CAN THE REFORM OF GREEN CREDIT POLICY PROMOTE ENTERPRISE ECO-INNOVATION? A THEORETICAL ANALYSIS

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ABSTRACT. The weakness that China’s traditional credit fails to effectively limit enterprise emissions has become increasingly evident. Although the industry-oriented green credit policy has achieved certain effects on environmental performance through the differentiated resource allocation of the industries, banking financial institutions have the ambiguity in the definition of the credit object and the characteristics of profit maximization, which cannot achieve the essential purpose of green credit sustainably. Hence, we propose a new eco-innovation-oriented green credit policy. We prove theoretically that the new green credit is feasible and can be used as an exogenous driver for improving enterprises’ eco-innovation. Contrasting with traditional credit, the newly proposed credit policy is an expansionary monetary policy, which has the characteristics of expanding credit lines and differential interest rates. Utilizing evolutionary game theory, we calculate the evolution stability conditions of green credit and eco-innovation. The results show that the key to green credit to maintaining sustainable development is the return on investment due to eco-innovation. Our theoretical analysis also reveals that environmental benefit-cost ratios and adjustment cost parameters of different assets are the important factors for green credit.

1. Introduction. Environmental risk is one of the biggest risks to humanity, but banking financial institutions have not fully played their role. To fulfill the requirements of sustainable development, green credit has become an important frontier research field. Although the prospect of green credit has been highly recognized by many academic institutions and organizations, because there are no theories on the changes in the traditional financial functions, the dislocation of the research methods in the epistemology, and the restriction of the empirical evidence [47], there are still debates on green credit in the academic field, which leads to the gap in the practice.

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Banking financial institutions do not affect the environment; thus, they can receive environmental benefits only from the external field [39]. The financing behavior of enterprises directly determines the purpose and nature of loans. In the perspective of enterprises, any activities to innovate and improve products, processes, services, or management and business methods, which can decrease the negative impacts on the environment and improve environmental benefits are classified as eco-innovation [31, 63]. Unlike the other financing activities that attempt to maximize the return on investment, eco-innovation focuses on the reduction of environmental risks, pollution, and resource consumption during the production cycle [43]. However, financing constraints are the main barrier to eco-innovation [25]. Therefore, we propose a new research idea: Because green credit and eco-innovation share the same starting point and purpose, that is, to pursue environmental benefits, can banks promote enterprises to conduct eco-innovation through green credit, to realize the development path of “green credit—eco-innovation—environmental benefits?” This proposal is also the motivation for this paper.

The main purpose of this paper is to structure the theory frame of green credit as linked to environmental benefits from the view that financial innovation can be a driver of technological innovation and economic growth [45] and to explore a new sustainable development path for green credit.

The remainder of the paper is organized as follows: Section 2 gives literature reviews and contributions of this paper. Section 3 proposes the theoretical framework of eco-innovation-oriented green credit (EOGC). Section 4 builds a comprehensive benefits model that includes economic benefits and environmental benefits. In Section 5, we conduct evolutionary game analysis and obtain the stable conditions for the evolution of EOGC and eco-innovation. Section 6 presents the numerical simulation results. Section 6 concludes.

2. Literature reviews and contributions. As an important part of sustainable finance, green credit has been widely discussed in academia. The essence of green credit is that it is a macro-control means to promote environmental protection by using credit [39], which is the main means for the banking financial institutions to uphold their environmental responsibilities [35]. Green credit originates from the Equator Principles and is originally a voluntary act of banks to conduct environmental assessments of projects. The Equator banks hold more liquidity buffers than the non-Equator banks and are regulated more effectively, but the Equator banks’ financial position and market value have not improved significantly [65, 28].

Different from the Equator Principles of voluntary nature, China’s green credit policy aims at industries and is conducted under administrative supervision. In cooperation with the Environmental Protection Administration, the China Banking Regulatory Commission (CBRC) ordered domestic banks to tighten the credit exposure of the high-pollution and high-emission industries and expand the credit exposure of the green industries, to decrease the negative effects of industrialization on the environment. Some of the literature has posited that this green credit policy has produced notable results, for example, seriously restricting the debt maturity of high-pollution and high-emission enterprises [74], inhibiting investment in energy-intensive industries [52], the negative net debt financing effect of state-owned enterprises [53], and the positive impact on renewable energy companies [77].
However, other studies have found that China’s green credit policy has not been fully implemented [78], has had a relatively poor effect on industrial structure adjustment [52], and may lead to collusion between enterprises and local governments because of preferential interest rates [41]. The effects of the green credit policy are unsatisfactory, mainly due to the unclear standards, the lack of environmental information [78], and the double threshold effects [35]. First, there is ambiguity in the definition of the credit object. Although the People’s Bank of China (PBOC) and CBRC have set the framework of green credit through several important documents issued since 2012, there remains a vague classification standard to distinguish the credit targets because the environmental risk analysis of China’s banking financial institutions is immature. Second, the estimation of the environmental benefits achieved by green credit funds is provided by the feasibility report of the loan project, which only covers the pre-loan environmental assessment and not the post-loan environmental information disclosure. Thus, as rational economics, the bank pursues the goal of profit maximization. Therefore, the financing constraints imposed on energy-saving and environmental protection projects will offset the supporting role of green credit to some extent because of low investment returns, such that green credit on energy-saving and environmental protection projects has the double threshold effect of promoting and then restraining [35].

Thus, how to design a credit policy linked to environmental benefits to promote the sustainable development of green credit from the perspective of the microeconomic subject of credit remains an open question. We attempt to answer this and other questions in this paper. Based on this problem, another problem must be solved, that is, how to build a path for green credit to ensure environmental benefits.

The theoretical contributions of this paper are as follows. (1) The theoretical framework of EOGC is proposed to show a new path to create environmental benefits, which resolves the limitations of industry-oriented green credit (IOGC). Different from traditional credit, which uses the maximization of economic benefits as the core, EOGC places more weight on comprehensive benefits than on economic benefits. The green attribute of credit funds displays a fusion of the sustainable development concept and financial activities, which enriches and expands the theoretical depth of sustainable finance theory.

The results of this paper show that it is possible in theory to promote enterprises to conduct eco-innovation as a means to create environmental benefits for green credit. This conclusion is consistent with the theoretical viewpoints of many researchers. One of the goals of green credit is to integrate ecological and environmental factors into the accounting and decision-making process of financial institutions to help enterprises decrease energy consumption [35]. However, by only relying on social responsibility, banking financial institutions cannot overcome the challenge of sustainability alone [24]. Therefore, banking financial institutions should become key enablers of most enterprises’ business activities through financial products and services [39]. In this respect, market-driven green credit is more sustainable than administrative-driven credit [78].

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1Announcement of the CBRC on the green credit guideline (2012. NO. 4); Announcement of the CBRC on the submission of green credit statistics (2013. NO. 185); Announcement of the PBOC on the performance evaluation of green credit for banking financial institutions (2018. NO. 180).
(2) Although many researchers have pointed out that the external factors play an important role in eco-innovation adoption, according to our review of the literature, little research has been conducted on the impact of bank credit on eco-innovation. Therefore, this paper provides a theoretical analysis of the organic relationship between green credit of banks and eco-innovation of enterprises from the perspective of stakeholders and contributes to filling the gap in the literature on green credit as an external driver of eco-innovation.

Some in the literature have doubted the relationship between credit and innovation. Atanassov et al. [7] consider that debt contracts might not be appropriate to fund innovative activities with uncertain returns. Benfratello et al. [12] argue that banks are not the ideal choice for enterprises to secure external capital because of high risk and a low guarantee of product innovation. Even the development of credit markets may thwart innovation in a high-technology-intensive industry [38]. However, others have affirmed the positive effect of credit on innovation and posit that credit is an effective source of funding for innovative activities [49, 22]. Empirical results also provide corresponding evidence. Herrera et al. [36] find that the duration of credit relationships promotes innovation. Amore et al. [4] confirm that interstate banking deregulation had significant beneficial effects on the quantity and quality of innovation activity. In summary, although there are different voices, the mainstream voices have affirmed the positive effect of credit on innovation. In addition, this research focuses on the economic issues between credit and innovation, without considering the environmental factors, that is, there is no literature on the relationship between green credit and eco-innovation.

This paper has filled this theoretical gap to some extent. The results show that by considering the maximized comprehensive benefits, banks can promote enterprises to conduct eco-innovation through differentiated credit lines and interest rates. The evolutionarily stable conditions for banks to conduct green credit and enterprises to conduct eco-innovation depend on banks’ environmental preference and the change in return on unit capital, due to enterprises’ investment activities. Although eco-innovation has value in environment improvement, competitive advantage, and profitability [37], enterprises tend to focus more on investing in activities with a higher return on investment.

However, we find that with the increase in environmental preference, enterprises are willing to decrease the return on capital in exchange for the environmental benefits’ growth, but there is a limit to the reduction of the return on capital. This conclusion indicates that the principle of sustainability is inseparable from the economic externality in the process of value accumulation [47], and verifies the hypothesis of enterprise resource dependence theory [58], that is, enterprise behavior is affected by external resource dependencies. Next, as an exogenous driver, green credit characterized by sustainability can stimulate enterprises to conduct eco-innovation from the market level and promote eco-innovation through economic channels, to fulfill double externalities.

(3) This paper contributes to monetary policy theory and innovation theory in different degrees. We find that the optimal credit line of EOGC is higher than that of the traditional credit, and the increase is positively correlated with the number of stakeholders.

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2There are very detailed statistics on the relationship between financial resources and eco-innovation in Scarpellini et al. [64], who point out that the literature has focused on financing operation risk, financial resource access, debt level, and internal financing, whereas there is almost no literature on bank credit.
environmental preference of both the bank and the enterprise. In terms of interest rate, when the environmental preference of the enterprise is greater than that of the bank, the interest rate of EOGC should be higher than that of the traditional credit, and when the environmental preference of the bank is greater than that of the enterprise, the interest rate of EOGC should be lower than that of the traditional credit. Then, EOGC is an expansionary monetary policy with differential interest rates. This conclusion is different from that in Yang et al. [77], who concluded that green credit should be a fiscal policy similar to low-interest or soft loans. Expansionary monetary policy does not mean low interest [27]. If the enterprise has a low environmental preference or is under little environmental pressure, the bank can only increase the credit line while reducing the interest rate, to attract the enterprise to conduct eco-innovation. Additionally, when the enterprise enhances the environmental preference, the interest rate of EOGC will also increase. The experimental results of Baeriswyl et al. [10] also prove that credit expansion has a significant distortion effect on resource allocation.

