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Analysis of Green Technology Upgrading Strategy Based on Collaborative Incentive of Environmental Policy and Green Finance

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Abstract With the continuous development of economy, the bottleneck problem of environmental resources has become increasingly prominent. Enterprise environmental governance technology innovation incentive has become an important issue for the development of government, society and enterprises. Under the control of enterprise's expected economic target, this paper discusses the synergistic incentive effect of environmental policy and green finance on enterprise's environmental governance technology innovation decision by using nonlinear programming model. The results show that when the funds for environmental governance technological innovation are insufficient, there is an optimal decision space to use green financial loans to implement technological innovation and upgrade, and then achieve the expected economic goals; Under a given level of environmental governance technology, environmental policies affect whether enterprises can make decisions on technological innovation and upgrading of environmental governance; Green financial mechanism will not. However, when the enterprise makes the decision of environmental governance technology upgrading, it will affect the enterprise's decision on green financial loan amount. The results of the study have guiding significance for the formulation of environmental policy and green financial policy, as well as the decision-making of enterprise environmental governance technology innovation and upgrading.

Keywords environmental policy; green finance; environmental governance; technological innovation; optimal decision

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1 Introduction

With the continuous development of economy, the bottleneck of environmental resources has become increasingly prominent. Environmental governance and green technology innovation have become an important topic of human sustainable development. In addition to governments at all levels and manufacturing enterprises (polluters) taking charge of environmental governance, third-party governance has also become a complementary and innovative tool for traditional governance models. For enterprises, due to the high cost of environmental governance technology innovation, if there is no certain incentive policy, enterprises would rather maintain the status quo or implement technological innovation in accordance with the government's minimum environmental governance standards.

In order to promote the effective use of resources, environmental governance and ecological civilization construction, the governments all over the world are exploring the establishment of environmental policy incentive mechanism and green financial support system, and issuing industry-related incentive policies to provide favorable conditions for enterprises. For example, in order to standardize and promote the healthy development of environmental governance industry, the general office of the CPC Central Committee and the general office of the State Council issued "Guiding Opinions on Construction of Modern Environmental Governance System" in March 2020, proposing to increase support for the environmental protection industry, strengthen the independent innovation of key environmental protection technology products, promote the demonstration and application of the first batch (sets) of major environmental protection technology and equipment, and accelerate the improvement level of technology and equipment in environmental protection industry. It suggested to strengthen leading enterprises, cultivate a number of professional backbone enterprises, and support a number of small and medium-sized enterprises with specialization, characteristics, excellence and quality. One belt, one road initiative, would be promoted to promote the development of cash technology, equipment and production capacity.

At the same time, financial institutions, starting from their own credit functions, formulate and issue green financial mechanisms according to the government's requirements for environmental governance. On the one hand, they provide enterprises with financing support for environmental governance technology innovation. On the other hand, they can realize their own business innovation and development through green finance. For example, the people's Bank of China issued "Notice on Supporting the Green Finance Reform and Innovation Pilot Zone to Issue Green Debt Financing Tools" on May 13, 2020, which supported to issue green debt financing tools in the green financial reform and innovation pilot zone, and encouraged enterprises in the pilot areas to increase their financing efforts and enrich their financing channels by registering and issuing green debt financing tools such as directional tools and asset-backed notes credit lines. It was emphasized that the research and development of innovative products suitable for the economic characteristics of the experimental zone should be carried out according to local conditions. It would support enterprises in pilot areas to carry out structural innovation of green debt financing tools, encourage to issue structural debt financing tools linked to various environmental rights and interests, green asset-backed bills and other innovative products supported by cash flow generated by green projects. At the same time, pilot areas were encouraged to set up market-oriented green industry guarantee funds or financing guarantee institutions according to the law, provide credit enhancement services for green bonds, and support the issuance of green bonds and the implementation of green projects.

The measures will have an important impact on the development of enterprise production, social environment management and green technology innovation. It also shows that environmental policy and green finance have an important impact and incentive effect on environmental governance technology innovation. However, at present, the implementation subjects of environmental policies and ones of green finance belong to the government and financial institutions respectively, and the impact mechanism of environmental policies and green finance on the environmental governance technological innovation of enterprises is different due to the different paths and modes of action. In addition, because their purpose of the same direction are to stimulate the environmental governance technological innovation of enterprises, complement each other. Therefore, the collaborative research on environmental policy and green finance is of great significance to the realization of enterprises environmental governance technology innovation. Besides, enterprises need a large amount of capital investment to carry out environmental governance technology innovation, which will inevitably increase the operating costs, thus affecting the realization of business objectives. On the one hand, enterprises take profitmaking as the purpose. On the other hand, enterprises carrying out environmental governance technology innovation, and implement energy conservation and emission reduction is their social responsibility. Under the guidance of government environmental policies and the green financial incentives of financial institutions, the coordination of environmental governance technology innovation and enterprises management objectives should will be inevitably considered as a whole.

