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# Research on Dynamic Selection of Corporate Carbon Information Disclosure Strategies Based on Reputation Theory

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## Abstract

With the continuous increase in global attention to climate change issues, corporate carbon information disclosure has become a key area of focus for both the academic and practical communities. This study uses the theories of information asymmetry, reputation, and the KMRW reputation model to explore the decision-making logic of Chinese enterprises' carbon information disclosure behavior. The research shows: (1) in a single-stage game, enterprises exhibit different behavioral preferences based on rational considerations. (2) In a multi-stage repeated game, they will carefully balance short-term interests and long-term reputation impacts. (3) Meanwhile, factors such as carbon prices, excess returns, and regulatory penalties will all influence the strategy choices of non-moral enterprises. The model's conclusions strongly reveal that enterprises should deeply recognize the significance of reputation for long-term sustainable development and rationally choose to truthfully disclose carbon information to achieve utility maximization. Promoting enterprises to actively fulfill their carbon information disclosure responsibilities, improving the quality of carbon information disclosure, and thereby promoting sustainable economic and social development will provide strong support for achieving the goals of "carbon peak and carbon neutrality".

**JEL classification numbers:** O30, O31, O32, O33.
**Keywords:** Carbon information disclosure, Incomplete information, Dynamic game, KMRW reputation model.

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# 1. Introduction

The trend of global climate warming continues to intensify, and the environmental problems caused by carbon emissions have become a core issue of common concern for countries worldwide. Reducing carbon emissions and promoting sustainable development models have become a widespread consensus in the international community. An internationally recognised effective measure for reducing carbon emissions is the carbon trading policy[1]. In 2011, China began to implement the carbon trading policy, which simultaneously significantly promoted the growth of sustainable economic welfare[2]. The advancement of the 'dual carbon' goals has entered a critical stage. Against this backdrop, China is actively constructing a green, low-carbon, circular economic development system. Enterprises, as the main practitioners of economic activities, have a significant impact on the environment through the carbon emissions generated in their production and operational processes[3-4], and also have a profound impact on national and global climate governance. Carbon disclosure can enhance the transparency of corporate operations, provide a basis for decision-making for stakeholders such as investors and consumers, and also help government regulatory agencies understand corporate carbon emissions and formulate scientific and rational environmental policies. For this reason, countries have introduced relevant regulations requiring enterprises to take a two-pronged approach, strengthening both carbon emission management and the transparency of carbon disclosure. Currently, many domestic scholars have analysed relevant policy documents on carbon disclosure and proposed corresponding countermeasures and suggestions[5-7]. Sun and Zhu[8] proposed that enterprises should not only disclose carbon emission information in their annual reports, but also supplement it in social responsibility reports, sustainable development reports, ESG reports, etc., to disclose more detailed carbon information. Guo et al.[9] proposed that high-quality carbon disclosure is an important prerequisite for achieving carbon emission reductions. Therefore, to achieve the dual carbon goals, the government should improve relevant policy requirements for enterprises to disclose high-quality carbon information.

Carbon information disclosure focuses on the public disclosure of corporate environmental information, and serves as an effective supplement to corporate accounting information disclosure in terms of carbon-related behaviour information. Whether enterprises proactively disclose carbon information or proactively undertake social responsibilities, they can guide carbon dioxide emission reduction practices with information, and it is also conducive to achieving national climate goals[10], further illustrating the importance of carbon information disclosure. However, in an information asymmetry market environment, the motivation and behaviour choices of enterprises in disclosing carbon information become complex and varied, and corporate reputation also affects the strategic choices of carbon information disclosure. At the same time, in the context of carbon information disclosure, information asymmetry may lead to investors and other stakeholders being unable to accurately assess the carbon performance and potential risks of

enterprises, which in turn affects their decisions[11].

Therefore, the study of the dynamic selection of corporate carbon information disclosure strategies under information asymmetry has certain theoretical and practical significance. Based on this, this research starts from the perspective of game theory and uses the KMRW reputation model to explore how companies disclose carbon information under information asymmetry. The possible marginal contributions are: first, the KMRW reputation model combines game theory with information economics. By analysing cooperative behaviour in finite repeated games, it provides a new theoretical perspective for understanding the strategic choices of companies in carbon information disclosure. Secondly, combining theory with practice, through numerical simulation, the conclusions derived from the KMRW reputation model are further analysed and verified in three parts: single factor changes, carbon price fluctuation scenarios, and regulatory intensity change scenarios. This allows for a more accurate simulation of information asymmetry and bounded rationality.

# 2. Literature Review

## 2.1 Influencing Factors of Carbon Information Disclosure Strategies

The selection of corporate carbon information disclosure strategies is influenced by a combination of internal and external factors. Scholars domestically and internationally primarily analyse these from two perspectives: internal corporate characteristics and external regulatory pressures. Regarding internal characteristics, factors such as corporate performance, size, institutional investor shareholding ratios, and corporate governance may all impact carbon information disclosure. Existing research indicates that the management capabilities of corporate executives have a significantly positive effect on carbon information disclosure[12], while the emotions of senior executives also influence low-carbon strategies[13]. Additionally, corporate political connections[14] affect the quality of carbon information disclosure. Furthermore, studies suggest that, compared to men, women may pay greater attention to environmental and ethical issues[15], implying that gender diversity could promote corporate carbon information disclosure. Externally, factors such as industry nature, equity structure, public pressure[16], regulatory incentives[17], investor attention, and media coverage[11,18] may also influence carbon information disclosure. Luo et al.[19] noted that the motivation behind corporate carbon information disclosure primarily stems from the public and government. Meanwhile, Ye et al.[20] found that consumer anticipated regret significantly impacts corporate low-carbon strategies, suggesting its potential influence on carbon information disclosure strategies. Moreover, Li et al.[6], using listed companies in China's heavily polluting industries as subjects, discovered that carbon performance can, to some extent, promote carbon information disclosure. Tian et al.[21], based on blockchain technology, examined a supply chain comprising suppliers, manufacturers, and consumers, where suppliers and manufacturers decide the degree of carbon information disclosure and product premium based on market

conditions. Chen et al.[22], in studying new energy vehicle supply chains, found uncertainty in supply chain members' decisions regarding whether to assume social responsibility and disclose carbon information. Beyond these driving factors, Zhang et al.[23] demonstrated that carbon market policies positively affect corporate environmental performance, incentivising carbon information disclosure. However, existing research predominantly employs static analysis, overlooking how firms dynamically adjust disclosure strategies based on reputational considerations across different development stages, policy cycles, or market fluctuations, failing to explain the complexity and variability of corporate disclosure behaviours.

## 2.2 Corporate Reputation and Carbon Information Disclosure Strategy Selection

Enterprises with a strong reputation secure a long-term and sustainable competitive advantage in the market. To date, extensive research has been conducted on corporate reputation both domestically and internationally. The international scholar Tadelis[24] posits that reputation is a long-standing intangible asset, and employs game theory in its study, notably utilising the KMRW model, which is built upon the theory of repeated games. The standard KMRW reputation model—the perfect public monitoring model—was initially developed by Kreps et al.[25]. Research employing this model indicates that under conditions of complete information, finite repeated games cannot induce cooperative behaviour among participants. Subsequently, Fudenberg and Levine[26] introduced the "imperfect public monitoring model", which demonstrates that if consumers assign a non-zero prior probability to an enterprise being of the Stackelberg type, and the enterprise exhibits sufficient patience, it can achieve an average discounted payoff approaching that of its commitment. Domestic scholars have predominantly applied reputation models to empirical research. For instance, Jiang et al.[27], utilising the reputation model from principal-agent theory, found that prospective reputational effects influence manufacturing firms' decisions regarding the level of their service innovation. Furthermore, Bai and Ding[28], through an analysis of a tripartite evolutionary game model, concluded that an increase in reputational rent can significantly enhance the motivation of enterprises to engage in the carbon finance market.

According to reputation theory, a company's choice of carbon information disclosure strategy is influenced not only by the costs and benefits of disclosure, but also by the potential impact of its reporting behaviour on its reputation. Due to external environmental shifts and internal corporate factors, these disclosure strategies are not static; they evolve over time. Moreover, if a company establishes a strong reputation in one period, this can yield greater advantages in its future strategic interactions[29].

To summarise, while prior research has established the internal and external drivers of corporate carbon disclosure and recognised the value of reputation as an intangible asset, attempts to integrate these two perspectives have their limitations.