By contrast, we find that the optimal eco-innovation investment ratio of intangible assets to fixed assets is equal to the ratio of the adjustment cost parameter of fixed assets to the adjustment cost parameter of intangible assets when environmental preferences are not considered. This conclusion is consistent with Peters et al. [59]. However, with the increase in enterprises’ environmental preference, the optimal eco-innovation investment ratio of intangible assets to fixed assets changes positively with the ratio of the intangible assets’ environmental benefit-cost ratio to the fixed assets’ environmental benefit-cost ratio. Enterprises should decide the types of eco-innovation according to the characteristics of the production structure and the environmental benefit-cost ratios of different assets. This conclusion is the first theoretical discovery of the impacts of environmental preferences and environmental benefit-cost ratios on eco-innovation investments and guides enterprises to enhance eco-innovation performances.

3. EOGC policy design.

3.1. Traditional credit. China has established a market-based interest rate mechanism [22]. Since China joined the WTO in 2001, the PBOC as a policy bank gradually deregulated the interest rates by removing the cap in 2004, releasing the lower limit in 2013, and allowing commercial banks to determine their lending rates based on benchmark rates.

Deregulation has improved the efficiency and competitiveness of commercial banks and provided a fair competitive environment for credit markets [61]. The credit scale of Chinese banking financial institutions expanded from ¥9,937.107 billion in 2000 to ¥13,629.665 billion in 2018, maintaining an average annual growth rate of 15.2% and providing important support for the growth of the national economy. However, one of the canons of lending is to ensure the most economic benefits in the credit-granting process, which leads to economic indicators such as profit margins and balance sheets being more important than environmental indicators in the analysis of credit risk.

To leverage the financial system on sustainability, China began to implement a green credit policy in 2007. This green credit policy has two areas: expanding loans to three strategic emerging industries, namely, the energy conservation industry,
new energy industry, and alternative-energy vehicles industry. Since statistics have been recorded, the scale of green credit in China has increased from ¥4,852.684 billion in 2013 to ¥8,295.663 billion in 2017, with an average annual growth rate of 14.39%. Another action is tightening the credit exposure of the high-pollution and high-emission industries. For example, in the paper industry, although domestic loans for fixed assets investment in the paper industry increased from ¥4.603 billion in 2003 to ¥19.933 billion in 2017, the average annual growth rate decreased substantially from 46.94% before 2007 to 9.22% after 2007.

As aforementioned, the current green credit policy in China is essentially IOGC, which allocates financial resources by administrative means. By expanding the credit exposure of green industries (tightening high-pollution and high-emission industries), IOGC can promote the external financing of green industries (restrain high-pollution and high-emission industries) and thus the economic growth of green industries (inhibit high-pollution and high-emission industries), to provide environmental benefits.

The difference between IOGC and ordinary credit is the differential exposure to the high-pollution and high-emission industries. IOGC provides environmental benefits at the cost of the economic development of some industries. Moreover, due to capital profit chasing, although tightening credit exposure can decrease the growth rate of external financing, it is difficult to control the growth rate of internal financing. In the long run, IOGC has little positive impact on capital and energy efficiency, and some key economic indicators are deteriorated [62].

For the rest, there is no essential difference between IOGC and ordinary credit; in the process of credit granting, both determine the credit line and interest rates by pursuing the greatest economic benefits. Therefore, IOGC and ordinary credit are collectively called traditional credit in this paper. The characteristics of the types of credit are presented in Table 1.

### Table 1. Comparison of types of credit.

| types characteristics | traditional credit | IOGC | EOOGC |
|-----------------------|-------------------|------|-------|
| credit object         | pollution industries | ✓   | ✓     | ✓     |
|                       | general industries | ✓   | ✓     | ✓     |
|                       | green industries  | ✓   | ✓     | ✓     |
| guidance              | market means      | ✓   | ✓     | ✓     |
|                       | administrative means | ✓ | ✓     | ✓     |
| credit standards      | maximum economic benefits | ✓ | ✓     | ✓     |
|                       | maximum comprehensive benefits | ✓ | ✓     | ✓     |
| loans usage           | activity with the greatest return on investment | ✓ | ✓     | ✓     |
|                       | eco-innovation    | ✓   | ✓     | ✓     |

3.2. Newly proposed EOOGC. Considering that the main function of IOGC is to distribute financial resources, which is only one of the traditional finance functions, and not show the nature of sustainability [46, 47], this paper proposes a new green credit policy: EOOGC.

(1) Theoretical basis of EOOGC

Eco-innovation is widely recognized as a source that can help enterprises decrease their negative environmental impacts and gain a competitive advantage in market competition [16, 34, 44]. Fussler et al. [31] pioneered the concept of eco-innovation
and described it as an innovation that can benefit both entrepreneurs and consumers without causing environmental impact and damage. A great deal of literature has affirmed the classification of eco-product innovation, eco-process innovation, and eco-organization innovation while debating the diversity of eco-innovation dimensions [23, 76, 32, 44]. Therefore, eco-innovation means the implementation of new or improved products, processes, or organizational methods [43] on the basis of the market demand, environmental sensitivity, and ecological consciousness [42], to pursue the double externality of the economy and environment [63].

The impact of eco-innovation on environmental benefits is realized by changing the intangible assets and fixed assets of enterprises. First, although eco-organization innovation usually does not directly decrease environmental impact but mainly promotes the implementation of eco-process innovation and eco-product innovation [55], effective eco-organization innovation can update organizational routines [23], improving the management technology of enterprises. From the perspective of industrial engineering, the improvement of management technology means the reduction of waste and the improvement of efficiency, which creates an energy-saving environmental benefit. Second, eco-product innovation is an innovation aimed at the ecological design of products [66], to reduce the environmental impact of a product’s lifecycle [23]. Due to the properties of materials and that the structure of products affects the environment [32], improving the type and quality of materials helps decrease waste and carbon emissions, and improving the sustainability of product structure performance helps decrease energy consumption. Therefore, these eco-product innovation activities are directly related to R&D and can change the intangible assets of enterprises. Finally, the reduction of environmental impacts from the production process is mainly from eco-process innovation. Eco-process innovation can be an additive solution or integrated into the production process by substituting input, optimizing production, and recycling output [63]. Eco-process innovation includes end-of-pipeline solutions and integrated cleaner production technologies, which are used to upgrade the equipment level of enterprises to fulfill the environmental goals of energy conservation and emission reduction [37]. Therefore, eco-process innovation gains environmental benefits by changing the fixed assets of enterprises.

As the largest creditor and an important stakeholder, banks can drive enterprises to conduct eco-innovation by giving them loans. The driving factors for enterprises to conduct eco-innovation are divided into internal and external. The internal factors are mainly environmental awareness and technical ability [16, 17]. The management’s environmental awareness has a positive impact on the scope and speed of the enterprise’s response to environmental problems [72]. The environmental vision and culture fostered by environmental consciousness is a foundation for the environmental innovation strategy of enterprises [6, 13]. Additionally, the environmental innovation strategy guides enterprises to conduct eco-innovation [16]. Technical capabilities show the effectiveness and availability of valuable, rare, unique, and irreplaceable resources [9] that enable an enterprise to gain a competitive advantage. Enterprises with higher technical capabilities have a greater pool of knowledge to develop new products and processes and a greater chance of success [18], that is, the path of innovation breeding innovation described by Baumol [11]. Although internal factors influence enterprises’ eco-innovation, many in the literature have provided empirical evidence that external factors have a greater driving effect [25, 37]. Among the external factors, regulatory pressure, market demand, and external cooperation
requirements are the most often mentioned drivers [16, 37, 17]. Regulatory pressure is from the government, which can cause substantial losses to companies when they do not comply with environmental regulations [40]. The market demand for environmentally friendly products is increasing, and this market segment has a market niche [57, 37]. Enterprises can rely on eco-innovation pioneers to enjoy first-mover advantage and thus build a green image [16]. However, when enterprises fulfill the environmental regulatory requirements while the market demand for green is not obvious, it is difficult for them to conduct sustainable eco-innovation by relying only on the endogenous power. Therefore, external cooperation can use the resource supply to provide enterprises with more incentives and drives. Due to the systematization and complexity of eco-innovation, the driving effect of external cooperation has been emphasized in the literature [20, 16, 73]. As one of the external stake holders of enterprises, banks can provide financial resources to enterprises to help them overcome financial constraints when conducting eco-innovation [64].

(2) Definition of EOGC
EOGC and eco-innovation have the same starting point and the same goals. As an exogenous driver to encourage enterprises to conduct eco-innovation, EOGC supports the economic growth of enterprises and helps them receive the environmental benefits of energy conservation and emission reduction, to realize the green attribute of loan funds.

Therefore, this paper defines EOGC is a type of credit, that is, banks adopt social responsibility as a core value by determining different credit lines and interest rates, which promotes enterprises to conduct eco-innovation and create energy conservation and emission reduction targets through the upgrading of the corporate structure. The core purpose of EOGC is to promote the coordinated, sustainable development of economic benefits and environmental benefits.

(3) The path of EOGC to provide environmental benefits
Figure 1 shows the path of EOGC to provide environmental benefits. To show the differences among the types of credit, ordinary credit, IOGC, and EOGC are compared.

From the perspectives of the resource-based view and enterprise capability theory, the framework in Figure 1 satisfies the analysis paradigm of resource–activity–capability. Banks have the capital resources needed by enterprises, and enterprises
invest after receiving bank loans. Different investment activities have different influences on economic growth and environmental improvement and ultimately lead to different benefit results.

In Figure 1, the ordinary credit only focuses on the economic benefits from the economic growth of enterprises, without considering the impact of enterprises’ investment activities on environmental benefits. There are two ways for IOGC to provide the benefits: give credit support to green enterprises to promote their economic growth with capital resources, to obtain economic and environmental benefits, and restrict the credit approval of polluting enterprises and suppress their economic growth by restricting their external financing, to obtain environmental benefits.