To sum up, in the study of environmental policy and green finance on enterprises environmental governance technology innovation incentive, the coordination of environmental policy and green finance, and the coordination of environmental governance technology innovation and enterprises business objectives (hereinafter referred to as "two collaboration") are two very important relationships in enterprises environmental governance technology innovation, which are also the main research content of this paper.

2 Literature Review

Just as the government and financial institutions pay close attention to the environmental governance technological innovation of enterprises, experts and scholars have studied the effect and the efficiency of environmental policy and green finance, and the impact mechanism of enterprises production and operation, environmental governance and green technology innovation from multi-level and multi-angle.

1) Starting from the effect and efficiency, the impact of environmental policy or green finance on green technology innovation of enterprises was studied. American scholar Michael Porter pointed out that appropriate intensity of environmental regulation could stimulate technological innovation of enterprises (weak Porter hypothesis). Through first mover advantage, enterprises actively sought to improve resource utilization, reduced costs or increased sales revenue, so as to establish a competitive advantage (strong Porter hypothesis)^[1]; There were still great

differences in the conclusions of the current domestic and foreign scholars on the validation of the Porter hypothesis, both in theory and in practice^[2]. In order to test this hypothesis, some scholars analyzed the data reflecting the behaviour of enterprises to verify whether the technological innovation behavior of enterprises was affected by environmental regulations in a certain range. For example, a number of scholars tested the applicability of Porter hypothesis based on the combined data of Chinese industrial enterprises and provincial environmental regulations^[3]; Based on the provincial panel data of China, some scholars used DEA Malmquist method to measure the industrial total factor productivity and its source decomposition, and tested the relationship among environmental regulation, technological innovation and industrial total factor productivity^[4]; Based on the system mechanics model, a few learned men discussed the impact of port environmental policy on port cost-benefit structure^[5]; In addition, based on the fixed effect model and intermediary effect analysis method of Hausman test, some scholars analyzed the panel data of 52 green enterprises and 81 high pollution and high emission enterprises in China from 2001 to 2017, and inspected the environmental policies and development of asymmetric effect of green credit on debt financing cost. The results showed that environmental policy and green credit had positive incentive effect on green technology innovation^[6]. This kind of research focuses on whether the environmental policy or green financial mechanism has an impact on the environmental governance technological innovation behaviour of enterprise. That is, it tests Porter's hypothesis, and generally do not consider the "two collaboration" problem.

- 2) Starting from the exogenous mechanism, the impact of environmental policy or green finance on green technology innovation of enterprises was studied. For example, some scholars used the method of multi case study to analyze the operation mode of risk management, sustainable accounting and financing adopted by large listed companies in the issuance of green bonds, and put forward the theoretical framework of the integration of legal policies and marketoriented financing to form an integrated green financing system^[7]: In addition, Christian used the transition management framework to conduct a longitudinal analysis of the policy-making cycle and discusses the evolution of green bonds with different forms of secondary evidence [8]. A few scholars used the fixed effect regression model to analyze the panel data of 320 enterprises in heavy pollution industry listed on Shanghai Stock Exchange from 2008 to 2016. The results showed that the environmental information disclosure system had not transmitted valuable signals to the market and had not become the decision of bank risk management Policy tools^[9]. Others have studied the path choice and policy support of manufacturing environmental governance technology upgrading in Guangdong Province based on system mechanics model^[10]. This kind of research discusses the external impact and path of environmental policy or green finance on enterprises environmental governance technology innovation through various perspectives, but does not focus on the "two synergies" in the influencing process.
- 3) Starting from the endogenous mechanism, the impact of environmental policy or green finance on green technology innovation of enterprises was studied. Some scholars have directly or indirectly carried out the evaluation research on the impact of environmental policies or green finance on green technology innovation. They believed that the comprehensive effect of various regulatory instruments would better reflect the green innovation effect of environmental

regulation^[11,12]. A number of scholars brought the demand, supply and selection mechanism of environmental policy into the economic framework, and proposed the integration and marketization path of environmental policy innovation^[13]; From the two important financial fields of bonds and funds, a few learned men studied their financing mode and its significance to the development of green PPP industry in China, and put forward policy suggestions to promote the development of green PPP industry^[14]; A few scholars have found that technological innovation and capital space are the key driving forces of green growth by analyzing the factors of green economic growth, or measuring the technological heterogeneity between super frontier environmental efficiency and group frontier environmental efficiency^[15-18]. Schinas, et al. tried to construct the export credit financing mode on the basis of summing up experience, and applied it to the transformation of existing ships and new green ships^[19].