Firstly, such analyses are predominantly static, overlooking dynamic factors like the corporate and policy life cycles, which limits their ability to explain variations in disclosure behaviour. Secondly, reputation theory is often applied generically, without a framework tailored to the specific context of carbon information disclosure. This study aims to address these gaps by focusing on dynamic interplay, theoretical suitability, and the expansion of the research's scope, thereby advancing this field of study.

# 3. Problem Description and Basic Assumptions

## 3.1 Problem Description

In recent years, the issue of global warming has intensified, presenting a severe threat to human existence. As key drivers of economic development, corporations are also significant contributors to greenhouse gas emissions. Corporate carbon disclosure represents a crucial measure for addressing global warming, as it satisfies stakeholder demand for environmental information and enables companies to cultivate a positive reputation linked to strong environmental performance. However, corporate carbon disclosure has now become a complex, multi-party strategic interaction. As the primary agents of disclosure, firms' decision-making processes are shaped not only by external factors such as government environmental regulations, competitive market pressures, and oversight from regulatory bodies, but are also intrinsically linked to internal organisational factors.

Consequently, the behavioural choices surrounding carbon disclosure exhibit significant temporal dynamics. Based on feedback from the market and regulators, firms must strategically manage their disclosures to balance short-term profit against long-term objectives, thereby shaping a reputable corporate image to maximise their own interests. The reputation mechanism offers a potent means of countering information asymmetry. This research will analyse the dynamic strategic choices of corporate carbon disclosure through the construction of a KMRW reputation model.

## 3.2 Fundamental Model Assumptions

Grounded in the behavioural logic between firms and regulatory bodies, this paper sets forth the following core assumptions:

**H1**: Bounded Rationality. The players in this game are characterised by bounded rationality, each acting to maximise their own self-interest.

**H2**: Enterprise Typology. In the context of carbon information disclosure, firms are faced with a strategic binary choice: to report their carbon data accurately, thus classifying as a 'moral' firm ($\alpha = 0$); or to engage in misleading or incomplete disclosure, thereby classifying as an 'immoral' firm ($\alpha = 1$). Over the T stages of this repeated game, the prior probability of a firm being 'moral' ($\alpha = 0$) is denoted as $P_T$, and consequently, the prior probability of it being 'immoral' ($\alpha = 1$) is

$1-P_T$. A firm choosing the immoral path is fully cognisant that discovery by the regulator will entail a loss of regulatory trust and the imposition of financial sanctions. Furthermore, such an action will invariably compromise its corporate reputation, precipitate negative public sentiment, and diminish its standing in the estimation of both regulators and the public, ultimately undermining its long-term developmental prospects.

**H3**: The firm's utility function. Drawing upon the simplified reputation model in Barro[30], which investigates the consistency of government monetary policy, we construct the following utility function for the periods $t = 0,1,2,.....T$:

$$U_t(R_t \text{ , } R_t^e)=-\frac{1}{2}R_t^2+\alpha(R_t-R_t^e) \tag{1}$$

Here, $U(\cdot)$ denotes the utility derived from corporate reputation; $\alpha = 0$ signifies that the company truthfully discloses its carbon information, characterising it as a moral enterprise, whereas $\alpha = 1$ signifies non-disclosure, concealment, or misrepresentation of carbon information, characterising it as an immoral enterprise; $-\frac{1}{2}R_t^2$ represents the penalty imposed by regulatory authorities on immoral enterprises during the t-th stage; $R_t$ denotes the enterprise's additional revenue, and for ease of discussion, it is posited that Rt may take only one of two values: 0 or 1. Here, $R_t = 0$ indicates that the enterprise truthfully discloses its carbon information in practice, while $R_t = 1$ indicates that the enterprise engages in concealment or misrepresentation during its carbon information disclosure; $R_t^e$ represents the regulatory authority's expected additional revenue for enterprises that do not truthfully disclose carbon information, with $0 \le R_t^e \le 1$; $\alpha(R_t - R_t^e)$ signifies the additional revenue of immoral enterprises, specifically the portion exceeding the regulatory authority's expectations.

In a multi-stage repeated game, a firm's total utility is given by the sum of the discounted utilities from each stage:

$$U(R_t \text{ , } R_t^e)=\sum_{t=0}^{\infty}\delta^t U_t \tag{2}$$

Here, $\delta$ is the discount factor (where $\delta \in [0,1]$), and it quantifies the importance that the firm attaches to its reputation in terms of its long-term interests.

**H4**: Information asymmetry. Neither enterprises nor regulators can accurately predict each other's behavioral choices. Enterprises cannot precisely know the regulatory measures regulators will impose during this phase, while regulators cannot precisely know how enterprises will disclose carbon information during this phase. However, regulators can observe the magnitude of additional profits enterprises gain from concealing or misreporting carbon information to determine enterprise types, thereby deciding regulatory measures for the next phase. $X_T$ denotes the probability that regulators believe companies will choose to disclose carbon information truthfully to maintain their reputation at stage T. $Y_T$ denotes the probability that companies truthfully disclose carbon information at stage T to maintain their reputation. When $X_T=Y_T$, both companies and regulators reach equilibrium and achieve mutual recognition.

**H5**: Firm Type Segmentation. Let n denote firm type, where n=0 indicates an ethical firm and n=1 indicates an unethical firm; let m denote whether the firm discloses carbon information truthfully, where m=0 indicates truthful disclosure and m=1 indicates concealment or misreporting.Based on the previous game analysis using Barro's total utility function, ethical firms (n=0) will choose to disclose carbon information truthfully under the principle of profit maximization, i.e., m=0. For unethical firms, behavior can be divided into two types: truthful disclosure and untruthful disclosure. The former constitutes compliant behavior, while the latter constitutes non-compliant behavior.

**H6**: Let $P_{mT}(0<P_{mT}<1)$ denote the probability that market participants detect non-truthful carbon disclosure by unethical firms at stage T, $P_{fT}$ $(0<P_{fT}<1)$ denote the probability that regulators detect and penalize such non-truthful disclosure, and $P_{0T}$ $(0<P_{0T}<P_{fT}$，$0<P_{0T}<P_{mT})$ denote the probability that both market participants and regulators detect such non-truthful disclosure at stage T.

**H7**: Due to imperfect carbon disclosure policies, a significant proportion of firms engage in non-compliant disclosure, falsifying or concealing carbon information [31]. This paper treats $P_t$ as the probability that a firm is ethical. A higher $P_t$ implies greater reputational utility for the firm. $L_m$、$L_f$ represent the losses incurred by a firm deemed unethical, with the former excluding regulatory oversight and the latter incorporating it. Furthermore, compared to market forces, regulatory penalties exert a greater impact on a firm's reputation for non-compliant carbon disclosure. Thus, $0<L_m<L_f$ and $R_0$ denote the benefits of compliant carbon disclosure for ethical firms, while $R_t$ represents the reputational gain for unethical firms choosing truthful disclosure at stage t. Consequently, $R_t=R_0-(1-P_t)L_m$ or $R_t=R_0-(1-P_t)L_f$ holds, and furthermore, $R_{t+k}-R_t=(P_{t+k}-P_t)L_m$ or $R_{t+k}-R_t=(P_{t+k}-P_t)L_f$ applies.

**H8**: Number of Game Rounds. Participants engage in multiple repeated rounds of the game. To simplify analysis, assume all firms choose truthful disclosure prior to round T. Starting from round T, all ethical firms will choose truthful disclosure, while unethical firms' choices will be influenced by profit-maximization principles.

**H9**: Bankruptcy Liquidation. During ongoing operations, firms will not undergo bankruptcy liquidation. To clearly analyze firms' behavioral choices at stage T, it is assumed that starting from stage T+1, the game generates no new information to influence public judgments about firm types. Thus, firms' compliance reputations remain unchanged, i.e., $P_{T+1}=P_{T+2}=...=P_{T+k}$ . Further, $R_{T+k}-R_T=(P_{T+1}-P_T)L_m$ or $R_{T+k}-R_T=(P_{T+1}-P_T)L_f$.
For readability, parameter symbols and definitions are listed in Table 1.