The traditional credits (i.e., ordinary credit and IOGC) are aimed at profit maximization, mainly focus on the safety and profitability of capital, and pay insufficient attention to the investment activities of enterprises. In this paper, enterprises’ investment activities are divided into eco-innovation and activities other than eco-innovation, both of which can obtain economic benefits, but only eco-innovation can obtain environmental benefits. Therefore, when enterprises apply for traditional credit, their investment activities are not restricted, and they only rely on endogenous factors as drivers of eco-innovation.

Different from the traditional credits, EOGC restricts enterprises’ investment activities through credit contracts, drives enterprises to actively conduct eco-innovation, and considers environmental improvement caused by eco-innovation the source path of environmental benefits.

EOGC uses expanding credit exposure as an external incentive and focuses on the environmental benefits gained by enterprises through energy conservation and emission reduction within the repayment period. However, to ensure the stability of EOGC and generate sufficient incentives for enterprises to conduct eco-innovation, the following problems must be solved: (a) As the most basic and important indicators of credit, the credit line and interest rates should be rationally designed to ensure the most comprehensive benefits; (b) different types of enterprises have different preferences for economic benefits and environmental benefits. Without loss of generality, EOGC needs to consider different environmental preferences of banks and enterprises; and (c) the difference in enterprise asset structure affects the investment direction of loans, that is, the difference between intangible asset investment and fixed asset investment leads to different implementation effects of eco-innovation and thus affects the use efficiency of loans. Therefore, different eco-innovation types should be determined according to the difference in enterprise asset structure.

Therefore, the remaining sections solve the aforementioned problems through model construction and numerical simulation. The risk adjusted return on capital (RAROC) model and the enterprise value model are used to measure the economic benefits of banks and enterprises, respectively; subsequently, the environmental economic model is used to measure the environmental benefit, and finally, the utility function is used to build the comprehensive benefits model. On the basis of the models, the stable conditions for the evolutionary equilibrium strategies of banks and enterprises are determined by evolutionary game analysis, and the optimal interest rates and the credit lines are determined.
4. Problem description and benefits model.

4.1. Problem description. The strategies of a bank can be divided into traditional credit and EOGC. Different strategies differ in the determination of credit lines and interest rates, that is, traditional credit uses economic benefits maximization as the principle, and EOGC uses comprehensive benefits maximization as the principle.

An enterprise applies for loan funds, \( I_t \), to invest at time \( t \), where \( I_{t,ina} \) is used to invest in intangible assets and \( I_{t,fia} \) is used to invest in fixed assets, that is, \( I_t = I_{t,ina} + I_{t,fia} \). The reason that the investment direction is divided into intangible assets investment and fixed assets investment is to analyze the impact of the difference in the assets structure. An assumption is that the enterprise will draw loans adequately after receiving a line of credit, and lump-sum repayment in full at the end. Then, \( I_t \) is reflected as the credit line.

There are also two strategies for the enterprise. One strategy is to use the loans for eco-innovation, and the other is to use the loans for the activities other than eco-innovation. Both strategies lead to economic benefits, and only eco-innovation leads to environmental benefits.

For the bank, under a certain level of credit risks, increasing interest rates and credit lines can increase interest income and economic benefits. However, the questions are how to ensure that enterprises use loans to conducted eco-innovation to improve the environment, and how should interest rates and credit lines be adjusted.

For the enterprise, the loans granted by a bank can ease financial constraints, but the questions are why the loans should be used for eco-innovation rather than the other activities, and how to distribute loans more effectively and rationally in different eco-innovations.

These questions are essentially a game problem. The bank and the enterprise can all choose different strategies, as well the weighing of economic and environmental benefits. Therefore, based on the benefits models of the bank and the enterprise, this paper uses evolutionary game theory to find the evolutionary stability conditions for green credit and eco-innovation, to provide a theoretical basis for EOGC. The variables and parameters used in the models are presented in Table 2.

4.2. Benefits model. (1) Economic benefits model of the bank

In the process of credit business, banks are paying increasing attention to the principle that the benefits are matched with the risks. Because RAROC can effectively allocate capital and control risks, it has become one of the most recognized performance indicators for banks [60] and is widely used to price the use of capital, based on the risk inherent in financial products.

An assumption is that the enterprise will draw loans adequately after receiving a line of credit, and lump-sum repayment in full at the end. According to the RAROC standard formula, at time \( t \), the bank’s economic benefit, \( R_t \), is

\[
R_t = r_t I_t - d I_t - C
\]

where \( r \) denotes the interest rate, and \( I \) denotes the credit line. \( C \) denotes the bank’s cost and is set to a constant. The credit risk is \( d = PD \times LGD \). \( PD \) is the probability of default, and \( LGD \) is the loss given default. To simplify the model, \( d \) is set to a constant.
Table 2. Variables and parameters.

| Notation | Definition |
|----------|------------|
| **Variables** | |
| $B$ | comprehensive benefits of the bank |
| $R$ | economic benefits of the bank |
| $F$ | comprehensive benefits of the enterprise |
| $V$ | economic benefits of the enterprise |
| $M$ | environmental benefits |
| $I$ | credit line |
| $r$ | interest rate |
| $\alpha$ | environmental preferences of the bank |
| $\beta$ | environmental preferences of the enterprise |
| $\eta$ | environmental benefit-cost ratio |
| $q$ | Tobin’s Q |
| $d$ | credit risk |
| **Parameters** | |
| $\rho$ | adjustment cost parameter |
| $J$ | return on capital of eco-innovation |
| $\varepsilon$ | return on capital of the other activities |
| $K$ | enterprise capital |
| $\tau$ | discount rate |
| $f_{na}$ | intangible assets of the enterprise |
| $f_{ia}$ | fixed assets of the enterprise |
| **Indexes** | |
| $o$ | traditional credits |
| $g$ | EOGC |
| $t$ | time |

The enterprise draw loans $I_t$ at time $t$ and invests $I_{t,ina}$ in the intangible assets and $I_{t,fia}$ in the fixed assets, that is

$$I_t = I_{t,ina} + I_{t,fia} \quad (2)$$

(2) Economic benefits model of the enterprise

Consistent with Abel et al. [2], we construct a value model based on neoclassical investment theory to measure the economic benefits of an enterprise.

We consider a competitive enterprise with a constant return to scale, and under certain technical conditions, the profit $^4$ of the enterprise at time $t$ is

$$\pi_t = \theta_t K_t \quad (3)$$

where $K$ denotes the enterprise’s capital, and denotes the return on capital. The investment decision of the enterprise is to maximize the present value of future expected profit deducted investment cost. Referring to Andrei et al. [5] and Peters et al. [59], the enterprise value model is constructed as follows:

$^4$According to the CD production function, the enterprise’s profit $\pi_t = Z_t L_t^{1-\zeta} K_t^\zeta - w_t L_t \cdot Z_t \cdot L_t, K_t$, and $w_t$ represents comprehensive technical level, labor force, capital, and return to scale at the moment $t$, respectively. $\zeta$ is the elasticity of capital output. Because the impact of the labor force is not the focus of this paper, we fixed labor force input and set $w_t$ to 1. Thus, $\pi_t = \max L_t \left( Z_t L_t^{1-\zeta} K_t^\zeta - L_t \right) = \zeta (1 - \zeta) ^ {1-\zeta} Z_t K_t \theta_t K_t$.
\[ V_t = E_t \int_t^{\infty} \left[ \pi(\theta_s, K_s) - \varphi_{ina}(I_{s,ina}, K_s) - \varphi_{fa}(I_{s,fia}, K_s) \right] e^{-\tau(s-t)} ds \] (4)

where \( \tau \) is the discount rate. The investment cost, \( \varphi \), includes the purchase cost and the adjustment cost:

\[ \varphi_{t,ina} = r_t I_{t,ina} + \rho_{ina} I_{t,ina}^2 / 2K_t \]
\[ \varphi_{t,fia} = r_t I_{t,fia} + \rho_{fia} I_{t,fia}^2 / 2K_t \] (5)

The first item on the right side of equation (5) represents the purchase cost, and the last item represents the adjustment cost [5, 59]. \( \rho_{ina} \) and \( \rho_{fia} \) represent the adjustment cost parameter of intangible asset investment and fixed asset investment, respectively.

According to the Hamilton-Jacobi-Bellman equation, the formula (4) can be solved as follows (the solution process is in the Appendix A):

\[ V_t = \frac{1}{\tau} \left[ \theta_t K_t - r_t (I_{t,ina} + I_{t,fia}) - \frac{\rho_{ina} I_{t,ina}^2}{2K_t} - \frac{\rho_{fia} I_{t,fia}^2}{2K_t} + \frac{E(\text{d}V_t)}{dt} \right] \] (6)

(3) Environmental benefits model

The most essential reason for banking financial institutions to develop green credit and enterprises to conduct eco-innovation is the pursuit of environmental benefits because of social responsibility. Banking financial institutions are mainly engaged in money and credit business, which cannot directly affect the environment [39]. The environmental benefits of banking financial institutions are obtained indirectly through enterprises. Therefore, the environmental benefits of banks are consistent with those of enterprises.

Because there is no undisputed definition of the environmental benefits thus far and no clear conceptualization of nature and dimensions [71], measurement indicators are not unique. The literature has mainly measured environmental benefits by using objective and subjective methods. An objective method is to investigate the pollution emission and energy consumption of enterprises, which is usually measured by carbon emission [10], pollutant emissions [51], life cycle assessments [48], or environmental performance indexes [69]. A subjective method is to estimate the effort in environmental improvement, such as third-party environmental certification [70, 19], Nikkei Environmental Management Survey [56], or expenditure on environmental improvement [3]. Many researchers have supported the substantial contribution of eco-innovation to environmental benefits from theoretical and empirical perspectives [63, 43, 23, 58], and in environmental economics, benefit-cost analysis has been widely used to compare the invested funds with the environmental benefits generated. Therefore, this paper uses the environmental benefit-cost model to measure environmental benefits.

\[ M_t = \eta_{ina} I_{t,ina} + \eta_{fia} I_{t,fia} \] (7)

In equation (7), environmental benefits depend on the capital invested in the eco-innovation, \( I \), and the environmental benefit-cost ratio, \( \eta \).