On the one hand, this kind of research studies the comprehensive effect of environmental policy and green finance on enterprises environmental governance technology innovation through the method of comprehensive evaluation, although which also includes the role of "two collaboration", the mechanism of "two collaboration" is not clear. On the other hand, research focuses on the integration of environmental policy and economic framework, which is the second collaborative problem proposed in this paper, but does not consider the "two collaboration" problem comprehensively. The third is to put forward some suggestions on environmental policy or green finance through summing up work experience. It is easy to see that there are many achievements in the research on the incentive and impact of environmental policies and green finance on green technology innovation which perspective and content are very rich. However, there are few research programs considering the collaboration of environmental policy and green finance, as well as the overall consideration of enterprises economic objectives, whether it is the effect and efficiency research, endogenous mechanism or exogenous mechanism research, and this is a very important practical problem. Based on the above background and the current research situation, this paper attempts to study the collaborative incentive of government environmental policy and green finance on enterprises environmental governance technology innovation, as well as the "two collaboration" relationship. Based on the existing research methods, starting from the problem orientation, this paper considers the dependence relationship between technical service cost and economic benefits of environmental governance enterprises, and studies the realization of environmental governance technology innovation objectives under the control of expected economic objectives of environmental governance enterprises, so as to make the research closer to the actual needs of environmental governance enterprises. Considering the comprehensive influence of government environmental policy and green finance policy on enterprises environmental governance technology innovation, this paper uses nonlinear programming method to study the collaboration mechanism and design suggestions of the collaboration mechanism of environmental policy and green finance on enterprises green technology innovation under the constraint of enterprises economic objectives, and gives the optimal strategy analysis of enterprises environmental governance technology innovation.

3 Basic Model

3.1 Model Description

It is assumed that environmental governance enterprise B is in the original state of environmental governance technology level and needs to achieve certain economic goals in a production cycle.

- 1) The government supervises the environment of environmental governance enterprise B. If enterprise B fails to meet the technical level of environmental governance stipulated by the state, it will be subject to certain economic punishment and its social reputation will also be affected.
- 2) If enterprise B is not a fraid of economic punishment and does not worry about the impact of social reputation, it cannot upgrade technology. However, if enterprise B is a fraid of economic punishment and social reputation reduction, it is necessary to implement technology upgrading for environmental governance according to the requirements of the government. When enterprise B implements the upgrading of environmental governance technology level, it needs to invest its own upgrading funds, which will increase the operating cost of the enterprise, which will choose between upgrading and not upgrading.
- 3) If the government issues environmental incentive policies to encourage enterprise B, it will give environmental policy subsidies when enterprise B upgrades. At this time, enterprise B will comprehensively consider these factors when upgrading environmental governance technology, and finally determine whether to upgrade.
- 4) If financial institutions issue green financial incentive policies to provide green financial preferential loans for enterprise B, then enterprise B will consider whether it can achieve the purpose of technology upgrading by applying for green financial loans when its own funds are insufficient. In this way, enterprise B can solve the problem of environmental governance technology upgrading without affecting its current assets, and obtain the government's environmental policy subsidies after upgrading. At the same time, it can also achieve the economic goal of the production cycle (as shown in Figure 1).

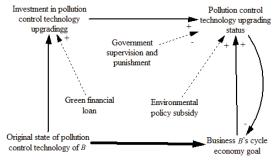


Figure 1 Collaborative incentive control model of environmental policy and green finance

3.2 Model Assumptions

We assume that the production purpose of environmental governance enterprise B is to use the professional technical services of environmental governance to obtain benefits, and the greater the output of technical services, the more economic benefits will be obtained. When

a pollutant discharge enterprise manages the pollutants discharged by itself, the pollutant discharge enterprise replaces the environmental governance enterprise B and becomes a special environmental governance professional service enterprise. For the convenience of research, we first make the following symbolic hypothesis (in the following hypothesis, if the lower foot of the variable symbol is marked as "0", it represents the initial value of the variable).