## 4. Model Analysis

Based on the assumptions of the aforementioned model, as shown in Figure 1 below, when $\alpha=0$, the firm is an ethical firm, then $U(R)=-\frac{1}{2}R^2$, pursuing maximization of firm utility. When$R=0$ , the maximum reputation utility the firm can obtain is 0, meaning that truthful carbon information disclosure will enhance the firm's reputation.If this ethical firm chooses to conceal or misreport carbon information (R=1), the utility of its reputation becomes $U(R)=-\frac{1}{2}<0$. At this point, the company is engaged in "carbon washing," deceiving consumers and regulatory authorities, and its reputation will decline. When $\alpha=1$ , the firm is unethical $U(R)=-\frac{1}{2}R^2+R-R^e$). If $R=0$, the utility of its reputation is $U(R)=-R^e$. Conversely, when $R=1$, the utility of its reputation becomes $U(R)=\frac{1}{2}-R^e$ . For rational firms, aware that regulatory oversight constitutes a long-term repeated behavior, they will choose to disclose carbon information truthfully to maximize profits until the final game. $R^e$ varies inversely with the number of games, until it can be guaranteed that $U(R)\geq 0$, indicating that a firm's positive reputation enhances regulatory trust. Analysis is conducted under two scenarios: single-stage games and multi-stage repeated games.

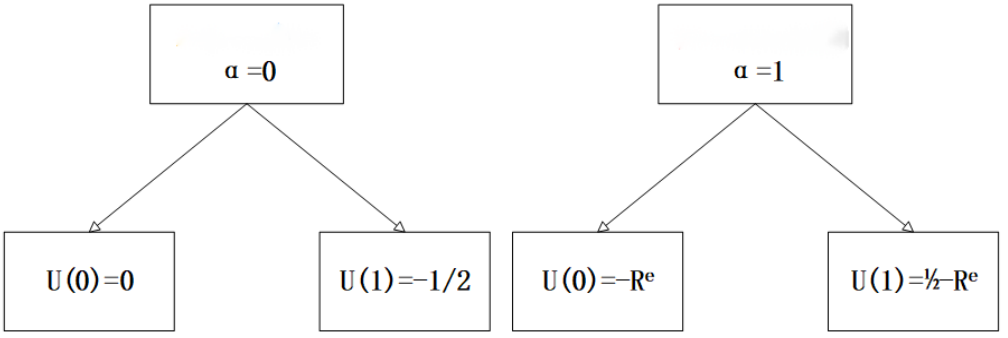


**Figure 1: Specific Corporate Carbon Disclosure Behavior**

### 4.1 Single-stage game

In single-stage games, firms pursue utility maximization. Applying the economic principle of utility maximization, differentiating the utility of corporate reputation $U(R)=-\frac{1}{2}R^2+\alpha(R-R^e)$, yields: $\frac{\partial U}{\partial R}=-R+\alpha$. Setting $\frac{\partial U}{\partial R}=0$, we obtain: $R=\alpha$. If the firm is unethical ($\alpha=1$), then pursuing utility maximization yields $R=\alpha=1$. The utility of corporate reputation is $U(R)=\frac{1}{2}-R^e$. Therefore, in single-stage games, rational unethical firms will conceal or misrepresent information during carbon disclosure to achieve a favorable reputation.If the firm is ethical ($\alpha=0$), then it seeks to maximize utility ($R=\alpha=0$), where the utility of corporate reputation is $U(R)=0$. Therefore, in a single-stage game, rational ethical firms should choose to disclose carbon information truthfully to obtain a good reputation, rather than conceal or misreport it, thereby avoiding the emergence of active "greenwashing" behavior[32].

### 4.2 Multi-stage Repeated Games

Assuming that in phase T, regulators did not observe concealment or misrepresentation in the company's carbon disclosure process, according to Bayes' theorem, the posterior probability that regulators will consider the company ethical in phase T+1 is:

$$P_{T+1}(\alpha=0|R_T=0)=\frac{P_T\times 1}{P_T\times 1+(1-P_T)\times X_T}\geq P_T \tag{3}$$

Thus, at stage T+1, the probability of the firm being perceived by regulators as a reputable, ethical firm increases. Conversely, if regulators observe concealment or misrepresentation in the firm's carbon information disclosure at stage T, the posterior probability of the firm being deemed ethical is:

$$P_{T+1}(\alpha=0|R_T=1)=\frac{P_T\times 0}{P_T\times 0+(1-P_T)\times(1-X_T)}=0 \tag{4}$$

This indicates that regulators will adopt a "ruthless strategy": once concealment or misrepresentation in carbon disclosure is detected, the company is deemed unethical, resulting in a reputation of zero in the subsequent phase. Therefore, rational unethical companies will avoid exposing their non-compliant carbon disclosures before the final phase to prevent reputational damage.

The following analysis examines the behavioral choices and influencing factors of unethical firms using the final two stages of the game as an example:

(1) Strategy Analysis for Firm T

At stage T, for an unethical company with poor reputation (α=1), the optimal choice for carbon disclosure is concealment or misrepresentation ( $R_T$=1 ).Regulators' expected judgment of profits generated by concealment or misrepresentation is$R_T^e$=1-$P_T$. Thus, the utility of corporate reputation at this point is$U_T(R)=P_T-\frac{1}{2}$. Differentiating this equation yields $\frac{\partial U_T}{\partial P_T}$=1>0, indicating that the utility of unethical firms is an increasing function of reputation. Therefore, unethical firms have incentives to build a good reputation.

(2) Analysis of the Firm's Strategy in Phase T-1

In phase T-1, assume the unethical firm has actively maintained a good reputation prior to this phase. For simplicity, we consider only the pure strategy scenarios:$Y_{T-1}$=0and $Y_{T-1}$=1 .Participants choose mixed strategies only when the expected utilities generated by two pure strategies are perfectly equal. In other words, mixed strategies are considered precisely when the utility values of pure strategies cannot be distinguished in terms of superiority. Furthermore, once the conditions under which pure strategies are optimal are determined, the conditions for applying mixed strategies become self-evident.

If an unethical firm chooses to conceal or misreport carbon information in phase T-1, i.e.,$Y_{T-1}$=0,$R_{T-1}$=1, and additionally$P_T$=0. This is because upon observing the firm's concealment or misreporting in phase T-1, regulators will inevitably classify it as unethical in phase T. Introducing a discount factor, the sum of the firm's utility in phases T-1 and T is

$$U_{T-1}(R_{T-1})+\delta\times U_T(R_T)=-R_{T-1}^e+\frac{1}{2}(1-\delta) \tag{5}$$

If an unethical firm chooses to disclose carbon information truthfully in phase T-1, then $Y_{T-1}$=1 ,$R_{T-1}$=0, and additionally $P_T$>0. When introducing a discount factor, the sum of the firm's utility in phases T-1 and T is

$$U_{T-1}(R_{T-1})+\delta\times U_T(R_T)=-R_{T-1}^e+\delta(P_T-\frac{1}{2}) \tag{6}$$

If $-R_{T-1}^e+\delta(P_T-\frac{1}{2})\geq-R_{T-1}^e+\frac{1}{2}(1-\delta)$ simplification yields $P_T\geq\frac{1}{2\delta}$. Furthermore, under equilibrium conditions, $X_{T-1}=Y_{T-1}$=1 implies $P_{T-1}=P_T$,thus $P_{T-1}\geq\frac{1}{2\delta}$.

When $P_T=\frac{1}{2\delta}$, the utility of whether a firm chooses to disclose carbon information truthfully is identical that is, for any $Y_{t-1}\in[0,1]$, it is optimal.

However, since $X_{T-1}=Y_{T-1}$, substituting $P_{T-1}=\frac{1}{2\delta}$ into Bayes theorem $P_T(\alpha=0|R_{T-1}=0)=\frac{P_{T-1}\times 1}{P_{T-1}\times 1+(1-P_{T-1})\times X_{T-1}}=\frac{1}{2\delta}$ further yields$X_{T-1}=Y_{T-1}=\frac{(2\delta-1)P_T}{1-P_T}$, i.e., $Y_T=\frac{(2\delta-1)P_T}{1-P_T}$ . Assuming $>\frac{1}{2}$ , taking the first-order partial derivative gives$\frac{\partial Y_T}{\partial P_T}=(2\delta-1)\frac{1}{(1-P_T)^2}>0$. Notably, as $P_T$ approaches $\frac{1}{2\delta}$, $Y_T$ approaches 1.This indicates that in phase T-1, if regulators perceive unethical firms as ethical with a probability greater than or equal to$\frac{1}{2\delta}$, unethical firms will disguise themselves as ethical, disclose carbon information truthfully, and establish and maintain a positive reputation. Extending this result from the T-1 stage to T-2, T-3, T-4, ..., T-1 reveals that unethical firms will conceal or falsify carbon information during the T stage to exploit the benefits of a positive reputation, thereby maximizing their own gains. However, prior to the T stage, they consistently choose to disclose carbon information truthfully to build a favorable reputation.

# 5. Extended Analysis of Corporate Carbon Disclosure Behavior in Phase T+1

Assuming firms operate continuously in the foreseeable future, their current actions significantly influence future periods. Building upon Barro's total utility function model, we incorporate variables such as excess returns and regulatory penalties. We then compare changes in immoral firms' carbon disclosure strategies under two scenarios: with and without regulatory oversight.

