \lambda C - \Delta P}{\lambda C}$, all values of $x$, $x \in [0,1]$, are the ESS of enterprise. When $y < \frac{C + \lambda C - \Delta P}{\lambda C}$, $x$=0 is the ESS of the enterprise. It means that the enterprise will not choose to make sustainable management if the cost and loss may caused by making sustainable management is higher than the additional profits, $\Delta P < C + (1 - y)C$. When $y > \frac{C + \lambda C - \Delta P}{\lambda C}$, $x$=1 is the evolutionary stable strategy of the enterprise.

It's reasonable to conclude that enterprise's choice will be weighed against the benefits and costs of making sustainable management. This is also true in real life.

For the investor, the present benefits is $I$. If the enterprise makes sustainable management, the additional revenue to investor will be $\beta\Delta P$. Making additional investment will bring an additional benefits when the enterprise makes sustainable management, $\alpha\Delta I$. Conversely, if the enterprise doesn't manage sustainably but the investor invests in more, the investment loss will be $\Delta C$. So we can get:

Expected benefits of investor when making additional investment:

$$E_I = x(I + \beta\Delta P + \alpha\Delta I) + (1 - x)(I - \Delta C) \tag{16}$$

Expected benefits of investor when not investing in more:

$$E_D = x(I + \beta\Delta P) + (1 - x)I \tag{17}$$

Average earnings of investor:

$$\overline{E} = yE_I + (1 - y)E_D = xy(\alpha\Delta I + \Delta C) + x\beta\Delta P - y\Delta C + I \tag{18}$$

Replicated dynamic equation:

$$F_2(y) = \frac{dy}{dt} = y(E_I - \overline{E}) = y(1 - y)[x(\alpha\Delta I + \Delta C) - \Delta C] \tag{19}$$

Using the equations above, we can analysis the formula (19) in the following three situations:

When $x = \frac{\Delta C}{\alpha \Delta I + \Delta C}$, $y \in [0,1]$ is the evolutionary stable strategy of the investor. When $x < \frac{\Delta C}{\alpha \Delta I + \Delta C}$, y=0 is the ESS of the investor. Investor will not invest more money in the enterprise if the expected additional benefits of investing more is lower than the loss may caused by the enterprise's unsustainable management, $x\alpha\Delta I < (1-x)\Delta C$. When $x > \frac{\Delta C}{\alpha \Delta I + \Delta C}$, y=1 is the ESS of the investor.

Summarize briefly, investor's choice will be made after considering the sum value of the expected additional profits of investing more and the investment loss when enterprise doesn't make sustainable management, $x\alpha\Delta I - (1-x)\Delta C$.

### 4.3.2 Evolutionary equilibrium analysis of the both sides

To analyze and study the evolutionary equilibrium of the two sides of the game, joint replicated dynamic equations of the enterprise and investor, (15) and (19). We can get five equilibrium points, $A(0,0)$, $B(1,0)$, $C(0,1)$, $D(1,1)$, $E(\frac{\Delta C}{\alpha \Delta I + \Delta C}, \frac{C + \lambda C - \Delta P}{\lambda C})$. By means of the equilibrium points, we can obtain the Jacobi matrix, and the determinant of the matrix is $\det(J)$, and the trace is $tr(J)$:

$$\begin{bmatrix} \frac{\partial F_2(x)}{\partial x} & \frac{\partial F_2(x)}{\partial y} \\ \frac{\partial F_2(y)}{\partial x} & \frac{\partial F_2(y)}{\partial y} \end{bmatrix} = \begin{bmatrix} a_5 & a_6 \\ a_7 & a_8 \end{bmatrix} \tag{20}$$

$$\det(J) = a_5 a_8 - a_6 a_7 \tag{21}$$

$$tr(J) = a_5 + a_8 \tag{22}$$

Similar to the part 4.2.2, we may assume that the increased profit to the company is significantly higher than the loss or cost that it anticipate, $\Delta P - C - \lambda C > 0$. Therefore, it's certain that $\Delta P - C > 0$. In this hypothetical case, we can obtain the equilibrium result in some points. The determinant of the matrix must be positive and its trace must be negative, $\det(J) > 0$ and $tr(J) < 0$, when it is an evolutionary stable strategy. Both of these requirements must be completed at the same time. Likewise, we can get the table below.