(4) Comprehensive benefits model

From the perspective of utility, economic benefits and environmental benefits are mutually independent for the bank and the enterprise, and the marginal utility of
economic benefits and environmental benefits is linear. Therefore, the comprehensive benefits model of the bank and the enterprise is established:

\[ B_t = (1 - \alpha)R_t + \alpha M_t \quad (8) \]

\[ F_t = (1 - \beta)V_t + \beta M_t \quad (9) \]

\( B \) in equation (8) denotes the comprehensive benefit of the bank, and \( F \) in equation (9) denotes the comprehensive benefit of the enterprise. \( \alpha \) and \( \beta \) are environmental preferences of the bank and enterprise, respectively, which range from 0 to 1.

5. **Evolutionary game analysis.** In this section, evolutionary game analysis is used to explore the evolutionary stability conditions. The game matrix of the bank and the enterprise under different strategies is presented in Figure 2. To distinguish traditional credit and EOGC, we set the credit line of the traditional credit as \( I_o \), and the interest rate as \( r_o \), and the credit line of EOGC is \( I_g \), and the interest rate is \( r_g \).

\[ \begin{array}{c|c|c}
\text{EOGC} & \text{Eco-innovation} & \text{Other activities} \\
\hline
\text{Bank} & \text{(1-x)} & \text{(1-y)} \\
\hline
\text{I} & B_t, F_t & \text{II} \\
\text{II} & B_t, F_t & \text{IV} \\
\end{array} \]

**Figure 2.** Game matrix

5.1. **Scenario analysis.** Scenario I: The bank chooses EOGC, and the enterprise chooses eco-innovation.

According to equation (3), the profit of the enterprise at time \( t \) depends on the capital, \( K_t \), and the return on capital, \( \theta_t \).

The capital \( K_t \) can be divided into the fixed assets capital \( K_{t,fia} \) and the intangible assets capital \( K_{t,ina} \) [59]:

\[ K_t = K_{t,fia} + K_{t,ina} \quad (10) \]

Through the perpetual inventory method, the enterprise maximizes equation (6) subject to the following capital stock accounting identity:

\[ \frac{dK_{t,ina}}{dt} = (I_{t,ina} - \delta_{ina}K_{t,ina}) \\
\frac{dK_{t,fia}}{dt} = (I_{t,fia} - \delta_{fia}K_{t,fia}) \quad (11) \]

where \( \delta \) is the rate of capital depreciation. In addition, because the return on capital \( \theta_t \) is a function of technology, and technology has random volatility [1, 68], the mean-reverting process for \( \theta_t \) is

\[ d\theta_t = \lambda(\mu - \theta_t) dt + \sigma_\theta dW_\theta^t + J_t dt \quad (12) \]

Equation (12) shows that the return on capital contains a mean-reverting drift term, a diffusion random process, and a change term affected by eco-innovation. \( \mu \) is a central tendency parameter for the return on capital \( \theta_t \), which reverts at rate \( \lambda \). The variance coefficient of the diffusion term is \( \sigma_\theta^2 \), and \( W_\theta^t \) is a standard Brownian motion.
The last item in equation (12) is the eco-innovation jump of the return on capital. Innovation jump theory proposes that an innovation will make the return on capital jump [75], and the jump size may be a constant or drawn from a probability distribution [26]. Therefore, for simplicity, this paper set $J$ as a constant, which is also applied in Andrei et al. [5].

By substituting equations (11) and (12) into equation (6) and using Ito’s lemma, the optimal investment and the maximum value of the enterprise under scenario I can be obtained. The calculation process is shown in Appendix B.

\[
I_{i, ina}^* = \frac{K}{\rho_{i, ina}} \left( q - r_{i, g} + \frac{\tau \beta \eta_{i, ina}}{1 - \beta} \right) \tag{13}
\]

\[
I_{i, fia}^* = \frac{K}{\rho_{i, fia}} \left( q - r_{i, g} + \frac{\tau \beta \eta_{i, fia}}{1 - \beta} \right)
\]

\[
V_1^* = \frac{1}{\tau} \left[ K \left( \frac{\rho_{i, ina}}{2\rho_{i, fia}} \right) (q - r_{i, g})^2 - \frac{K \left( \frac{\rho_{i, ina}^2 + \rho_{i, fia}^2}{2\rho_{i, fia}} \right)}{\rho_{i, fia}^2} \left( \frac{\tau \beta}{1 - \beta} \right)^2 + JV_0 \right]
\tag{14}
\]

By substituting the optimal investment $I_{i, ina}^*$ and $I_{i, fia}^*$ into formula (7), the environmental benefit under scenario I can be obtained as follows:

\[
M_1 = \frac{K (\eta_{i, ina} \rho_{i, fia} + \eta_{fia} \rho_{i, ina}) (q - r_{i, g})}{\rho_{i, ina} \rho_{i, fia}} + \frac{K \tau \beta \left( \frac{\rho_{i, ina}^2 + \rho_{i, fia}^2}{\rho_{i, fia}} \right)}{\rho_{i, ina} \rho_{i, fia} (1 - \beta)} \tag{15}
\]

Therefore, the comprehensive benefit of the enterprise is as follows:

\[
F_1 = (1 - \beta) \frac{1}{\tau} \left[ K \left( \frac{\rho_{i, ina} + \rho_{i, fia}}{2\rho_{i, fia}} \right) (q - r_{i, g})^2 - \frac{K \left( \frac{\rho_{i, ina}^2 + \rho_{i, fia}^2}{2\rho_{i, fia}} \right)}{\rho_{i, fia}^2} \left( \frac{\tau \beta}{1 - \beta} \right)^2 + JV_0 \right]
\tag{16}
\]

By substituting the optimal investment $I_{i, ina}^*$ and $I_{i, fia}^*$ into formula (7), the environmental benefit under scenario I can be obtained as follows:

\[
M_1 = \frac{K (\eta_{i, ina} \rho_{i, fia} + \eta_{fia} \rho_{i, ina}) (q - r_{i, g})}{\rho_{i, ina} \rho_{i, fia}} + \frac{K \tau \beta \left( \frac{\rho_{i, ina}^2 + \rho_{i, fia}^2}{\rho_{i, fia}} \right)}{\rho_{i, ina} \rho_{i, fia} (1 - \beta)} \tag{15}
\]

\[
F_1 = (1 - \beta) \frac{1}{\tau} \left[ K \left( \frac{\rho_{i, ina} + \rho_{i, fia}}{2\rho_{i, fia}} \right) (q - r_{i, g})^2 - \frac{K \left( \frac{\rho_{i, ina}^2 + \rho_{i, fia}^2}{2\rho_{i, fia}} \right)}{\rho_{i, fia}^2} \left( \frac{\tau \beta}{1 - \beta} \right)^2 + JV_0 \right]
\tag{16}
\]

The comprehensive benefit of the bank is as follows:

\[
B_1 = (1 - \alpha) \frac{1}{\tau} \left[ (r_{i, g} - d) \frac{K \left( \rho_{i, fia} + \rho_{i, ina} \right) (q - r_{i, g}) + (\eta_{i, ina} \rho_{i, ina} + \eta_{fia} \rho_{i, ina}) \left( \frac{\tau \beta}{1 - \beta} \right)}{\rho_{i, fia} \rho_{i, ina}} \right] - C
\tag{17}
\]

\[
B_1 = (1 - \alpha) \frac{1}{\tau} \left[ (r_{i, g} - d) \frac{K \left( \rho_{i, fia} + \rho_{i, ina} \right) (q - r_{i, g}) + (\eta_{i, ina} \rho_{i, ina} + \eta_{fia} \rho_{i, ina}) \left( \frac{\tau \beta}{1 - \beta} \right)}{\rho_{i, fia} \rho_{i, ina}} \right] - C
\tag{17}
\]

Because the bank conducts EOGC under this scenario, the interest rate that maximizes the bank’s comprehensive benefit is

\[
r_{i, g}^* = \frac{1}{2} (q + d) + \frac{\tau (\eta_{i, ina} \rho_{i, fia} + \eta_{fia} \rho_{i, ina})}{2 (\rho_{i, ina} + \rho_{i, fia})} \left( \frac{\beta}{1 - \beta} - \alpha \frac{1}{1 - \alpha} \right) \tag{18}
\]

At this time, the optimal credit line is

\[
I_{i, g}^* = \frac{K (\rho_{i, ina} + \rho_{i, fia}) (q - d) + \tau K (\eta_{i, ina} \rho_{i, fia} + \eta_{fia} \rho_{i, ina})}{2 (\rho_{i, ina} + \rho_{i, fia})} \left( \alpha \frac{1}{1 - \alpha} + \beta \frac{1}{1 - \beta} \right) \tag{19}
\]

Scenario II: The bank chooses traditional credit, and the enterprise chooses eco-innovation.
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Under this scenario, the enterprise implements eco-innovation and uses comprehensive benefit maximization in investment decisions. Thus, there is

\[ I_{2,ina}^* = \frac{K}{\rho_{ina}} \left( q - r_{2,o} + \frac{\tau \beta \eta_{ina}}{1 - \beta} \right) \]

and

\[ I_{2,fia}^* = \frac{K}{\rho_{fia}} \left( q - r_{2,o} + \frac{\tau \beta \eta_{fia}}{1 - \beta} \right) \] (20)

The comprehensive benefit of the enterprise under this scenario can be obtained as follows:

\[ F_2 = (1 - \beta) \frac{1}{\tau} \left[ K (\rho_{ina} + \rho_{fia}) (q - r_{2,o}) + \frac{\tau \beta (\eta_{ina} \rho_{fia} + \eta_{fia} \rho_{ina})}{1 - \beta} - C \right] \]

The comprehensive benefit of the bank as follows:

\[ B_2 = (1 - \alpha) \frac{1}{\tau} \left[ \right] \]

Because of the traditional credit under this scenario, the interest rate is determined according to the maximum economic benefit of the bank:

\[ r_{2,o}^* = \frac{1}{2} (q + d) + \frac{\tau \beta (\eta_{ina} \rho_{fia} + \eta_{fia} \rho_{ina})}{2(1 - \beta) (\rho_{ina} + \rho_{fia})} \] (23)

The optimal credit line under this scenario is

\[ I_{3,ina}^* = \frac{K}{\rho_{ina}} (q - r_{3,g}) \]

Scenario III: The bank chooses EOGC, and the enterprise chooses the activities other than eco-innovation.