## 5.1 Analysis of Unethical Firm Strategies Without Regulatory Intervention

According to Bayes' theorem, if $Y_T = 1$, meaning an unethical firm chooses to disclose carbon information truthfully in phase T, then the posterior probability that the public perceives this firm as ethical in phase T+1 is:

$$P_{T+1}(n = 0|m = 0) = \frac{P_T \times 1}{P_T \times 1 + (1 - P_T) \times X_T} \geq P_T \tag{7}$$

This implies that if the market detects the firm's compliance at stage T, its reputation improves at stage T+1, with the market compliance reputation increasing from $P_T$ to $P_{T+1}(n = 0|m = 0)$. The incremental benefit gained by an unethical firm choosing to disclose carbon information truthfully at stage T is:

$$\begin{aligned} \Delta \mathrm{R}(\mathrm{n} = 1, \mathrm{m} = 0) &= \delta(\mathrm{R_{T+1}} - \mathrm{R_T}) + \delta^2(\mathrm{R_{T+2}} - \mathrm{R_T}) + \ldots \\ &= \delta(\mathrm{P_{T+1}} - \mathrm{P_T}) + \delta^2(\mathrm{P_{T+1}} - \mathrm{P_T}) + \ldots \\ &= \frac{\delta}{1-\delta}(\mathrm{P_{T+1}} - \mathrm{P_T})\mathrm{L_m} \end{aligned} \tag{8}$$

Therefore, the expected incremental benefit for unethical firms choosing to disclose carbon information truthfully at stage T is:

$$E(\Delta R(n=1,m=0)) = \Delta R(n=1,m=0) = \frac{\delta}{1-\delta}(P_{T+1} - P_T)L_m \tag{9}$$

If $Y_T = 0$, meaning the unethical firm non-compliantly discloses carbon information in phase T, the following two outcomes exist:
(1) If the market perceives the firm as compliant with carbon disclosure (probability $1 - P_{mT}$), then at stage T+1 the market's perception of the firm as ethical increases. The firm not only gains the excess profit$R_1$（$R_1 > 0$）but also receives additional benefits from its positive compliance reputation. The increased profit at this point is:

$$\begin{aligned}\Delta R(n=1,m=1) &= R_1 + \delta(R_{T+1} - R_T) + \delta^2(R_{T+2} - R_T) + \ldots \\ &= R_1 + \delta(P_{T+1} - P_T) + \delta^2(P_{T+1} - P_T) + \ldots \\ &= R_1 + \frac{\delta}{1-\delta}(P_{T+1} - P_T)L_m\end{aligned} \tag{10}$$

(2) If the market perceives the company as non-compliant in disclosing carbon information with probability $P_{mT}$, the posterior probability that the public views the company as ethical at stage T+1 is:

$$P_{T+1}(n=0|m=1) = \frac{P_T \times 0}{P_T \times 0 + (1-P_T) \times (1-X_T)} = 0 \tag{11}$$

This implies that when the market detects non-compliant carbon information disclosure, it classifies the firm as unethical. Although the firm achieves excess returns $R_1$ at stage T, it faces reputational losses upon future truthful disclosure. Thus, the incremental firm revenue is:

$$\begin{aligned}\Delta R(n=1,m=1) &= R_1 + \delta(R_{T+1} - R_T) + \delta^2(R_{T+2} - R_T) + \ldots \\ &= R_1 + \delta(P_{T+1} - P_T) + \delta^2(P_{T+1} - P_T) + \ldots \\ &= R_1 + \frac{\delta}{1-\delta}(P_{T+1} - P_T)L_m = R_1 - \frac{\delta}{1-\delta}P_T L_m\end{aligned} \tag{12}$$

Thus, the expected incremental profit from non-compliant carbon disclosure in phase T for an unethical firm is:

$$\begin{aligned}\mathrm{E}(\Delta \mathrm{R}(\mathrm{n}=1,\mathrm{m}=1)) &= (1-\mathrm{P_{mT}})[\mathrm{R_1}+\frac{\delta}{1-\delta}(\mathrm{P_{T+1}}-\mathrm{P_T})\mathrm{L_m}]+\mathrm{P_{mT}}(\mathrm{R_1} \\ &-\frac{\delta}{1-\delta}\mathrm{P_T}\mathrm{L_m}) \\ &= \mathrm{R_1}-\frac{\delta}{1-\delta}\mathrm{P_T}\mathrm{L_m}+(1-\mathrm{P_{mT}})\frac{\delta}{1-\delta}\mathrm{P_{T+1}}\mathrm{L_m}\end{aligned} \tag{13}$$

If $\mathrm{E}(\Delta \mathrm{R}(\mathrm{n}=1,\mathrm{m}=0)) > \mathrm{E}(\Delta \mathrm{R}(\mathrm{n}=1,\mathrm{m}=1))$, unethical firms will choose to comply with carbon disclosure requirements. Thus, the optimal strategy for unethical firms at equilibrium is compliant carbon disclosure, yielding:

$$\frac{\delta}{1-\delta}(\mathrm{P_{T+1}}-\mathrm{P_T})\mathrm{L_m} > \mathrm{R_1}-\frac{\delta}{1-\delta}\mathrm{P_T}\mathrm{L_m}+(1-\mathrm{P_{mT}})\frac{\delta}{1-\delta}\mathrm{P_{T+1}}\mathrm{L_m} \tag{14}$$

Thus, we obtain

$$P_{T+1} > \frac{1-\delta}{\delta}\times\frac{\mathrm{R_1}}{L_m \times P_{mT}} \tag{15}$$

Under pure strategy conditions, since the equilibrium condition is$X_T = Y_T$, meaning public expectations align with firm choices, when$Y_T = 1$, the unethical firm's strategy equilibrates. Thus, $X_T = Y_T = 1$ , and consequently $P_{T+1} = P_T$ . Therefore, we obtain

$$P_T > \frac{1-\delta}{\delta}\times\frac{\mathrm{R_1}}{L_m \times P_{mT}} \tag{16}$$

That is, when the public perceives the firm as unethical at stage T with a probability greater than $\frac{1-\delta}{\delta}\times\frac{\mathrm{R_1}}{L_m\times P_{mT}}$ , unethical firms will pretend to be ethical. The better the firm's reputation, the more proactively it will maintain its reputation.

Further analysis shows that when $P_T = P_{T+1} > \frac{1-\delta}{\delta}\times\frac{\mathrm{R_1}}{L_m\times P_{mT}}$ , the firm chooses the optimal pure strategy of compliantly disclosing carbon information. Conversely, when $P_{T+1} = \frac{1-\delta}{\delta}\times\frac{\mathrm{R_1}}{L_m\times P_{mT}}$ , the mixed strategy is optimal for any $Y_T \in [0,1]$ .

First, analyzing the mixed strategy: When $P_{T+1} = \frac{1-\delta}{\delta}\times\frac{\mathrm{R_1}}{L_m\times P_{mT}}$, $Y_t \in [0,1]$ are both optimal, the firm adopts a mixed strategy. Substituting $P_{T+1} = \frac{1-\delta}{\delta}\times\frac{\mathrm{R_1}}{L_m\times P_{mT}}$ into$P_{T+1}(n=0|m=0) = \frac{P_T\times 1}{P_T\times 1+(1-P_T)\times X_T}$ yields:

$$X_T = \frac{P_T}{1-P_T}\times(\frac{1}{P_{T+1}}-1) = \frac{P_T}{1-P_T}\times(\frac{\delta}{1-\delta}\times\frac{L_m\times P_{mT}}{R_1}-1) \tag{17}$$

Furthermore, since at equilibrium $X_T = Y_T$ , we have

$$\begin{aligned} Y_T = X_T &= \frac{P_T}{1-P_T} \times (\frac{1}{P_{T+1}} - 1) \\ &= \frac{P_T}{1-P_T} \times (\frac{\delta}{1-\delta} \times \frac{L_m \times P_{mT}}{R_1} - 1) \end{aligned} \tag{18}$$

Thus, we obtain

$$\frac{\partial Y_T}{\partial P_T} = \frac{1}{(1-P_T)^2} \times (\frac{\delta}{1-\delta} \times \frac{L_m \times P_{mT}}{R_1} - 1) > 0 \tag{19}$$

It follows that the more the public perceives a company as ethical, the higher the probability that unethical companies will choose to disclose carbon information in compliance.