**Table 5.** Evolutionary stable points for both sides of the game and expression for the value of the equilibrium point

| Equilibrium Point | $\det(J)$ And Its Symbol | $tr(J)$ And Its Symbol | Equilibrium Result |
|---|---|---|---|
| $A(0,0)$ | $\Delta C(C + \lambda C - \Delta P)$ ( - ) | $\Delta P - C - \lambda C - \Delta C$ ( \ ) | Unstable point |
| $B(1,0)$ | $\alpha \Delta I(C + \lambda C - \Delta P)$ ( - ) | $C + \lambda C - \Delta P + \alpha \Delta I$ ( \ ) | Unstable point |
| $C(0,1)$ | $\Delta C(\Delta P - C)$ ( + ) | $\Delta P - C + \Delta C$ ( + ) | Unstable point |
| $D(1,1)$ | $\alpha \Delta I(\Delta P - C)$ ( + ) | $C - \Delta P - \alpha \Delta I$ ( - ) | ESS |
| $E(\frac{\Delta C}{\alpha \Delta I + \Delta C}, \frac{C + \lambda C - \Delta P}{\lambda C})$ | $\frac{\Delta C(\alpha \Delta I)^2(\Delta P - C)^2(\Delta P - \lambda C - C)}{(\alpha \Delta I + \Delta C)^2(\lambda C)^2}$ ( + ) | 0 | Saddle Point |

We can noticed that when the additional profit is much higher than all the loss or cost that the enterprise think of, it will choose to take responsibility and investor will choose to invest more simultaneously. It's the evolutionary stable strategy in this situation.

Use the Matlab numerical simulation again to visualize the trajectory of the game players evolving from different initial values towards the equilibrium point. Remember that the additional benefits are much higher than the cost here.

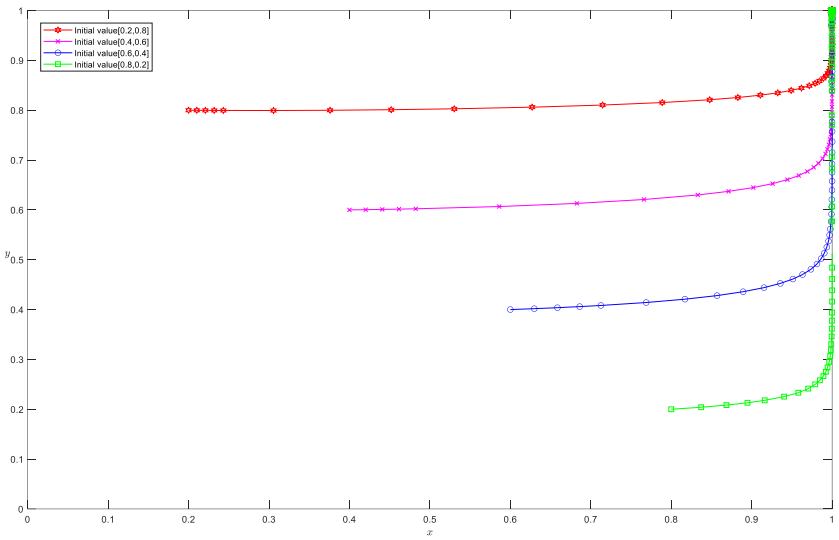


**Figure 3.** Dynamic evolutionary process between the enterprise and investor when the gap between additional benefits and costs is large

The changes in $x$ and $y$ in the evolutionary scenario here have similarities to the evolutionary process between the enterprise and employee that we discussed above. This shows that in the process of evolution, regardless of the initial value, enterprise evolves more quickly to make sustainable management and investor gradually evolves and finally chooses to invest more.

When the value of the loss to the investor is very close to the additional benefits but lower than it:

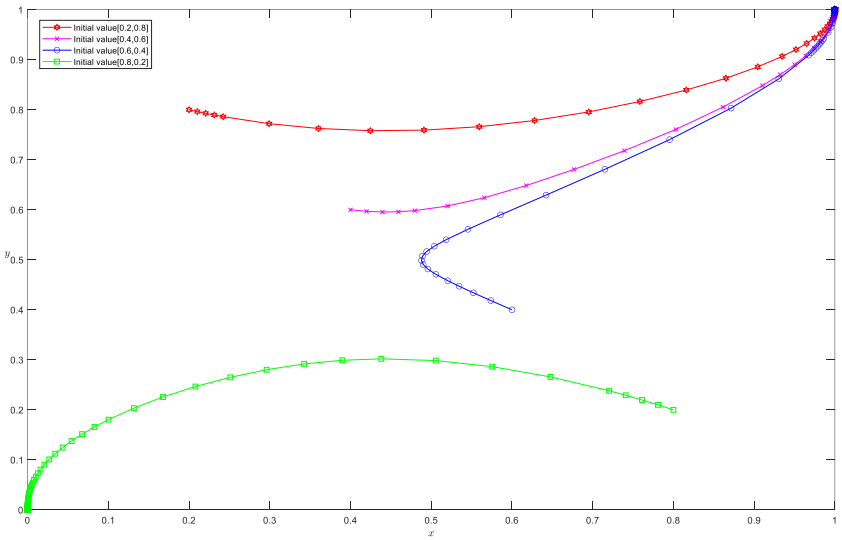


**Figure 4.** Dynamic evolutionary process between the enterprise and investor when the gap between additional benefits and costs is small

It is worth noting that when the difference between additional revenue and loss is small for the enterprise and investor, there is likely to be an evolutionary trend towards the investor choosing not to invest and enterprise choosing not to manage sustainably if the probability of the investor's strategy of investing more is initially low.