Q represents the output of environmental governance of enterprise B;

p represents the profit margin per unit output of enterprise B assumed to be relatively fixed within a certain period of time and not affected by other factors;

 α represents the technological level of environmental governance of enterprise B, $\alpha \in [0, 1]$. The smaller the α , the higher the technological level, the stronger the technological innovation ability of enterprise B;

 $I(\alpha)$ represents enterprise B needs to use the technology upgrading fund invested in one time by green financial loan in order to realize technology α , which is abbreviated as I, $I'(\alpha) < 0$, $I''(\alpha) > 0$, I(1) = 0. The smaller the α , the greater the one-time investment required by enterprise B. When α reaches the maximum value of 1, the realization of technology level α does not need any investment;

 $C(\alpha,Q)$ represents the variable cost of enterprise B, affected by the technical level and production, which is abbreviated as C, $\frac{\partial (C(\alpha,Q)}{\partial \alpha} > 0$, $\frac{\partial C(\alpha,Q)}{\partial Q} > 0$, without confusion, and recorded as $C(1,Q) = C_0$.

 $t(\alpha)$ represents loan interest rate of green finance (financial loan that financial institutions support green innovation of enterprise B), $t(\alpha) \in [0,1]$, $t'(\alpha) > 0$, repayment term is T;

 $\pi(\alpha, Q)$ represents the total profit of enterprise B at the technical level of α and the output of Q, which is abbreviated to π without confusion;

 $\beta(\alpha)$ represents environmental policy, that is, the subsidy coefficient given by the government to enterprise B after the upgrading of environmental governance technology, namely, the subsidy coefficient for unit output of enterprise B, $\beta(\alpha) \geq 0$, $\beta(1) = 0$, $\beta'(\alpha) < 0$, $\beta''(\alpha) > 0$;

 $S(\alpha)$ represents the control function of economic expectation target of enterprise B. $S(\alpha) \ge 0$ is a continuous differentiable function on [0,1];

 $\Delta \pi = \pi - \pi_0$ represents the total profit increment of enterprise B.

For enterprise B, in the case of insufficient self-owned funds for technology upgrading, the following non-linear planning problems need to be considered before making green financial loan decisions in order to realize technology upgrading as soon as possible by using green financial loans and obtain green technology innovation subsidies from the government, to obtain the maximum economic benefits within the loan term T, and to achieve a certain economic expected goal $\Delta \pi \geq S(\alpha)$:

$$\begin{cases} \max \pi = [p + \beta(\alpha)]Q - [C(\alpha, Q) + (1 + t(\alpha))^T I(\alpha)] \\ \text{s.t. } \Delta \pi(\alpha, t, Q) \ge S(\alpha), \quad \alpha \ge 0, \quad t \ge 0, \quad Q \ge 0. \end{cases}$$

4 Model Solution

It can be proved that the above planning issues meet Kuhn-Tucker conditions. The gradient of the objective function with respect to α is

$$\nabla(-\pi) = C'\alpha + (1+t)^{T-1}[TIt' + (1+t)I'] - \beta'Q. \tag{1}$$

Let $\Delta \pi = [p + \beta(\alpha)]Q - [C(\alpha, Q) + (1 + t(\alpha))^T I(\alpha)] - pQ_0 + C_0$, then the gradient of $\Delta \pi$ with respect to α is

$$\nabla(\Delta \pi - S(\alpha)) = \beta' Q - [C'_{\alpha} + (1+t)^{T-1} (TIt' + (1+t)I'] - S'(\alpha). \tag{2}$$

By introducing the generalized Lagrange multiplier μ^* to the above constraints, the Kuhn-Tucker conditions of the program are as follows:

$$\begin{cases} L = \nabla(-\pi) - \mu^* \nabla(\Delta \pi - S(\alpha)) = 0, \\ \mu^* (\Delta \pi - S(\alpha)) = 0, \ \mu^* \ge 0. \end{cases}$$

The following solution equations (4) are discussed in two cases.