The return on capital of the enterprise under this scenario is

\[ d \theta_t = \lambda (\mu - \theta_t) dt + \sigma dW_t^p + \varepsilon_t dt \] (25)

where \( \varepsilon \) denotes the change in the return on capital due to the other investment activities.

Because the enterprise in this scenario invests in the activities other than eco-innovation, it needs to ensure the most economic benefit for the enterprise. Therefore, the optimal investments under this scenario are as follows:

\[ I_{3,ina}^* = \frac{K}{\rho_{ina}} (q - r_{3,g}) \]

\[ I_{3,fia}^* = \frac{K}{\rho_{fia}} (q - r_{3,g}) \] (26)
Therefore, the comprehensive benefit of the enterprise under this scenario can be solved as follows:

\[
F_3 = \frac{1 - \beta}{\tau} \left[ \frac{K(\rho_{ina} + \rho_{fia})(q-r_{3,g})^2}{2\rho_{ina}\rho_{fia}} + \varepsilon V_0 + \theta K - (\delta_{ina}K_{ina} + \delta_{fia}K_{fia})q + \lambda(\mu - \theta)V_0 + \frac{1}{2}\sigma_0^2 V_{0,\theta} \right] \tag{27}
\]

Because the bank in this scenario conducts EOGC, the interest rate is determined according to equation (26), the expected comprehensive benefit of the bank is

\[
\frac{1}{\tau} \left[ \frac{K(\rho_{ina} + \rho_{fia})(q-r_{3,g})}{\rho_{ina}\rho_{fia}} - C \right] + \frac{\alpha\xi(\eta_{ina}\rho_{fia} + \eta_{fia}\rho_{ina})}{\rho_{ina}\rho_{fia}(1 - \alpha)} (q - r_{3,g}) \]

Therefore, the optimal interest rate under this scenario is determined as follows:

\[
r_{3,g}^* = \frac{1}{2}(q + d) - \tau \alpha (\eta_{ina}\rho_{fia} + \eta_{fia}\rho_{ina})
\tag{28}
\]

The real comprehensive benefit of the bank is

\[
B_3 = \frac{1 - \alpha}{\tau} \left[ (r_{3,g} - d) \frac{K(\rho_{ina} + \rho_{fia})(q - r_{3,g})}{\rho_{ina}\rho_{fia}} - C \right] \tag{29}
\]

The optimal credit line is

\[
I_{3,g}^* = \frac{K(\rho_{ina} + \rho_{fia})}{2\rho_{ina}\rho_{fia}}(q - d) + \frac{\tau \alpha K(\eta_{ina}\rho_{fia} + \eta_{fia}\rho_{ina})}{2\rho_{ina}\rho_{fia}(1 - \alpha)} \tag{30}
\]

Scenario IV: The bank chooses the traditional credit, and the enterprise chooses the activities other than eco-innovation.

The optimal investments of the enterprise under this scenario are

\[
I_{4,ina}^* = \frac{K}{\rho_{ina}}(q - r_{4,o}) \tag{31}
\]

\[
I_{4,fia}^* = \frac{K}{\rho_{fia}}(q - r_{4,o})
\]

Because the enterprise invests in the activities other than eco-innovation, according to equation (21), the comprehensive benefit of the enterprise under this scenario can be solved as follows:

\[
F_4 = (1 - \beta) \frac{1}{\tau} \left[ \frac{K(\rho_{fia} + \rho_{ina})(q-r_o)^2}{2\rho_{fia}\rho_{ina}} + \varepsilon V_0 + \theta K - (\delta_{ina}K_{ina} + \delta_{fia}K_{fia})q + \lambda(\mu - \theta)V_0 + \frac{1}{2}\sigma_0^2 V_{0,\theta} \right] \tag{32}
\]

The comprehensive benefit of the bank is as follows:

\[
B_4 = (1 - \alpha) \left[ (r_o - d) \frac{K(\rho_{fia} + \rho_{ina})(q - r_o)}{\rho_{fia}\rho_{ina}} - C \right] \tag{33}
\]

Therefore, in this scenario, the loan interest rate and the loan amount are

\[
r_{4,o}^* = \frac{1}{2}(q + d) \tag{34}
\]

\[
I_{4,o}^* = \frac{K(\rho_{ina} + \rho_{fia})}{2\rho_{ina}\rho_{fia}}(q - d)
\]

5.2. Replicator dynamics and evolutionarily stable strategy. An assumption is that the probability of the bank to choose EOGC or traditional credit is \(x\) and \((1 - x)\), and the probability of the enterprise to invest in eco-innovation or the other activities is \(y\) and \((1 - y)\) (Figure 2). The payoff of the bank with EOGC
is $E_{x,b} = yB_1 + (1 - y)B_3$, and the payoff of the bank with traditional credit is $E_{1-x,b} = yB_2 + (1 - y)B_4$. Then, the average earning of the bank is denoted as $\overline{E}_b$:

$$\overline{E}_b = xE_{x,b} + (1 - x)E_{1-x,b} = xyB_1 + x(1 - y)B_2 + y(1 - x)B_3 + (1 - y)(1 - x)B_4$$  (35)

In the same manner, the payoff of the enterprise to invest in eco-innovation is $E_{y,f} = xF_1 + (1 - x)F_2$, and the payoff of the enterprise to invest in the other activities is $E_{1-y,f} = xF_3 + (1 - x)F_4$. The average earning of the enterprise is denoted as $\overline{E}_f$:

$$\overline{E}_f = yE_{y,f} + (1 - y)E_{1-y,f} = xyF_1 + (1 - x)yF_2 + x(1 - y)F_3 + (1 - x)(1 - y)F_4$$  (36)

In evolutionary game theory, when the expected payoff of one strategy is higher than the average expected payoff of other strategies, the strategy strongly prevents the invasion of other strategies and drives the adaptation of the population evolution process [29]. The replicator dynamic system is a dynamic differential equation that describes the frequency of a special strategy used in a population [21]. Therefore, the replicator dynamic equation of EOGC chosen by bank $P(x)$ and the replicator dynamic equation of eco-innovation chosen by enterprise $P(y)$ describes the dynamic frequency change of discrete phenotypes in evolutionary games.

$$P(x) = \frac{dx}{dt} = x(E_{x,b} - \overline{E}_b) = x(1 - x)[y(B_1 - B_2) + (1 - y)(B_3 - B_4)]$$  (37)

$$P(y) = \frac{dy}{dt} = y(E_{y,f} - \overline{E}_f) = y(1 - y)[x(F_1 - F_3) + (1 - x)(F_2 - F_4)]$$  (38)

Solving equations (37) and (38) demonstrates that the five replicator dynamic equilibrium points are respectively $(0, 0), (0, 1), (1, 0), (1, 1), \text{ and } \left(\frac{F_3 - F_2}{F_1 + F_4 - F_2 - F_3}, \frac{B_4 - B_3}{B_1 + B_4 - B_2 - B_3}\right)$.

The equilibrium points obtained by the replicator dynamic equations must be strictly in the pure strategy Nash equilibrium, but $\left(\frac{F_3 - F_2}{F_1 + F_4 - F_2 - F_3}, \frac{B_4 - B_3}{B_1 + B_4 - B_2 - B_3}\right)$ is a mixed strategy Nash equilibrium, not a stable point. Thus, we must decide the stability of the other four equilibrium points.

Not all equilibrium points are evolutionary stable strategies (ESS) because of ESS must have the ability to resist errors or deviations caused by finite rationality, that is, the ability to recover from disturbance to a stability point [50]. Considering the stability of the differential equations and the robustness to slight disturbances of ESS, the Jacobian matrix can be used to decide whether the equilibrium point of the evolutionary system is stable by referring to the Friedman [30] local asymptotic stability method.

The Jacobian matrix of the replicator dynamical system is defined as follows:

$$T = \begin{bmatrix} i_{11} & i_{12} \\ i_{21} & i_{22} \end{bmatrix} = \begin{bmatrix} \frac{\partial P(x)}{\partial x} & \frac{\partial P(x)}{\partial y} \\ \frac{\partial P(y)}{\partial x} & \frac{\partial P(y)}{\partial y} \end{bmatrix}$$  (39)
Hence,
\[ i_{11} = (1 - 2x) [y (B_1 - B_2) + (1 - y) (B_3 - B_4)] \]
\[ i_{12} = x (1 - x) (B_1 - B_2 + B_4 - B_3) \]
\[ i_{21} = y (1 - y) (F_1 - F_3 + F_4 - F_2) \]
\[ i_{22} = (1 - 2y) [x (F_1 - F_3) + (1 - x) (F_2 - F_4)] \]  \hspace{1cm} (40)

The determinant and trace of the Jacobian matrix are denoted by \( \text{det} T \) and \( \text{tr} T \), respectively; in addition, \( \text{det} T = i_{11} i_{22} - i_{12} i_{21} \) and \( \text{tr} T = i_{11} + i_{22} \). If \( \text{det} T > 0 \) while \( \text{tr} T < 0 \), the equilibrium points of the replicator dynamic system are locally stable, that is, the ESS of the evolutionary game. Therefore, the evolutionary stability conditions under four scenarios are presented in Table 3.

Table 3. Evolutionary stability conditions.

| Scenarios | Points | \( \text{det} T \) | \( \text{tr} T \) | Equilibrium results | Stability conditions |
|-----------|--------|-----------------|---------------|---------------------|---------------------|
| I         | (0,0)  | +               | +             | instability point   | \( B_1 > B_2 \)     |
|           | (0,1)  | - ±             | saddle point  |                     |                     |
|           | (1,0)  | - ±             | saddle point  | \( F_1 > F_3 \)     |                     |
|           | (1,1)  | +               | +             | ESS                 |                     |
| II        | (0,0)  | - ±             | saddle point  |                     | \( B_2 > B_1 \)     |
|           | (0,1)  | +               | ESS           |                     | \( F_2 > F_4 \)     |
|           | (1,0)  | + +             | instability point |                     |                     |
|           | (1,1)  | - ±             | saddle point  |                     |                     |
| III       | (0,0)  | - ±             | saddle point  |                     | \( B_3 > B_4 \)     |
|           | (0,1)  | + +             | instability point |                     | \( F_3 > F_1 \)     |
|           | (1,0)  | +               | ESS           |                     | \( F_4 > F_2 \)     |
|           | (1,1)  | - ±             | saddle point  | \( B_4 > B_3 \)     | \( F_4 > F_2 \)     |

5.3. Comparison of credit policies and the optimal strategy of EOGC.

(1) Comparison of credit policies

Based on the analysis in Section 4.1, the optimal interest rates and the optimal credit lines under four scenarios are listed (Table 4).