By the same token:

$$\frac{\partial Y_T}{\partial \delta} = \frac{P_T}{1-P_T} \times \frac{L_m \times P_{mT}}{R_1} \times \frac{1}{(1-\delta)^2} > 0 \tag{20}$$

$$\frac{\partial Y_T}{\partial R_1} = -\frac{P_T}{1-P_T} \times \frac{\delta}{1-\delta} \times \frac{L_m \times P_{mT}}{R_1^2} < 0 \tag{21}$$

$$\frac{\partial Y_T}{\partial L_m} = \frac{P_T}{1-P_T} \times \frac{\delta}{1-\delta} \times \frac{P_{mT}}{R_1} > 0 \tag{22}$$

$$\frac{\partial Y_T}{\partial P_{mT}} = \frac{P_T}{1-P_T} \times \frac{\delta}{1-\delta} \times \frac{L_m}{R_1} > 0 \tag{23}$$

Analysis yields: (1) From $\frac{\partial Y_T}{\partial \delta} > 0$ , it is evident that as $\delta$ increases, $Y_T$ also increases. This indicates that enterprises place greater emphasis on future benefits, leading them to leverage their reputation in the subsequent phase to actively maintain a positive corporate image, thereby enhancing the overall quality of carbon information disclosure;(2) As shown by $\frac{\partial Y_T}{\partial R_1} < 0$ , the greater the excess returns $R_1$ that unethical firms gain from non-compliant carbon disclosure, the smaller $Y_T$ becomes. This indicates that unethical firms are more likely to engage in non-compliant carbon disclosure to pursue short-term gains, thereby reducing the overall quality of carbon disclosure.(3) As shown in $\frac{\partial Y_T}{\partial L_m} > 0$ , when the public places greater emphasis on market reputation, unethical firms are more inclined to comply with carbon disclosure requirements to build a positive reputation as the reputational damage from non-compliant disclosure increases ($L_m$). This tendency contributes to an overall improvement in the quality of carbon disclosure. (4) As shown in $\frac{\partial Y_T}{\partial P_{mT}} > 0$, when the market's ability to detect non-compliant carbon disclosures

increases, such disclosures become more likely to be uncovered. Consequently, firms exercise greater caution in their disclosures, leading to a certain improvement in overall disclosure quality.

When $P_T > \frac{1-\delta}{\delta} \times \frac{R_1}{L_m \times P_{mT}}$, firms adopt the optimal pure strategy of compliant disclosure, i.e.,$X_T = Y_T = 1$ and $P_T = P_{T+1}$. When $\mathrm{N} = \frac{1-\delta}{\delta} \times \frac{R_1}{L_m \times P_{mT}}$, meaning the probability that the public perceives a firm as ethical at stage T exceeds $\frac{1-\delta}{\delta} \times \frac{R_1}{L_m \times P_{mT}}$, unethical firms will disguise themselves as ethical. In other words, the better a firm's reputation, the greater its incentive to maintain it. Additionally, the smaller N is, the larger the range of $P_T$ for firms complying with carbon disclosure. Consequently, more non-ethical firms will choose to comply with carbon disclosure at stage T, leading to an overall improvement in the quality of carbon information disclosure.

Taking the partial derivative with respect to the parameter$\delta$、$\mathrm{R_1}$、$\mathrm{L_m}$、$\mathrm{P_{mT}}$ yields

$$\frac{\partial N}{\partial \delta} = -\frac{1}{\delta^2} \times \frac{R_1}{L_m \times P_{mT}} < 0 \tag{24}$$

$$\frac{\partial N}{\partial R_1} = \frac{1-\delta}{\delta} \times \frac{1}{L_m \times P_{mT}} > 0 \tag{25}$$

$$\frac{\partial N}{\partial L_m} = -\frac{1-\delta}{\delta} \times \frac{R_1}{P_{mT}} \times \frac{1}{{L_m}^2} < 0 \tag{26}$$

$$\frac{\partial N}{\partial P_{mT}} = -\frac{1-\delta}{\delta} \times \frac{R_1}{L_m} \times \frac{1}{{P_{mT}}^2} < 0 \tag{27}$$

Further analysis is analogous to that of mixed strategies.

Without regulatory intervention, the primary considerations influencing firms' carbon disclosure decisions include: market oversight of compliant disclosure behavior ($L_m$), excess returns from non-compliant disclosure ($R_1$), and the discount factor ($\delta$).

### 5.2 Strategy Analysis for Unethical Firms with Regulatory Authorities

If $Y_T = 1$, an unethical firm that truthfully discloses carbon information in compliance at stage T will see its reputation rise to $P_{T+1}(n = 0|m = 0)$. The expected incremental benefit for an unethical firm choosing compliant carbon disclosure at stage T is:

$$\mathrm{E}(\Delta \mathrm{R}(\mathrm{n} = 1, \mathrm{m} = 0)) = \Delta \mathrm{R}(\mathrm{n} = 1, \mathrm{m} = 0) = \frac{\delta}{1-\delta}(\mathrm{P_{T+1}} - \mathrm{P_T})\mathrm{L_m} \tag{28}$$

When regulators detect non-compliant carbon disclosure, penalties are imposed, with fines assumed to be $R_2$（$R_2 > 0$）. If $Y_T = 0$ , an unethical firm choosing non-compliant disclosure in period T faces four possible outcomes:
(1) Neither the market nor regulators detect the non-compliant disclosure. The market initially classifies the firm as ethical, with a probability of $(1 + P_{0T} - P_{mT} - P_{fT})$. The incremental benefit gained is:

$$\begin{aligned}\Delta R(n=1,m=1) &= R_1 + \delta(R_{T+1} - R_T) + \delta^2(R_{T+2} - R_T) + \ldots \\ &= R_1 + \delta(P_{T+1} - P_T) + \delta^2(P_{T+1} - P_T) + \ldots \\ &= R_1 + \frac{\delta}{1-\delta}(P_{T+1} - P_T)L_m\end{aligned} \tag{29}$$

(2) Both the market and regulators detect the non-compliant disclosure. The probability of this occurring is $P_{0T}$. The market will reclassify the company from the $T+1$ stage to unethical. Thus, $P_{T+1}(n=0|m=1)=0$. The incremental profit gained by the company is:

$$\begin{aligned}\Delta R(n=1,m=1) &= -R_2 + \delta(R_{T+1} - R_T) + \delta^2(R_{T+2} - R_T) + \ldots \\ &= -R_2 + \delta(P_{T+1} - P_T) + \delta^2(P_{T+1} - P_T) + \ldots \\ &= -R_2 + \frac{\delta}{1-\delta}(P_{T+1} - P_T)L_f \\ &= -B + \frac{\delta}{1-\delta}(0 - P_T)L_f = -R_2 - \frac{\delta}{1-\delta}P_T L_f\end{aligned} \tag{30}$$

(3) The market discovers the company's non-compliant carbon information disclosure, but the regulatory authorities do not. The probability of this occurring is $(P_{mT} - P_{0T})$. The market will classify the company as unethical from the $T+1$ stage, then $P_{T+1}(n=0|m=1)=0$. The incremental benefit gained by the company at this point is:

$$\begin{aligned}\Delta R(n=1,m=1) &= R_1 + \delta(R_{T+1} - R_T) + \delta^2(R_{T+2} - R_T) + \ldots \\ &= R_1 + \delta(P_{T+1} - P_T) + \delta^2(P_{T+1} - P_T) + \ldots \\ &= R_1 + \frac{\delta}{1-\delta}(P_{T+1} - P_T)L_m \\ &= R_1 + \frac{\delta}{1-\delta}(0 - P_T)L_m = R_1 - \frac{\delta}{1-\delta}P_T L_m\end{aligned} \tag{31}$$

(4) Regulatory authorities detect the company's non-compliant carbon disclosure, but the market does not. The probability of this scenario is $(P_{fT} - P_{0T})$. The market will classify the company as unethical from the $T+1$ stage, then $P_{T+1}(n=0|m=1)=0$. The incremental benefit gained by the company at this point is:

$$\begin{aligned}\Delta R(n=1,m=1) &= -R_2 + \delta(R_{T+1} - R_T) + \delta^2(R_{T+2} - R_T) + \ldots \\ &= -R_2 + \delta(P_{T+1} - P_T) + \delta^2(P_{T+1} - P_T) + \ldots \\ &= -R_2 + \frac{\delta}{1-\delta}(P_{T+1} - P_T)L_f \\ &= -R_2 + \frac{\delta}{1-\delta}(0 - P_T)L_f = -R_2 - \frac{\delta}{1-\delta}P_T L_f\end{aligned} \tag{32}$$