1) $\mu^* > 0$. In this case, let $\mu^* > 0$ the second formula from formula (4) can derived $\Delta \pi = S(\alpha)$, namely

$$[p + \beta(\alpha)]Q - [C(\alpha, Q) + (1 + t(\alpha))^T I(\alpha)] - pQ_0 + C_0 = S(\alpha).$$
(3)

Finding partial derivatives of Formula (5) on both sides on α , we have $C'_{\alpha} + (1+t)^{T-1}[TIt' + (1+t)I'] - \beta'Q + S'(\alpha) = 0$. Then it is substituted into Formula (2), and considering the formula (2.4) $L = \nabla(-\pi) - \mu^*\nabla(\Delta\pi) = 0$, we have $S'(\alpha)(1+\mu^*) = 0$, then $S'(\alpha) = 0$. So in this case, $S(\alpha)$ is constant in any case or α is the extreme point of $S(\alpha)$. Then, it can be obtained by Formula (5).

$$I(\alpha) = (1 + t(\alpha))^{-T} [p(Q - Q_0) + (C_0 - C(\alpha)) + \beta(\alpha)Q - S(\alpha)].$$
(4)

Obviously, $p(Q-Q_0)+(C_0-C(\alpha))+\beta(\alpha)Q>S(\alpha)$ is the necessary and sufficient condition for $I(\alpha)>0$. In this case, as long as the enterprise actively apply for green financial loans $I(\alpha)>0$, they can not only achieve technical level α , but also achieve the expected economic goals $\Delta\pi=S(\alpha)$, then total profit $\pi_1=\pi_0+\Delta\pi=pQ_0-C_0+S(\alpha)$ is gained.

2) $\mu^* = 0$. In this case of $\mu^* = 0$, $L = \nabla(-\pi) - \mu^* \nabla(\Delta \pi - S(\alpha)) = 0$, as only one condition left in Formula (4). Computing and simplifying, the following equation can be obtained:

$$C'_{\alpha} + (1+t)^{T-1} [TIt' + (1+t)I'] - \beta' Q = 0.$$

Integral on both sides, we have $C(\alpha, Q) + (1 + t(\alpha))^T I(\alpha) - \beta(\alpha) Q = E$ (E is a constant). Let $\alpha = 1$, substituted this formula (mind $C(1, Q) = C_0$, $I(1) = \beta(1) = 0$), then $E = C_0$, namely, $C(\alpha, Q) + (1 + t(\alpha))^T I(\alpha) - \beta(\alpha) Q = C_0$, so we have

$$I(\alpha) = (1 + t(\alpha))^{-T} [C_0 - C(\alpha) + \beta(\alpha)Q]. \tag{5}$$

Therefore, $\beta(\alpha)Q > C(\alpha) - C_0$ is the necessary and sufficient condition for $I(\alpha) > 0$. In this case, if the enterprise applies for green financial loans $I(\alpha) > 0$, they can achieve technical level α .

There is $\Delta \pi = [p + \beta(\alpha)]Q - [C(\alpha, Q) + (1 + t(\alpha))^T I(\alpha)] - pQ_0 + C_0 = p(Q - Q_0)$. If $p(Q - Q_0) \geq S(\alpha)$ can be met at this time, the environmental governance enterprise can apply for green financial loans $I(\alpha) > 0$ to achieve the technical level of α and also the expected economic goals $\Delta \pi = p(Q - Q_0) \geq S(\alpha)$, then total profit $\pi_2 = \pi_0 + \Delta \pi = pQ - C_0$ is gained.

In totally, planning problem (1) has two extreme points $\pi_1 = pQ_0 - C_0 + S(\alpha)$ and $\pi_1 - \pi_2 = S(\alpha) - p(Q - Q_0)$. So when $p(Q - Q_0) < S(\alpha), \pi_1 > \pi_2$, the optimal solution is $\pi_1 = pQ_0 - C_0 + S(\alpha)$; When $p(Q - Q_0) \ge S(\alpha), \pi_1 \ge \pi_2$, the optimal solution is $\pi_2 = pQ - C_0$. Thus, the following propositions and their corollaries are obtained:

Proposition 1 For planning problems (1), when $p(Q - Q_0) < S(\alpha)$, the optimal solution is $\pi_1 = pQ_0 - C_0 + S(\alpha)$; When $p(Q - Q_0) \ge S(\alpha)$, the optimal solution $\pi_2 = pQ - C_0$.

Corollary 1 For planning problems (1), if the expected economic goal is $\Delta \pi \geq 0, Q < Q_0$, $I(\alpha) = (1+t(\alpha))^{-T}[p(Q-Q_0)+(C_0-C(\alpha))+\beta(\alpha)Q]$ being selected, $\pi_1 = pQ_0-C_0$ as optimum economic benefits can be achieved; when $Q > Q_0$, $I(\alpha) = (1+t(\alpha))^{-T}[C_0-C(\alpha)+\beta(\alpha)Q]$ being selected, $\pi_2 = pQ - C_0$ as the optimum economic benefits can be achieved.