Table 4. Optimal interest rates and credit lines.

| Scenarios | Optimal interest rates | Optimal credit lines |
|-----------|------------------------|----------------------|
| I         | \( \frac{1}{2} (q + d) + \frac{q (P_{i1} + P_{i2}) - q (P_{i3} + P_{i4})}{2 (P_{i1} + P_{i2})} \) | \( \frac{K (P_{i1} + P_{i2})}{2 (P_{i1} + P_{i2})} (q - d) \) + \( \frac{K (P_{i3} + P_{i4})}{2 (P_{i3} + P_{i4})} \) |
| II        | \( \frac{1}{2} (q + d) + \frac{q (P_{i1} + P_{i2}) - q (P_{i3} + P_{i4})}{2 (P_{i1} + P_{i2})} \) | \( \frac{K (P_{i1} + P_{i2})}{2 (P_{i1} + P_{i2})} (q - d) \) + \( \frac{K (P_{i3} + P_{i4})}{2 (P_{i3} + P_{i4})} \) |
| III       | \( \frac{1}{2} (q + d) - \frac{q (P_{i1} + P_{i2}) - q (P_{i3} + P_{i4})}{2 (P_{i1} + P_{i2})} \) | \( \frac{K (P_{i1} + P_{i2})}{2 (P_{i1} + P_{i2})} (q - d) \) + \( \frac{K (P_{i3} + P_{i4})}{2 (P_{i3} + P_{i4})} \) |
| IV        | \( \frac{1}{2} (q + d) \) | \( \frac{K (P_{i1} + P_{i2})}{2 (P_{i1} + P_{i2})} (q - d) \) |

When the bank or the enterprise adopts different behavior strategies, the optimal interest rates and credit lines are obviously different.
Under the same credit policy, namely, scenarios I and III (or scenario II and scenario IV), the optimal interest rate when the enterprise invests in eco-innovation should be higher than that of the optimal interest rate when the enterprise invests the other activities, and the difference is \( \frac{\tau(\eta_{ina}\rho_{fia}+\eta_{fia}\rho_{ina})\beta}{2(\rho_{ina}+\rho_{fia})(1-\beta)} \). In addition, under different credit policies, namely, scenarios I and II (or scenarios III and IV), the optimal interest rate of EOGC should be lower than that of the traditional credit, and the difference is \( \frac{\tau(\eta_{ina}\rho_{fia}+\eta_{fia}\rho_{ina})\alpha}{2(\rho_{ina}+\rho_{fia})(1-\alpha)} \).

In terms of credit lines, regardless of the strategy enterprises choose, the optimal credit line of EOGC should be higher than that of the traditional credit, and the difference is \( \frac{\tau(K(\eta_{ina}\rho_{fia}+\eta_{fia}\rho_{ina})\alpha}{2(\rho_{ina}+\rho_{fia})(1-\alpha)} \).

(2) Optimal strategy of EOGC

Based on the analysis in Section 4.2, the evolutionary stability conditions for EOGC and eco-innovation strategy are \( B_1 > B_2 \) and \( F_1 > F_3 \). Next, we build two constraint functions, \( X_1 = B_1 - B_2 \) and \( X_2 = F_1 - F_3 \). If \( X_1 > 0 \), stability condition \( B_1 > B_2 \) is guaranteed. Additionally, \( X_2 > 0 \) means stability condition \( F_1 > F_3 \) is guaranteed.

\( B_1 \) and \( B_2 \) are the comprehensive benefits of the bank under scenarios I and II. Based on equations (17) and (20) we can obtain

\[
X_1 = \frac{K\tau(\eta_{ina}\rho_{fia}+\eta_{fia}\rho_{ina})^2\alpha^2}{4\rho_{ina}\rho_{fia}(\rho_{ina}+\rho_{fia})(1-\alpha) \} (41) \]

By contrast, \( F_1 \) and \( F_3 \) are the comprehensive benefits of the enterprise under scenarios I and III. Then, \( X_2 \) can be solved based on equations (16) and (27) as follows:

\[
X_2 = (J - \epsilon) + \frac{K\tau(\eta_{ina}\rho_{fia}+\eta_{fia}\rho_{ina})\beta}{2V_0\rho_{ina}\rho_{fia}(1-\beta)}(q-d) + \frac{K\tau^2(\eta_{ina}\rho_{fia}+\eta_{fia}\rho_{ina})^2\alpha\beta}{2V_0\rho_{ina}\rho_{fia}(\rho_{fia}+\rho_{fia})(1-\beta)(1-\beta)} + \frac{K\tau^2(\eta_{fia}-\eta_{fia})^2\beta^2}{2V_0(\rho_{fia}+\rho_{fia})(1-\beta)^2} \] (42)

Because \( 1 > \alpha > 0 \), \( X_1 > 0 \) permanently. The following conclusion can be drawn: when \( \frac{\tau(\eta_{ina}\rho_{fia}+\eta_{fia}\rho_{ina})\beta}{2(\rho_{fia}+\rho_{fia})(1-\beta)}(q-d) + \frac{\tau^2(\eta_{ina}\rho_{fia}+\eta_{fia}\rho_{ina})^2\alpha\beta}{2(\rho_{fia}+\rho_{fia})(1-\beta)(1-\beta)} + \frac{\tau^2(\eta_{fia}-\eta_{fia})^2\beta^2}{2(\rho_{fia}+\rho_{fia})(1-\beta)^2} > \frac{\beta}{K}(\epsilon - J) \), the credit line is \( I_g = \frac{K(\rho_{fia}+\rho_{fia})(q-d)}{2(\rho_{fia}+\rho_{fia})} \), and the interest rate is \( r_g = \frac{1}{2}(q + d) + \frac{\tau(\eta_{ina}\rho_{fia}+\eta_{fia}\rho_{ina})}{2(\rho_{fia}+\rho_{fia})} \left( \frac{\beta}{1-\beta} - \frac{1}{1-\alpha} \right) \), EOGC and eco-innovation can be evolution stable.

6. Simulation and discussion. This section employs the MATLAB to simulate the aforementioned theoretical results and further discusses the impacts of environmental preferences and environmental benefit-cost ratios on EOGC and eco-innovation.

6.1. Impacts of environmental preferences. Peters et al. [59] conduct an in-depth study on adjustment cost parameters and demonstrate that the adjustment cost parameter of intangible assets is nearly twice that of fixed assets. Therefore, using the research conclusions of Peters et al. [59], this paper sets \( \rho_{ina} = 20 \) and \( \rho_{fia} = 10 \). Other relevant parameters are set as follows: \( \tau = 0.8, d = 0.03 \), and \( q = 1 \).

(1) Impacts of environmental preferences on EOGC
Figure 3 shows the impact of the bank’s environmental preference $\alpha$ and the enterprise’s environmental preference $\beta$ on the evolution stability constraint $X_2$ when $\varepsilon = J$. In Figure 3, the evolutionary stability constraint $X_2$ increases with the increase in environmental preferences of the enterprise and the bank, and the enterprise’s environmental preference has a bigger impact than that of the bank.

If the added value of eco-innovation to the enterprise’s return on capital is greater than or equal to the other activities, that is, $J \geq \varepsilon$, the evolution stability constraint $X_2 > 0$ is permanent. In this case, EOGC and eco-innovation are an equilibrium strategy for the bank and the enterprise. One of the obstacles to the enterprise conducting eco-innovation is that the enterprise often considers that investing in eco-innovation is a cost burden [33] because eco-innovation has a lower return on investment. However, in Figure 3, when $\varepsilon > J$, there is also a space greater than 0 for the evolution stability constraint $X_2$. In particular, when the environmental preference of the enterprise is greater than 0.5, the curve of the evolutionary stability constraint $X_2$ increases significantly, indicating that the enterprises under greater environmental pressure are less likely to consider the difference in the return on capital when deciding investment strategies. This fully shows that EOGC and eco-innovation have the characteristic of coexistence.

Figure 3. Impacts of $\alpha$ and $\beta$ on $X_2$ when $\varepsilon = J$. Evolution stability constraint $X_2$ increases with the increase of the bank’s environmental preference $\alpha$ and the enterprise’s environmental preference $\beta$. The figure shows that some space remains where $X_2 > 0$ if $\varepsilon > J$ with the increase in $\alpha$ and $\beta$.

Figure 4 shows the impact of environmental preferences $\alpha$ and $\beta$ on the optimal interest rate $r^*_g$ of EOGC. For comparison, the red surface in Figure 4 is the optimal interest rate of the traditional credit $r^*_o$, and the green surface is the optimal interest rate of EOGC $r^*_g$. We observe that $r^*_o$ mainly depends on the Tobin-q of the enterprise and does not change with $\alpha$ and $\beta$. However, $r^*_g$ is significantly affected by environmental preferences. $r^*_g$ should increase with the increase in $\beta$ and decrease with the increase in $\alpha$. When $\alpha > \beta$, $r^*_g$ should be lower than $r^*_o$, and when $\beta > \alpha$, $r^*_g$ should be higher than $r^*_o$. 

**Figure 4.** Impacts of $\alpha$ and $\beta$ on $r$. The green surface denotes the optimal interest rate of EOGC, and the red surface denotes the optimal interest rate of the traditional credit. The figure shows the change in the optimal interest rate of different credits with respect to environmental preferences.