Therefore, the expected incremental benefit from non-ethical companies' non-compliant carbon information disclosure is:

$$\begin{aligned}&E(\Delta R(n=1,m=1)) \\ &= (1 + P_{0T} - P_{mT} - P_{fT})[R_1 + \frac{\delta}{1-\delta}(P_{T+1} - P_T)L_m] \\ &+ P_{0T}[-R_2 - \frac{\delta}{1-\delta}P_T L_f] + (P_{mT} - P_{0T})[R_1 \\ &- \frac{\delta}{1-\delta}P_T L_m] + (P_{fT} - P_{0T})[-R_2 - \frac{\delta}{1-\delta}P_T L_f] \\ &= R_1 - P_{fT}(R_1 + R_2) + (1 + P_{0T} - P_{mT} \\ &- P_{fT}) \times \frac{\delta}{1-\delta}P_{T+1}L_m + [(L_m - L_f)P_{fT} \\ &- L_m] \times \frac{\delta}{1-\delta}P_T\end{aligned} \tag{33}$$

If $E(\Delta R(n=1,m=0)) > E(\Delta R(n=1,m=1))$, the unethical firm will choose to comply with carbon disclosure requirements, requiring only yields

$$\begin{aligned}&\frac{\delta}{1-\delta}(P_{T+1} - P_T)L_m \\ &> R_1 - P_{fT}(R_1 + R_2) + (1 + P_{0T} - P_{mT} \\ &- P_{fT}) \times \frac{\delta}{1-\delta}P_{T+1}L_m + [(L_m - L_f)P_{fT} \\ &- L_m] \times \frac{\delta}{1-\delta}P_T\end{aligned} \tag{34}$$

$$P_{T+1} > \frac{1-\delta}{\delta} \times \frac{R_1 - P_{fT}(R_1 + R_2)}{L_f P_{fT} + L_m(P_{mT} - P_{0T})} \tag{35}$$

Under pure strategy conditions, since the equilibrium condition is $X_T = Y_T$, meaning the public's expectations align with the firm's choices, when $Y_T = 1$, the non-ethical firm strategy equilibrium holds: $X_T = Y_T = 1$. Thus, $P_{T+1} = P_T$, yielding

$$P_T > \frac{1-\delta}{\delta} \times \frac{R_1 - P_{fT}(R_1 + R_2)}{L_f P_{fT} + L_m(P_{mT} - P_{0T})} \tag{36}$$

That is, when the public perceives the firm as unethical at stage T with probability greater than $\frac{1-\delta}{\delta} \times \frac{R_1 - P_{fT}(R_1+R_2)}{L_f P_{fT} + L_m(P_{mT} - P_{0T})}$, unethical firms will pretend to be ethical. The better the firm's reputation, the more proactively it will maintain it.

Further analysis shows that when $P_T = P_{T+1} > \frac{1-\delta}{\delta} \times \frac{R_1 - P_{fT}(R_1+R_2)}{L_f P_{fT} + L_m(P_{mT} - P_{0T})}$, firms choose the optimal pure strategy of compliantly disclosing carbon information; when$P_{T+1} = \frac{1-\delta}{\delta} \times \frac{R_1 - P_{fT}(R_1+R_2)}{L_f P_{fT} + L_m(P_{mt} - P_{0T})}$, firms adopt a mixed strategy for any $Y_T \in [0,1]$.

First, analyzing the mixed strategy: when $P_{T+1} = \frac{1-\delta}{\delta} \times \frac{R_1 - P_{fT}(R_1+R_2)}{L_f P_{fT} + L_m(P_{mT} - P_{0T})}$,$Y_T \in [0,1]$ are both optimal. Under equilibrium conditions where $X_T = Y_T$ holds, substituting $P_{T+1} = \frac{1-\delta}{\delta} \times \frac{R_1 - P_{fT}(R_1+R_2)}{L_f P_{fT} + L_m(P_{mT} - P_{0T})}$ into $P_{T+1}(n=0|m=0) = \frac{P_T \times 1}{P_T \times 1 + (1-P_T) \times X_T}$ yields:

$$\begin{aligned} X_T &= \frac{P_T}{1-P_T} \times \left(\frac{1}{P_{T+1}} - 1\right) \\ &= \frac{P_T}{1-P_T} \times \left[\frac{\delta}{1-\delta} \times \frac{L_f P_{fT} + L_m(P_{mT} - P_{0T})}{R_1 - P_{fT}(R_1+R_2)} - 1\right] \end{aligned} \tag{37}$$

Furthermore, since at equilibrium, $X_T = Y_T$, we have

$$\begin{aligned} Y_T = X_T &= \frac{P_T}{1-P_T} \times \left(\frac{1}{P_{T+1}} - 1\right) \\ &= \frac{P_T}{1-P_T} \times \left[\frac{\delta}{1-\delta} \times \frac{L_f P_{fT} + L_m(P_{mT} - P_{0T})}{R_1 - P_{fT}(R_1+R_2)} - 1\right] \end{aligned} \tag{38}$$

Thus, we obtain

$$\frac{\partial Y_T}{\partial P_T} = \frac{1}{(1-P_T)^2} \times \left[\frac{\delta}{1-\delta} \times \frac{L_f P_{fT} + L_m(P_{mT} - P_{0T})}{R_1 - P_{fT}(R_1+R_2)} - 1\right] > 0 \tag{39}$$

This indicates that after introducing regulation, the conclusion remains consistent with the scenario without regulatory oversight: the higher the public perception of a firm as ethical, the greater the probability that unethical firms will choose to comply with carbon disclosure requirements.

Since the parameter $\delta$、$R_1$、$L_m$、$P_{mT}$in the incentive conditions for non-ethical firms to choose compliant carbon disclosure yields results similar to those under regulatory oversight, the following discussion focuses on the three parameters $P_{fT}$、$R_1$、$L_f$. Taking the partial derivative with respect to $P_{fT}$、$R_1$、$L_f$ yields

$$\frac{\partial Y_T}{\partial P_T} = \frac{1}{(1-P_T)^2} \times [\frac{\delta}{1-\delta} \times \frac{\mathrm{L_f} P_{fT} + \mathrm{L_m}(P_{mT} - P_{0T})}{\mathrm{R_1} - P_{fT}(\mathrm{R_1} + \mathrm{R_2})} - 1] > 0 \tag{40}$$

$$\begin{aligned} \frac{\partial Y_T}{\partial P_{fT}} &= \frac{P_T}{1-P_T} \times \frac{\delta}{1-\delta} \times \frac{\mathrm{L_f}[\mathrm{R_1} - P_{fT}(\mathrm{R_1} + \mathrm{R_2})] + \mathrm{L_f} P_{fT}(\mathrm{R_1} + \mathrm{R_2})}{[\mathrm{R_1} - P_{fT}(\mathrm{R_1} + \mathrm{R_2})]^2} \\ &= \frac{P_T}{1-P_T} \times \frac{\delta}{1-\delta} \times \frac{\mathrm{L_f} R_1}{[\mathrm{R_1} - P_{fT}(\mathrm{R_1} + \mathrm{R_2})]^2} > 0 \end{aligned} \tag{41}$$

$$\frac{\partial Y_T}{\partial R_1} = \frac{P_T}{1-P_T} \times \frac{\delta}{1-\delta} \times \frac{P_{fT}}{[\mathrm{R_1} - P_{fT}(\mathrm{R_1} + \mathrm{R_2})]^2} > 0 \tag{42}$$

$$\frac{\partial Y_T}{\partial L_f} = \frac{P_T}{1-P_T} \times \frac{\delta}{1-\delta} \times \frac{P_{fT}}{\mathrm{R_1} - P_{fT}(\mathrm{R_1} + \mathrm{R_2})} > 0 \tag{43}$$

Further analysis reveals that all three parameters $P_{fT}$、$R_2$、$L_f$ are positively correlated with $Y_T$. As $P_{fT}$、$R_2$、$L_f$ increases, the probability of firms choosing to comply with carbon information disclosure rises, thereby curbing non-compliant disclosure and enhancing overall carbon disclosure quality.