5 Technology Upgrading Strategy

Under the collaborative incentives of government environmental policy and green finance of financial institutions, the environmental governance enterprise will choose different technology upgrading strategies according to their economic benefit objectives and their own capital conditions.

5.1 Impact of Environmental Policy β on Technological Upgrading Decision

From the solution process of Model (1) and Proposition 1, it can be seen that the decision of technological upgrading of the environmental governance enterprise will be affected by production income $p(Q - Q_0)$ and expected target $S(\alpha)$ given technological level α . Regarding the impact of environmental policy on the decision of technological upgrading of the environmental governance enterprise, we have the following inferences:

Corollary 2 Given the technological level α , when $p(Q-Q_0) < S(\alpha)$ and $p(Q-Q_0) + (C_0 - C(\alpha)) + \beta(\alpha)Q > S(\alpha)$, with other conditions unchanged, improving β can not only increase the enthusiasm of the environmental governance enterprise to use green financial loans to achieve technological upgrading, but also increase the amount to use green financial loans.

Proof According to proposition 1, when the production income is greater than the expected target, namely $p(Q-Q_0) < S(\alpha)$, the optimal solution of planning (1) is as follows: $\pi_1 = pQ_0 - C_0 + S(\alpha)$. From the solution process of planning (1), it can be seen that the decision of the environmental governance enterprise follows the path $\mu^* > 0$, namely $\Delta \pi = S(\alpha)$. There is a formula (6) on this path, namely $I(\alpha) = (1+t(\alpha))^{-T}[p(Q-Q_0)+(C_0-C(\alpha))+\beta(\alpha)Q-S(\alpha)]$, and the necessary and sufficient condition for $I(\alpha) > 0$ is $p(Q-Q_0) + (C_0-C(\alpha)) + \beta(\alpha)Q > S(\alpha)$, equivalent to $\beta(\alpha) > Q^{-1}[S(\alpha) - p(Q-Q_0) - C_0 + C(\alpha)]$, namely environmental policy $\beta(\alpha)$ is the factor that affects whether $I(\alpha)$ is greater than 0. So if other conditions remain unchanged, as long as $\beta(\alpha) > Q^{-1}[S(\alpha) - p(Q-Q_0) - C_0 + C(\alpha)]$, there will be $I(\alpha) > 0$. Because I is an increasing function of β , that is to say, improving β can not only increase the enthusiasm of the environmental governance enterprise to use green financial loans to achieve technological upgrading, but also increase the quota to use. Certificate is completed.

Corollary 3 When $p(Q - Q_0) \ge S(\alpha)$ and $\beta(\alpha)Q > C(\alpha) - C_0$, under other conditions unchanged, reducing β can not only improve the enthusiasm of the environmental governance enterprise to use green financial loans to achieve technological upgrading, but also promote to increase the quota.

Proof According to Proposition 1, when the production income is greater than the expected target, namely, $p(Q - Q_0) \geq S(\alpha)$, the optimal solution of planning (1) is as follows: $\pi_2 = pQ - C_0$. From the solution process of planning (1), it can be seen that the decision of the environmental governance enterprise follows the path of $\mu^* = 0$. There is a formula (7) on this path, namely $I(\alpha) = (1+t(\alpha))^{-T}[C_0 - C(\alpha) + \beta(\alpha)Q]$, and the necessary and sufficient condition for $I(\alpha) > 0$ is $\beta(\alpha)Q > C(\alpha) - C_0$, equivalent to $\beta(\alpha) > Q^{-1}[C_0 - C(\alpha)]$, namely environmental policy $\beta(\alpha)$ is the factor that affects whether $I(\alpha)$ is greater than 0. Because I is an decreasing function of β , under other conditions unchanged, on the premise that $\beta(\alpha) > Q^{-1}[C_0 - C(\alpha)]$, reducing β can not only increase the enthusiasm of the environmental governance enterprise to use green financial loans to achieve technological upgrading, but also increase the quota to use. Certificate is completed.

5.2 The Impact of Green Finance Loan Interest Rate t on Technological Upgrading Decision

Corollary 4 Given technological level α , the interest rate t of green financial loans can not affect the decision of technological upgrading of the environmental governance, but after it is made by the enterprise, reducing $t(\alpha)$ will promote the environmental governance enterprise to increase the quota of green financial loans.