EOGC differs from the traditional credit not only in the optimal interest rate but also in the optimal credit line. Because the credit line is directly related to the enterprise capital, the vertical axis of Figure 5 is the ratio of the credit line to the enterprise capital, that is, $\frac{I}{K}$. The red surface in Figure 5 is the ratio of the optimal credit line of the traditional credit to the enterprise capital $\frac{I_o}{K}$, and the green surface is the ratio of the optimal credit line of EOGC to the enterprise capital $\frac{I_g}{K}$. We observe that $\frac{I_o}{K}$ is not affected by environmental preferences, and $\frac{I_g}{K}$ has a positive change with environmental preferences. This finding indicates that EOGC must increase the credit line on the basis of the traditional credit, and the size of the increase depends on $\alpha$ and $\beta$.

(2) Impacts of environmental preferences on eco-innovation

Environmental preferences influence EOGC and eco-innovation. Figure 6 shows the impacts of environmental preferences $\alpha$ and $\beta$ on the eco-innovation investment ratio of intangible assets to fixed assets. Although the neoclassical investment theory is mainly tested by fixed assets investment at the enterprise level, it is still helpful to explain intangible assets investment [59]. In Figure 6, when $\beta = 0$, the optimal eco-innovation investment ratio of intangible assets to fixed assets is equal to the ratio of the adjustment cost parameter of fixed assets to the adjustment cost parameter of intangible assets, that is, $\frac{I_{ina}}{I_{fia}} = \frac{\rho_{fia}}{\rho_{ina}}$. This conclusion is consistent with Peters et al. [59], who proposes that the allocation of investment funds for intangible assets and fixed assets should mainly rely on the adjustment cost parameters.

However, the allocation of investment capitals varies with environmental preferences. In Figure 6, the optimal eco-innovation investment ratio of intangible assets to fixed assets does not change with the bank’s environmental preference but changes with the enterprise’s environmental preference. Because eco-product...
Figure 5. Impacts of $\alpha$ and $\beta$ on $\frac{L}{K}$. The green surface denotes the ratio of the optimal credit line to the enterprise capital under EOGC, $\frac{L^*}{K}$, and the red surface denotes the ratio of the optimal credit line to the enterprise capital under the traditional credit, $\frac{L^*_o}{K}$. The figure shows that the credit line of EOGC changes with the environmental preference, and the credit line of the traditional credit does not.

innovation and eco-organization innovation are more random than eco-process innovation [25], the environmental benefit-cost ratio of intangible assets has greater uncertainty than that of fixed assets. When $\eta_{fia} > \eta_{ina}$, we observe from the change of the yellow surface in Figure 6 that the optimal eco-innovation investment ratio of intangible assets to fixed assets decreases with the increase in enterprise environmental preference $\beta$. This finding suggests that when the environmental benefit-cost ratio of intangible assets $\eta_{ina}$ is lower than that of fixed assets $\eta_{fia}$, the enterprise is more willing to increase investment in fixed assets eco-innovation. By contrast, in the change of the green surface in Figure 6, the optimal eco-innovation investment ratio of intangible assets to fixed assets increases with the increase in enterprise environmental preference $\beta$ when $\eta_{ina} > \eta_{fia}$, and the increasing range is positively correlated with the environmental benefit-cost ratio of intangible assets.

6.2. Impacts of environmental benefit-cost ratios. Because environmental benefit-cost ratios directly affect environmental benefits, this section discusses the impacts of environmental efficiency ratios on EOGC and eco-innovation.

(1) Impacts of environmental benefit-cost ratios on EOGC

In Figure 7, there is always an evolutionary stable constraint $X_2 > 0$ when $\varepsilon = J$. With the increase in the environmental benefit-cost ratios $\eta_{ina}$ and $\eta_{fia}$, the evolutionary stability constraint $X_2$ reveals a trend of increases. This finding suggests that the expected return on capital of investment eco-innovation, $J$, can be decreased with the increase in the environmental benefit-cost ratios. Moreover, the environmental benefit-cost ratio of fixed assets, $\eta_{fia}$, has a greater impact on the evolutionary stability constraint $X_2$ than $\eta_{ina}$, and the difference in impacts is from the ratio of the adjustment cost parameter of intangible assets to the adjustment cost parameter of fixed assets. In addition, when we fix the environmental preference of bank, $\alpha$, the evolutionary stability constraint increases with the increase in the
environmental preference of the enterprise, which is consistent with the result in Figure 3. This phenomenon reflects that the evolutionary stability of EOGC and eco-innovation is more from the environmental preference and the environmental benefit-cost ratio of the enterprise than from the bank.

(2) Impacts of environmental benefit-cost ratios on eco-innovation

The environmental benefit-cost ratios also affect the optimal eco-innovation investment ratio of intangible assets to fixed assets (Figure 8). The optimal eco-innovation investment ratio of intangible assets to fixed assets, $\frac{I_{ina}}{I_{fia}}$, decreases with the increase in the environmental benefit-cost ratio of fixed assets $\eta_{fia}$, and increases with the increase in the environmental benefit-cost ratio of intangible assets $\eta_{ina}$, and the changing trends are more obvious with the increase in the enterprise’s environmental preference $\beta$. This finding reflects that an enterprise under greater environmental pressure is more sensitive to the environmental benefit-cost ratios of intangible assets and fixed assets and will make a greater adjustment to the allocation of investment funds for intangible assets and fixed assets on the basis of $\frac{\rho_{fia}}{\rho_{ina}}$.

The enterprise often has the choice of eco-innovation diversity when making investment decisions on eco-innovation [20]. In the process of conducting eco-innovation, the investment in intangible assets can be regarded as promoting two types of eco-innovation-eco-organization innovation and eco-production-innovation [54] and the investment in fixed assets is eco-process innovation.

Although any type of eco-innovation can decrease the impact of production activities on the environment, the difference among different types of eco-innovation
Figure 7. Impacts of $\eta_{ina}$ and $\eta_{fia}$ on $X_2$ when $\varepsilon = J$. The green surface denotes the evolution stability constraint $X_2$ when $\beta = 0.7$, the red surface denotes $X_2$ when $\beta = 0.5$, and the yellow surface denotes $X_2$ when $\beta = 0.2$, with the condition of $\alpha = 0.3$. The figure shows that some space remains where $X_2 > 0$ if $\varepsilon > J$ with the increase in $\eta_{ina}$ and $\eta_{fia}$, and the impact of $\eta_{ina}$ is greater than that of $\eta_{fia}$.

Figure 8. Impacts of $\eta_{ina}$ and $\eta_{fia}$ on $I_{ina}^*$ and $I_{fia}^*$. The green surface denotes the optimal eco-innovation investment ratio of intangible assets to fixed assets when $\beta = 0.7$, the red surface denotes the optimal investment ratio when $\beta = 0.5$, and the yellow surface denotes the optimal investment ratio when $\beta = 0.2$, with the condition of $\alpha = 0.3$. The figure shows that the impacts of the environmental benefit-cost ratios on the optimal eco-innovation investment ratio of intangible assets to fixed assets change with the enterprise’s environmental preference.

is related to environmental functions [20]. Eco-process innovation can reduce emissions and pollution by a change in fixed assets. Eco-product innovation can make
products less resource intensive and more energy-efficient, and even higher intangible capital. Additionally, the contribution of eco-organization innovation to environmental benefits is indirect and can promote other types of ecological innovation [58]. Therefore, when making eco-innovation investment decisions, the enterprise can determine the investment ratio of intangible assets to fixed assets according to the environmental benefit-cost ratio of intangible assets and fixed assets, to avoid the investment imbalance caused by different characteristics of various types of eco-innovation.

6.3. Impacts of EOGC on economic benefits. In the conclusion of Section 4.3, EOGC and eco-innovation can be evolutionary stable when $X_2 > 0$. However, economic benefits are still important for the bank and the enterprise. Because the enterprise’s Tobin-q and credit risk are still the main factors that directly affect both the traditional credit and EOGC, this section discusses the impact of EOGC on economic benefits when using Tobin-q and credit risk as independent variables.

To show the insufficient endogenous driver for eco-innovation more clearly, we assume that eco-innovation has a lower return on investment, that $i, \varepsilon = 0.8, J = 0.5$. Other relevant parameters are set as follows: $\rho_{ina} = 20, \rho_{fia} = 10, \tau = 0.8, \eta_{fia} = 0.4, \eta_{ina} = 0.6, K = 500$ and $V_0 = 10$. The range of the Tobin-q is from 0.6 to 1.5, and the range of the credit risk is from 0 to 0.1. The environmental preferences of the bank and the enterprise are 0.1, 0.3, and 0.6, respectively.

Figure 9 shows the impacts of EOGC on the economic benefits of the bank. The red surface in Figure 9 represents the economic benefits of the bank under the traditional credit, $R_o$, and the green surface represents the economic benefits of the bank under EOGC, $R_g$.

In Figure 9, whether it is traditional credit or EOGC, the bank’s economic benefits increase with the increase in Tobin-q and decrease with the increase in the credit risk. This result verifies the conclusion of Andrei et al. [5], in which the enterprise’s Tobin-q plays an important role in investment decision-making. Due to the volatility of asset allocation decisions and asset markets, banking financial institutions prefer to base their capital allocation process on the concept of shareholder value [67] and tend to prove tradeoffs between profits and risks. Figure 9 shows that the economic benefits of the bank increase when $q > 1$. This conclusion indicates that Tobin-q not only plays a core role in equity capital investment of enterprises [15] but also is particularly instructive to credit.

Under the circumstance of EOGC, the economic benefits of the bank decrease with the increase in the bank’s environmental preference, $\alpha$, and increase with the increase in the enterprise’s environmental preference, $\beta$. Generally, compared with traditional credit, EOGC can provide the bank with higher economic benefits. However, in Figure 9(7), the reverse applies. This finding shows that the bank with a large environmental preference can only attract the enterprise with little environmental preference to conduct eco-innovation by using low interest rates and high credit lines, to create environmental benefits while reducing economic benefits.

Figure 10 reflects the impacts of EOGC on the economic benefits of the enterprise. The red surface in Figure 10 represents the enterprise’s value growth caused by the other activities under the traditional credit, the yellow surface represents the enterprise’s value growth caused by eco-innovation under the traditional credit, and
Figure 9. Impacts of EOGC on the bank’s economic benefits. The green surface denotes the bank’s economic benefits under EOGC, and the red surface denotes the bank’s economic benefits under the traditional credit. The values of the bank’s environmental preference $\alpha$ and the enterprise’s environmental preference $\beta$ in the figure are 0.1, 0.3, and 0.6, respectively. The figure shows that the bank’s economic benefits under EOGC change with the environmental preferences and differ from that of traditional credit.