When $P_T > \frac{1-\delta}{\delta} \times \frac{\mathrm{R_1} - P_{fT}(\mathrm{R_1} + \mathrm{R_2})}{\mathrm{L_f} P_{fT} + \mathrm{L_m}(P_{mT} - P_{0T})}$, firms adopt the optimal pure strategy of compliant carbon disclosure, i.e., $X_T = Y_T = 1$ and $P_T = P_{T+1}$. Let $\mathrm{M} = \frac{1-\delta}{\delta} \times \frac{\mathrm{R_1} - P_{fT}(\mathrm{R_1} + \mathrm{R_2})}{\mathrm{L_f} P_{fT} + \mathrm{L_m}(P_{mT} - P_{0T})}$, meaning the probability that the public perceives a firm as ethical in period T exceeds $\frac{1-\delta}{\delta} \times \frac{\mathrm{R_1} - P_{fT}(\mathrm{R_1} + \mathrm{R_2})}{\mathrm{L_f} P_{fT} + \mathrm{L_m}(P_{mT} - P_{0T})}$. In this case, unethical firms will disguise themselves as ethical ones. It can be said that the better a firm's reputation, the more proactively it will strive to maintain it. Additionally, the smaller M is, the larger the range of $P_T$ for companies complying with carbon disclosure requirements. This encourages more non-ethical companies to comply with carbon disclosure in period T, thereby improving the overall quality of carbon information disclosure.

Furthermore, taking the partial derivative of $P_{fT}$、$R_2$、$L_f$ yields

$$\frac{\partial M}{\partial P_{fT}} = \frac{1-\delta}{\delta} \times \frac{-R_1[\mathrm{L_f} P_{fT} + \mathrm{L_m}(P_{mT} - P_{0T})] - \mathrm{L_f}[R_1 - P_{fT}(R_1 + R_2)]}{[\mathrm{L_f} P_{fT} + \mathrm{L_m}(P_{mT} - P_{0T})]^2} < 0 \tag{44}$$

$$\frac{\partial M}{\partial R_2} = \frac{1-\delta}{\delta} \times \frac{-P_{fT}}{\mathrm{L_f} P_{fT} + \mathrm{L_m}(P_{mT} - P_{0T})} < 0 \tag{45}$$

$$\frac{\partial M}{\partial L_f} = \frac{1-\delta}{\delta} \times \frac{-P_{fT}[R_1 - P_{fT}(R_1 + R_2)]}{[\mathrm{L_f} P_{fT} + \mathrm{L_m}(P_{mT} - P_{0T})]^2} < 0 \tag{46}$$

Further analysis shows that as $P_{fT}$ 、$R_2$ 、$L_f$ increases, the value of M decreases, expanding the range $P_T$ where firms choose to comply with carbon disclosure requirements. Consequently, more non-ethical firms will opt for compliance in period T. Analysis indicates that as penalties intensify, the overall quality of carbon disclosure improves to a certain extent.

# 6. Numerical Simulation

Referencing studies by Ye et al.[20], Chen et al.[22], Yang et al.[33], and Chen et al.[34], and following the theoretical derivation, we validate our conclusions through numerical simulations to bridge theoretical analysis with practical application. This section presents a simulation analysis to provide a more intuitive illustration of how firms choose to disclose carbon information under varying conditions.

## 6.1 Parameter Settings

This study focuses on the energy sector. Parameter settings fully consider industry benchmarks for each variable and incorporate estimates based on China's carbon market (referencing Shanghai Environment & Energy Exchange data). Detailed parameter symbols, definitions, and settings are presented in Table 1.

**Table 1: Detailed Parameter Settings**

| Parameter Symbol | Parameter Meaning | Industry Benchmark | Parameter Estimation Source | Set Value |
|---|---|---|---|---|
| δ | Discount Factor | In the energy sector, due to large project investments and extended return cycles, companies typically prioritize long-term benefits, with discount factors often ranging between 0.8 and 0.95. Manufacturing enterprises generally apply discount factors between 0.7 and 0.9. Service-oriented businesses, benefiting from greater operational flexibility, typically use discount factors around 0.6 to 0.8. A higher discount factor indicates a stronger emphasis on long-term profitability. | Referencing transaction data from enterprises across various industries at the Shanghai Environment & Energy Exchange in recent years, along with factors such as investment project payback periods and market stability, analysis indicates that the average investment payback period across industries is 3-5 years. Given relatively stable market fluctuations, enterprises hold certain expectations and place importance on future returns. | 0.8 |
| $R_0$ | Benefits of Ethical Enterprises Disclosing Carbon Information | In the energy sector, compliant disclosure yields greater policy support and market share, typically generating 5-10 units of benefit. Manufacturing enterprises generally gain 3-8 units, while service providers see 2-6 units. These benefits encompass increased market share from enhanced social reputation, government subsidies, and tax incentives. | Analyze annual reports of enterprises across different industries disclosed on the Shanghai Environment Exchange to quantify the additional market benefits and policy incentives obtained by ethical enterprises after compliantly disclosing carbon information. | 5 |
| $R_1$ | Excess Returns from Non-Compliant Carbon Disclosure by Unethical Enterprises | In the energy sector, companies achieve higher cost savings by reducing carbon reduction investments, yielding excess profits of 3-7 units. Manufacturing enterprises typically gain 2-5 units, while service sector firms see approximately 1-3 units. These excess profits primarily stem from cost reductions achieved by cutting carbon reduction expenditures. | Analyze transaction records from the Shanghai Environment Exchange and cost data across different industries to compare cost differences between compliant and non-compliant enterprises. | 3 |

| | | | | |
|---|---|---|---|---|
| $L_m$ | Market Losses Incurred by Companies Perceived as Unethical | The energy sector, due to its significant environmental impact, may incur market losses of 4-10 units if labeled unethical; manufacturing firms face losses of approximately 3-6 units; service sector firms generally experience losses of 2-5 units. Market losses manifest as diminished consumer trust, reduced partnerships, and decreased market share. | Through market research and analysis of financial statements across industries, assess the impact of reputational damage on the operations of unethical companies. | 4 |
| $L_f$ | Losses incurred when companies are detected and penalized by regulatory authorities | The energy sector, due to high carbon emissions, faces heavier penalties, with losses ranging from 8 to 20 units; penalties for manufacturing enterprises typically range from 6 to 10 units; penalties for service enterprises are generally around 3 to 8 units. Penalties include fines, production restrictions, license revocation, and other measures. | Government regulatory agencies' records of penalties imposed on non-compliant enterprises across industries and relevant policy regulations. | 8 |
| $P_{mT}$ | Probability of market detection for non-ethical companies' non-compliant carbon disclosure practices | The energy sector, being highly scrutinized by the public, has a market detection probability generally ranging from 0.6 to 0.8. For manufacturing enterprises, this probability typically falls between 0.5 and 0.7, while service enterprises have a probability of approximately 0.4 to 0.6. As market oversight and information transparency improve, the probability of detection gradually increases. | Analyze market monitoring data from the Shanghai Environment Exchange and industry dynamics across sectors to calculate the proportion of violations exposed. | 0.6 |
| $P_{fT}$ | Probability of non-ethical enterprises' non-compliant carbon disclosure practices being detected and penalized by regulators | The energy sector is a regulatory priority, with a probability of detection and punishment by regulators ranging from 0.4 to 0.6. For manufacturing enterprises, this probability typically falls between 0.3 and 0.5, while for service enterprises, it generally ranges from 0.2 to 0.4. Regulatory enforcement intensity and monitoring technology influence this probability. | Refer to regulatory enforcement reports and inspection frequencies across industries. | 0.4 |
| $P_{0T}$ | Probability that non-compliant carbon disclosure practices by unethical enterprises in phase t are detected simultaneously by both the market and regulators | For the energy sector, which faces high scrutiny and stringent regulation, this probability ranges from 0.2 to 0.4; for manufacturing enterprises, it is approximately 0.1 to 0.3; and for service enterprises, it is roughly 0.05 to 0.2. | Estimated based on information-sharing mechanisms between markets and regulators and joint enforcement activities across industries. | 0.2 |
| $R_2$ | Penalty | Fines in the energy sector typically range from 2 to 8 units; manufacturing enterprises generally face fines of 1 to 3 units; and service sector enterprises incur fines of approximately 0.5 to 2 units. | Refer to relevant policies and regulations for penalty standards applicable to non-compliant enterprises across different industries. | 2 |
| $P_T$ | Probability that the public perceives the enterprise as ethical during Phase T | This is initially set at 0.5 and may be adjusted based on the historical overall performance of enterprises in different industries. | Based on initial market perception and the historical overall performance of enterprises across different industries. | 0.5 |

### 6.2 Simulation Without Regulatory Authorities

First, calculate the expected incremental benefit for unethical firms complying with truthful carbon disclosure at stage T. Calculate $P_{T+1}$. Assuming a firm truthfully discloses carbon information at stage T, according to Bayes' theorem: $P_{T+1}(n=0|m=0)=\frac{P_T\times 1}{P_T\times 1+(1-P_T)\times X_T}$. At equilibrium: $X_T=Y_T=1$. Thus: $P_{T+1}=P_T=0.5$. Therefore, the expected incremental benefit for unethical firms complying with truthful carbon disclosure at stage T is: $E(\Delta R(n=1,m=0))=\Delta R(n=1,m=0)=\frac{\delta}{1-\delta}(P_{T+1}-P_T)L_m=0$.