Proof From the solution process of planning (1), it can be seen that when the production income is greater than the expected target, namely, $p(Q-Q_0) < S(\alpha)$, the decision of the environmental governance enterprise follows the path of $\mu^* > 0$, namely $\Delta \pi = S(\alpha)$. There is a formula (6) on this path, namely $I(\alpha) = (1+t(\alpha))^{-T}[p(Q-Q_0)+(C_0-C(\alpha))+\beta(\alpha)Q-S(\alpha)].$ Obviously, no matter how $t(\alpha)$ changes, it will not affect the positivity and negativity of $I(\alpha)$. That is to say, changing $t(\alpha)$ will not change the decision of the environmental governance enterprise on whether to use green financial loans to upgrade technology. However, in the case of $I(\alpha) > 0$, $I(\alpha)$ is the subtraction function of t, which can affect the green financial loan quota of the enterprise after making technological upgrading decisions, that is, reducing $t(\alpha)$ will to improve the quota of green financial loan. Similarly, when $p(Q - Q_0) \geq S(\alpha)$, the decision of the environmental governance enterprise follows the path of $\mu^* = 0$, and there is a formula (7) in this path, namely $I(\alpha) = (1 + t(\alpha))^{-T} [C_0 - C(\alpha) + \beta(\alpha)Q]$. Similarly, no matter how $t(\alpha)$ changes, it will not affect the positive and negative of $I(\alpha)$. That is to say, changing $t(\alpha)$ will not change the decision of the environmental governance enterprise on whether to use green financial loans to upgrade technology. However, in the case of $I(\alpha) > 0$, $I(\alpha)$ is the subtraction function of t, which can affect the green financial loan quota of the enterprise after making technological upgrading decisions, that is, reducing $t(\alpha)$ will improve the green financial loan quota. Certificate is completed.

The above propositions and corollaries also prove the correctness of Porter hypothesis under certain conditions.

6 Simulation

Case 1 Simulates the impact of environmental policy β on technology upgrading decisions. Given the technical level α , according to the nature of the variables and functions in the hypothesis of the model, it is assumed that the interest rate function of green financial loans of financial institutions is $t(\alpha) = \alpha^{0.3}$, and the loan cycle is T = 3; The environmental policy function of local government is as follows: $\beta(\alpha) = (\frac{1}{\alpha-1})^3$; The production cost function (including technological upgrading) of the environmental governance enterprise is as follows: $C(\alpha, Q) = 10(\alpha - 1) + 0.7Q$. clearly $C_0 = C(1, Q) = 0.7Q$. Assume that the initial output of the enterprise is $Q_0 = 80$; The objective function of economic expectation control for the enterprise to achieve technological upgrading is as follows: $S(\alpha) = \frac{35}{\alpha} - 35$. For the convenience of discussion, let $D_1 = p(Q - Q_0) - S(\alpha)$ be the first discriminant, $D_2 = p(Q - Q_0) + (C_0 - C(\alpha)) + \beta(\alpha)Q - S(\alpha)$ be the second discriminant. According to inference 2, if $D_1 < 0$, but $D_2 > 0$, it can be concluded that the enterprise will use green financial loans to implement technological upgrading, and the loan quota is as follows $I(\alpha) = (1+t(\alpha))^{-T} [p(Q-Q_0) + (C_0 - C(\alpha)) + \beta(\alpha)Q - S(\alpha)] > 0$. We use Matlab R2008a for numerical simulation (see Figure 2). In order to display the position relationship of each curve in a coordinate system, the vertical coordinates of the points of curve D_2 and the longitudinal coordinates of points of curve $I(\alpha)$ are compressed 100 times in equal proportion in Figure 2. It can be seen from the graph that when $\alpha \in [0, 0.538]$ (when $D_1 = 0, \alpha = \frac{35}{65} = 0.538$), $D_1 < 0, D_2 > 0$ and $I(\alpha) > 0$ which is consistent with the conclusion of Corollary 2. Therefore, when $\alpha \in [0, 0.538]$, the enterprise can use green financial loans $I(\alpha)$ to achieve the goal of technological upgrading, and can achieve the economic control target of $\Delta \pi_1 = S(\alpha)$.