## 5. Conclusions

Using knowledge of game theory, such as evolutionary stable strategy and mixed strategy, this paper constructs a model for both sides from three aspects of ESG, and analyses the relevant evolutionary stable strategy through simple replication dynamics. By using the Matlab numerical simulation to visualize the trajectory of the game players evolving from different initial values, we can notice the procession of evolution and find the ESS by considering both sides.

In terms of E, environmental, the model is constructed by Le Li et.al, and it is concluded that whether the government fulfill responsibilities depends on the balance between social responsibility and financial issues, and whether enterprises adopt green innovation depends on the consideration of profit and cost.

In terms of social responsibility, S, the model considers the enterprise's sense of corporate and social responsibility and the loyalty of its employee. Both of them make strategic decision after considering the additional benefits and the cost and loss it may occur. And the Matlab simulation shows that regardless of the initial probability and the size of the gap between their additional benefits and cost or loss, as long as the profit is higher than cost and loss may incur, their ESS is that the enterprise chooses to take responsibility and the employee chooses to be highly loyal. This seems to be a win-win strategy.

The G side looks at the game between the enterprise and investor. Whether or not an enterprise chooses to manage sustainably will be measured against the additional benefits it can bring and the loss it may incur. While whether or not an investor chooses to continue investing will be measured against the additional benefits it can bring and the loss it may incur if the enterprise does not manage sustainably. When profits are significantly higher than costs, both will choose sustainable management and continued investment. However, when the gap between profits and costs is small and the initial value of the investor's choice to continue investing is small, there is a possible evolution in which both will choose a strategy of unsustainable management and no investment simultaneously.

These three aspects of the analysis line up with reality. In the future, it's necessary to consider the impact and its strength of the changing considerations of the game players brought about by the prevalence of ESG standards.

## References

[1] Anton Lisin, Andrei Kushnir, Alexey G. Koryakov, Natalia Fomenko and Tatyana Shchukina. *Financial Stability in Companies with High ESG Scores: Evidence from North America Using the Ohlson O-Score*. Sustainability 2022, 14, 479. https://doi.org/10.3390/su14010479

[2] Ellen Pei-yi Yu, Christine Qian Guo, Bac Van Luu. *Environmental, ocial and governance transparency and firm value*. Bus Strat Env. 2018;27:987–1004

[3] Violeta Díaz * , Denada Ibrushi, Jialin Zhao. *Reconsidering systematic factors during the Covid-19 pandemic–The rising importance of ESG.* St. Mary's University, 1 Camino Santa Maria, San Antonio, TX 78228

[4] Ans Kolk. *The social responsibility of international business:From ethics and the environment to CSR and sustainable development.* Journal of World Business 51 (2016) 23–34

[5] Bob Doherty, Helen Haugh and Fergus Lyon. *Social Enterprises as Hybrid Organizations: A Review and Research Agenda.* International Journal of Management Reviews, Vol. 16, 417–436 (2014) DOI: 10.1111/ijmr.12028

[6] Antony Upward and Peter Jones. *An Ontology for Strongly Sustainable Business Models: Defining an Enterprise Framework Compatible With Natural and Social Science.* Organization & Environment 2016, Vol. 29(1) 97–123, DOI:10.1177/1086026615592933 oae.sagepub.com

[7] Hilke Elke Jacke Bos-Brouwers. *Corporate Sustainability and Innovation in SMEs: Evidence of Themes and Activities in Practice.* Business Strategy and the Environment, Bus. Strat. Env. 19, 417–435 (2010) ,Published online 23 June 2009 in Wiley Online Library (wileyonlinelibrary.com), DOI: 10.1002/bse.652

[8] Nigel P. Melville. *Information Systems Innovation for Environmental Sustainability*. MIS Quarterly Vol. 34 No. 1, pp. 1-21/March 2010

[9] XU Xinhe1, WANG Yan, LIU Jihong, ZHANG Xuefeng. *Analysis on the Achievement Milestones and Limitations of Game Theory*. 2008 Chinese Control and Decision Conference (CCDC 2008)

[10] Xiaoyu Huang, Xiaohong Chen,ID and Ping Huang. Research on Fuzzy *Cooperative Game Model of Allocation of Pollution Discharge Rights*. Water 2018, 10, 662; doi:10.3390/w10050662

[11] Wei-Min Ma, Xiao-Na Zhang. *Study On The Game Analysis Of Environment Pollution Controlling*. Proceedings of the Eighth International Conference on Machine Learning and Cybernetics, Baoding, 12-15 July 2009

[12] Le Xu, Yonggang Ma, Xiaofei Wang. *Environmental policy choices for green technology innovation based on the evolutionary game: government action vs. public participation.* Chinese Journal of Management Science, https://doi.org/10.16381/j.cnki.issn1003-207x.2020.1786

[13] Guangshao Tu. *The Philosophy and Practice of ESG Responsible Investment.*