The green surface represents the enterprise’s value growth caused by eco-innovation under EOGC.

Under traditional credit, the enterprise’s economic benefits caused by the other activities are higher than those caused by eco-innovation when $\varepsilon > J$, and this

\[ V'_0 = V_0 - V_0. \]

5According to equation (A.5), the first value of the enterprise is $V_0 = \frac{1}{\tau} \left[ \theta K + \lambda (\mu - \theta) V_0 - (\delta_K K_{ina} + \delta_{fia} K_{fia}) V_K + \frac{1}{2} \sigma^2 V_{\theta, \theta} \right]$. Therefore, the dependent variable in Figure 10 is set to the enterprise’s value growth to reduce parameters, that is, $V' = V - V_0$. 
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Figure 10. Impacts of EOGC on the enterprise’s economic benefits. The green surface denotes the enterprise’s economic benefits growth caused by eco-innovation under EOGC, the red surface denotes the enterprise’s economic benefits growth caused by the other activities under the traditional credit, and the yellow surface denotes the enterprise’s economic benefits growth caused by eco-innovation under the traditional credit. The values of the bank’s environmental preference \( \alpha \) and the enterprise’s environmental preference \( \beta \) in the figure are 0.1, 0.3, and 0.6, respectively. The figure shows the change of the enterprise’s economic benefits with the environmental preferences under EOGC.

difference does not vary with environmental preferences, as shown by the red and yellow surfaces in Figure 10. Bitat [14] also proposes this difference as the main reason for the insufficient endogenous driver for eco-innovation.

EOGC changes the enterprise’s economic benefits caused by eco-innovation, as shown by the green surface in Figure 10. The enterprise’s economic benefits caused
by eco-innovation under EOGC decrease with the increase in the enterprise’s environmental preference and increase with the increase in the bank’s environmental preference. Compared with the traditional credit, EOGC can enable the enterprise to realize more economic benefits caused by eco-innovation when the environmental preference of the enterprise is small (Figure 10) (1), (4), and (7). However, the opposite occurs when the environmental preference of the enterprise is high (Figure 10) (3), (6) and (9). This phenomenon indicates that an enterprise with higher environmental preference is willing to exchange reduced economic benefits for more environmental benefits, and the expansion of credit lines is more important than the increase in interest rates.

7. Conclusion. As an important part of sustainable finance, the theoretical framework of green credit is imperfect. China’s green credit policy is an industry-oriented credit policy enforced by administrative means, which cannot realize the intended effect. This paper proposes a new green credit policy named EOGC, which promotes enterprises’ eco-innovation. The results show that EOGC has theoretical feasibility.

EOGC is an expansionary monetary policy, and the bank’s environmental preference is the foundation of its existence. Compared with traditional credit, EOGC needs to expand the credit lines. In the aspect of interest rates, when the enterprise’s environment preference is greater than the bank’s environment preference, the optimal interest rate of EOGC is higher than that of traditional credit, and when the bank’s environment preference is greater than the enterprise’s environment preference, the optimal interest rate of EOGC is lower than that of traditional credit.

As an external driver, EOGC can stimulate enterprises to conduct eco-innovation. Additionally, in the process of using loans to conduct eco-innovation, enterprises can find the investment ratio of intangible assets to fixed assets according to the environmental benefit-cost ratios, to choose appropriate, effective types of eco-innovation.

This paper only discusses the feasibility of EOGC in theory, and many problems remain to be solved in the implementation of specific policies. Because the current enterprise rating, which is a critical link in credit approval, does not consider the enterprise’s activities of environmental improvement, it is particularly important for EOGC to build a green rating model that includes environmental preferences and environmental benefit-cost ratios. In addition, because it is difficult for banks and enterprises to engage in sustainable development by relying only on social responsibility and environmental preferences, the impact of eco-innovation on the return on capital remains a topic of further research.

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Appendix A. According to equation (4), the value function of the enterprise is:

\[ V_t = E_t \int_t^\infty \left[ \pi (\theta_s, K_s) - \varphi_{ina} (I_{s,ina}, K_s) - \varphi_{fia} (I_{s,fia}, K_s) \right] e^{-\tau(s-t)} ds \]  

(A.1)
This can be written as the present value of profits up to a time $\nu$, plus the present value of the value function at that moment \([2]\).

$$V_t = E_t \left[ \int_t^\nu \left[ \pi (\theta_s, K_s) - \varphi_{ina} (I_{s,ina}, K_s) - \varphi_{fia} (I_{s,fia}, K_s) \right] e^{-\tau (s-t)} ds + V_t e^{-\tau (\nu-t)} \right]$$ \hspace{1cm} (A.2)

Define $Z_t = V_t e^{-\tau t}$, and subtract the left hand side of (A.3) from both sides. Divide through by $\nu$ and take the limit as $\nu$ approaches $t$.

$$0 = \lim_{\nu \to t} \left\{ \frac{1}{\nu} E_t \left[ \int_t^\nu \left[ \pi (\theta_s, K_s) - \varphi_{ina} (I_{s,ina}, K_s) - \varphi_{fia} (I_{s,fia}, K_s) \right] e^{-\tau (s-t)} ds + e^{-\tau t} E_t (Z_t - Z_t) \right] \right\}$$ \hspace{1cm} (A.3)

Note $\lim_{\nu \to t} E_t (Z_t - Z_t) = E(dZ)$, and $dZ = -\tau Z dt + e^{-\tau t} dV$, there is:

$$\pi (\theta, K) - \varphi_{ina} (I_{s,ina}, K) - \varphi_{fia} (I_{fia}, K) - \tau V + \frac{E(dV)}{dt} = 0 \hspace{1cm} (A.4)$$

Then, we can get equation (6).

**Appendix B.** From equations (10) and (11), there is:

$$dK_t = (I_{t,ina} + I_{t,fia} - \delta_{ina} K_{t,ina} - \delta_{fia} K_{t,fia}) dt \hspace{1cm} (B.1)$$

and $d\theta_t = [\lambda (\mu - \theta_t) + j_i \theta_t] dt + \sigma_d dW^\theta_t$. Thus, we can calculate $dV$ using Ito’s Lemma:

$$dV = \frac{\partial V}{\partial \theta} d\theta + \frac{\partial V}{\partial K} dK + \frac{1}{2} \frac{\partial^2 V}{\partial \theta^2} (d\theta)^2 + \frac{1}{2} \frac{\partial^2 V}{\partial K^2} (dK)^2 + \frac{\partial^2 V}{\partial \theta \partial K} d\theta dK \hspace{1cm} (B.2)$$

Substitute equations (B.1) and (12) into (B.2), and define $V_\theta = \frac{\partial V}{\partial \theta}, V_K = \frac{\partial V}{\partial K}, V_{\theta, \theta} = \frac{\partial^2 V}{\partial \theta^2}$, we can get:

$$dV_t = \left\{ V_\theta [\lambda (\mu - \theta_t) + J_\theta] + V_K (I_{t,ina} + I_{t,fia} - \delta_{ina} K_{t,ina} - \delta_{fia} K_{t,fia}) + \frac{1}{2} V_{\theta, \theta} \sigma^2_\theta \right\}$$

$$dt + V_{\theta, \sigma} dW^\theta_t \hspace{1cm} (B.3)$$

and

$$\frac{E(dV_t)}{dt} = (I_{t,ina} + I_{t,fia} - \delta_{ina} K_{t,ina} - \delta_{fia} K_{t,fia}) \lambda (\mu - \theta_t) + J_\theta V_\theta + \frac{1}{2} \sigma^2_\theta V_{\theta, \theta} \hspace{1cm} (B.4)$$

Substitute equation (B.4) into (6), there is:

$$V_t = \frac{1}{\tau} \left[ \frac{\theta_t K_t - r_t (I_{t,ina} + I_{t,fia}) - \rho_{ina} t^2_{ina} - \rho_{fia} t^2_{fia}}{2 K_t} + (I_{t,ina} + I_{t,fia} - \delta_{ina} K_{t,ina} - \delta_{fia} K_{t,fia}) \lambda (\mu - \theta_t) + J_\theta \right] V_\theta$$

$$\hspace{1cm} (B.5)$$

According to the Tobin-q theory, the enterprise value $V = K q$, and there is $V_K = q q$ is the Tobin- $q$. We substitute equation (B.5) into (9) to get the enterprise’s
comprehensive benefits:

$$\max_{I_{t,ina}} \max_{I_{t,fia}} F_t = \max \left\{ (1 - \beta) \frac{1}{2} \left[ \theta I_{t,ina} - r_s (I_{t,ina} + I_{t,fia}) - \frac{\nu I_{t,ina}}{2} \right] + \beta \theta I_{t,ina} \right\}$$

where

$$\theta = 1 - \beta - \frac{k}{1 - \beta}.$$ 

Partially differentiating (B.6) with respect to $I_{t,ina}$ and $I_{t,fia}$, we can find the Optimal investment under Scenario I:

$$I_{t,ina}^* = \frac{K}{\rho_{ina}} \left( q - r_g + \frac{\tau \beta \theta_{ina}}{1 - \beta} \right)$$

$$I_{t,fia}^* = \frac{K}{\rho_{fia}} \left( q - r_g + \frac{\tau \beta \theta_{fia}}{1 - \beta} \right)$$

Substitute $I_{t,ina}^*$ and $I_{t,fia}^*$ into equation (B.5), the maximum enterprise value is:

$$V^*_t = \frac{1}{2} \left[ \frac{K (\rho_{ina} + \rho_{fia}) (q - r_g)^2}{2 \rho_{ina} \rho_{fia}} - \frac{K (\eta_{ina} \theta_{ina} + \eta_{fia} \theta_{fia})}{2 \rho_{ina} \rho_{fia}} \left( \frac{\tau \beta}{1 - \beta} \right)^2 + J_0 V_0 \right]$$

The calculation process of the optimal investments and the maximum value in other scenarios is similar.

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