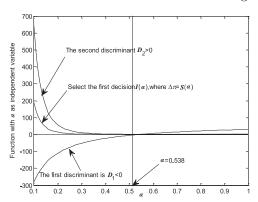


Figure 2 The enterprise's decision on technology upgrading under the condition of $D_1 < 0, D_2 > 0$, i.e., $\alpha \in [0, 0.538]$

Case 2 In the variable and function hypothesis of Case 1, let $D_1 = p(Q - Q_0) - S(\alpha)$ still the first discriminant and $D_2 = C_0 - C(\alpha) + \beta(\alpha)Q$ be the second discriminant. According to inference 3, if $D_1 > 0$, $D_2 > 0$, it can be concluded that the enterprise will use green financial loans to implement technological upgrading, and the loan quota is as follows $I(\alpha) = (1 + t(\alpha))^{-T}[(C_0 - C(\alpha)) + \beta(\alpha)Q] > 0$. The numerical simulation is shown in Figure 3. It is found that there is no second discriminant $D_2 = C_0 - C(\alpha) + \beta(\alpha)Q > 0$ in the decision space $D_1 > 0$. According to Corollary 3, we can bring about conditions for technological upgrading of the enterprise by adjusting environmental policy $\beta(\alpha)$ of local governments. In this regard, we increase the adjustment of $\beta(\alpha) = (\frac{1}{\alpha} - 1)^3$ to $\beta(\alpha) = \frac{1}{27}(\frac{1}{\alpha} - 1)^3$. The simulation shows that after the adjustment of $\beta(\alpha)$, there is $D_2 > 0$, when the enterprise enter the decision of technological upgrading, and the green financial loan quota is I: $I(\alpha) = (1 + t(\alpha))^{-T}[(C_0 - C(\alpha))]$

 $C(\alpha)$) – $\beta(\alpha)Q$] > 0. It can be seen from Figure 3 when $\alpha \in [0.538, 1], D_1 > 0, D_2 > 0$ and $I(\alpha) > 0$ which is consistent with the conclusion of Corollary 3. When the enterprise is in $\alpha \in [0.538, 1]$, there is an optimal decision $I(\alpha) = (1 + t(\alpha))^{-T}[(C_0 - C(\alpha)) - \beta(\alpha)Q]$. At the same time of technological upgrading, the economic control target of $\Delta \pi_2 = S(\alpha)$ can be achieved.

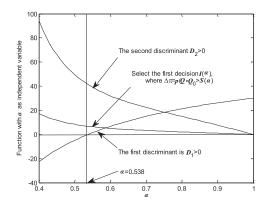


Figure 3 The enterprise's decision on technology upgrading under the condition of $D_1 > 0$, $D_2 > 0$, i.e., $\alpha \in [0.538, 1]$

7 Conclusions

In addition to emission reduction and autonomy of pollutant-discharging enterprises, the government, as the main body of public utilities, is also responsible for public environmental governance. In addition, third-party governance is also an important force to environmental governance. Regardless of enterprises autonomy, government governance, or third-party governance, it is inseparable from the continuous upgrading of environmental governance technology. Because the investment in environmental governance is large and the profit is small, it is difficult for enterprises to upgrade their technology. Therefore, it is of great significance to play the role of government environmental policy and green financial leverage.

- 1) The government's environmental policy has played a significant role in promoting the upgrading of environmental governance enterprises. For environmental governance enterprises, there is always the best decision space to upgrade environmental governance technology by using green financial loans. For a given technological level α , and economic expected objective control function $S(\alpha)$, whether $p(Q Q_0) < S(\alpha)$ or $p(Q Q_0) \ge S(\alpha)$, enterprises can enter the decision space of technological upgrading by adjusting government environmental policy $\beta(\alpha)$, which lays a theoretical foundation for government environmental policy adjustment.
- 2) The design of government environmental policy $\beta(\alpha)$ must pay attention to two important relationships: Firstly, it is to be linked to the level α of technological upgrading of enterprises $\beta(\alpha) \geq 0$, $\beta(1) = 0$, $\beta'(\alpha) < 0$, $\beta''(\alpha) > 0$; Secondly, it is to affect the whole environmental governance output Q. Only in this way can the government's environmental policy not only have an impact on the quantity of technological upgrading, but also play a role in the quality of it.
 - 3) Although the interest rate $t(\alpha)$ of green finance loans is also linked to the level α of tech-

nological upgrading of enterprises, $t(\alpha)$ only affects the loan quota $I(\alpha)$, which limits the scope of green finance to a certain extent. Although green finance cannot have a qualitative impact on technological upgrading behaviour, it can play a catalytic role in encouraging enterprises to improve the level of technological upgrading after making technological upgrading decisions. This provides a direction for financial institutions to promote green technology innovation, and also provides a theoretical reference for the design of green financial mechanism.

Given the time constraints, the design of non-linear programming for collaborative incentive mechanism of environmental policy and green finance mainly comes from the abstraction of reality, and empirical research is also the next research topic of the author.

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