Next, calculate the expected incremental profit of an unethical firm for non-compliant carbon disclosure at stage T. When the market perceives the firm's disclosure as compliant with probability $1-P_{mT}=1-0.6=0.4$, the incremental profit is $\Delta R(n=1,m=1)=R_1+\frac{\delta}{1-\delta}(P_{T+1}-P_T)L_m=3+\frac{1-0.8}{0.8}$（0.5-0.5）×4=3; when perceived as non-compliant with probability $P_{mT}=0.6$, the incremental profit is

$$\Delta R(n=1,m=1)=R_1+\delta(R_{T+1}-R_T)+\delta^2(R_{T+2}-R_T)+...=R_1-\frac{\delta}{1-\delta}P_TL_m=3-\frac{0.8}{1-0.8}\times 0.5\times 4=-5$$

Thus, the expected incremental profit for non-compliant disclosure at stage T is

$$E(\Delta R(n=1,m=1))=(1-P_{mT})[R_1+\frac{\delta}{1-\delta}(P_{T+1}-P_T)L_m]+P_{mT}(R_1-\frac{\delta}{1-\delta}P_TL_m)=0.4\times 3+0.6\times(-5)=-1.8$$

The final comparison shows that non-ethical firms will choose to comply with carbon disclosure because $E(\Delta R(n=1,m=0))>E(\Delta R(n=1,m=1))$.

### 6.3 Simulation with Regulatory Authorities

Similar to the scenario without regulators, the expected incremental profit for an unethical firm complying with carbon disclosure at stage T is $E(\Delta R(n=1,m=0))=\Delta R(n=1,m=0)=\frac{\delta}{1-\delta}(P_{T+1}-P_T)L_m=0$.

Next, we calculate the incremental expected value of benefits for unethical firms that non-compliantly disclose carbon information at stage T. This is divided into four scenarios:

(1) Neither the market nor regulators detect non-compliant disclosure. The market initially classifies the firm as ethical with probability $1+P_{0T}-P_{mT}-P_{fT}=1+0.2-0.6-0.4=0.2$.

The incremental benefit gained is: $\Delta R(n=1,m=1)=R_1+\frac{\delta}{1-\delta}(P_{T+1}-P_T)L_m=3$;

(2) Both the market and regulators detect non-compliant disclosure, with probability $P_{0T}=0.2$. The market will reclassify the firm as unethical from the T+1 stage, resulting in $P_{T+1}(n=0|m=1)=0$. The incremental profit gained by the firm is: $\Delta R(n=1,m=1)=-R_2-\frac{\delta}{1-\delta}P_TL_f=-18$;

(3) The market discovers the company's non-compliant carbon disclosure, but regulators do not detect it, with a probability of $P_{mT}$-$P_{0T}$=0.6-0.2=0.4. The market will classify the company as unethical from the T+1 stage, where $P_{T+1}(n=0|m=1)=0$. The incremental benefit gained by the company at this point is: $\Delta R(n=1,m=1)=R_1-\frac{\delta}{1-\delta}P_T L_m=-5$.

(4) Regulatory authorities detect non-compliant carbon disclosure by a company, but the market remains unaware, with a probability of $P_{fT}$-$P_{0T}$=0.4-0.2=0.2. The market will then reclassify the company from theT+1 stage to an unethical entity, resulting in $P_{T+1}(n=0|m=1)=0$. At this point, the incremental benefit gained by the company is: $\Delta R(n=1,m=1)=-R_2-\frac{\delta}{1-\delta}P_T L_f=-18$.

Therefore, the expected incremental benefit for unethical firms from non-compliant carbon disclosure is: $E(\Delta R(n=1,m=1))=(1+P_{0T}-P_{mT}-P_{fT})[R_1+\frac{\delta}{1-\delta}(P_{T+1}-P_T)L_m]$ $+P_{0T}[-R_2-\frac{\delta}{1-\delta}P_T L_f]+(P_{mT}-P_{0T})[R_1-\frac{\delta}{1-\delta}P_T L_m]+(P_{fT}-P_{0T})[-R_2-\frac{\delta}{1-\delta}P_T L_f]=-10$.

Comparing the two scenarios reveals that unethical companies would choose to comply with carbon disclosure requirements because:
$E(\Delta R(n=1,m=0))>E(\Delta R(n=1,m=1)$.

### 6.4 Sensitivity Analysis

To investigate the impact of different parameters on corporate equilibrium strategies, we focus on analyzing how changes in the discount factor $\delta$ affect the carbon information disclosure strategy choices of unethical firms.

#### 6.4.1 Single-Factor Variation

By altering the discount factor, we observe changes in the expected incremental benefit of non-compliant disclosure for unethical firms ($E(\Delta R(n=1,m=1))$ ), as illustrated in Figure 2 below.

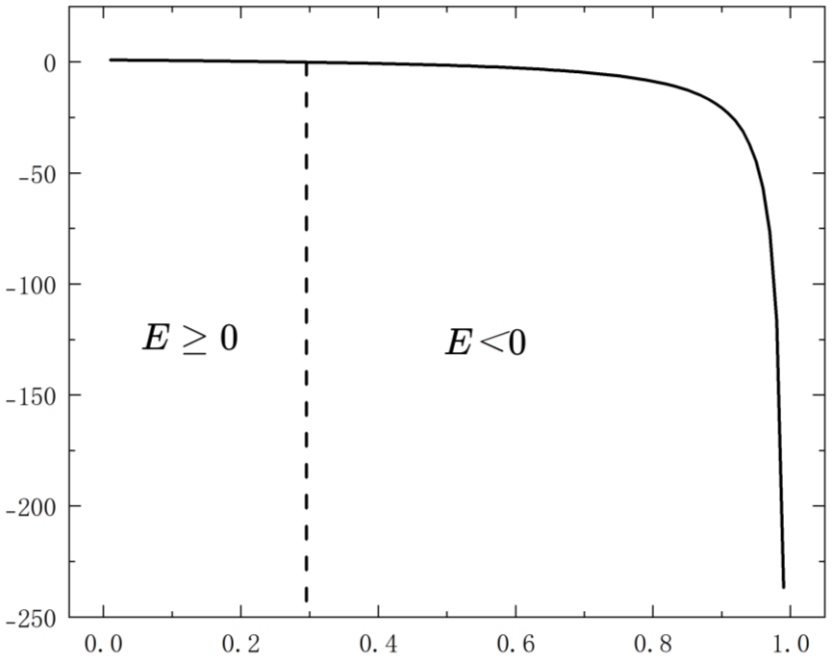


**Figure 2: Relationship between Discount Factor and Expected Incremental Benefits of Non-Compliant Disclosure for Unethical Firms**

Based on the figure above, it can be concluded that as the discount factor δ increases, the expected incremental benefit of non-compliant carbon disclosure by unethical firms decreases. This indicates that firms become more inclined to choose compliant carbon disclosure. This is because a larger discount factor leads firms to place greater emphasis on future reputational benefits, causing them to forego the short-term excess profits from non-compliant disclosure.

### 6.4.2 Carbon Price Volatility Scenario

Carbon price is a key factor influencing corporate carbon disclosure strategies. Fluctuations in carbon price directly impact firms' emission reduction costs and excess profits, thereby affecting their disclosure strategy choices. Below, we simulate firms' disclosure strategy selections under varying carbon price levels.

We incorporate the carbon price P into the original model and assume that the excess returns $R_1$ obtained by unethical firms through non-compliant carbon disclosure are correlated with carbon price P, expressed as: $R_1=k\times P$, where k is the coefficient representing the degree of carbon price influence on excess returns.Based on historical data from the Shanghai Environment & Energy Exchange, where carbon prices exhibit significant volatility, we selected three representative price levels for simulation: low price (P=30 CNY/ton), medium price (P=50 CNY/ton, baseline scenario), and high price (P=70 CNY/ton). We further assume k=0.1.

**Table 2: Detailed Parameter Settings for Different Carbon Prices**

| Carbon Price Level | Carbon Price P (CNY/ton) | Excess Return $R_1$ |
|---|---|---|
| **Low** | 30 | 3 |
| **Medium (Benchmark)** | 50 | 5 |
| **High** | 70 | 7 |

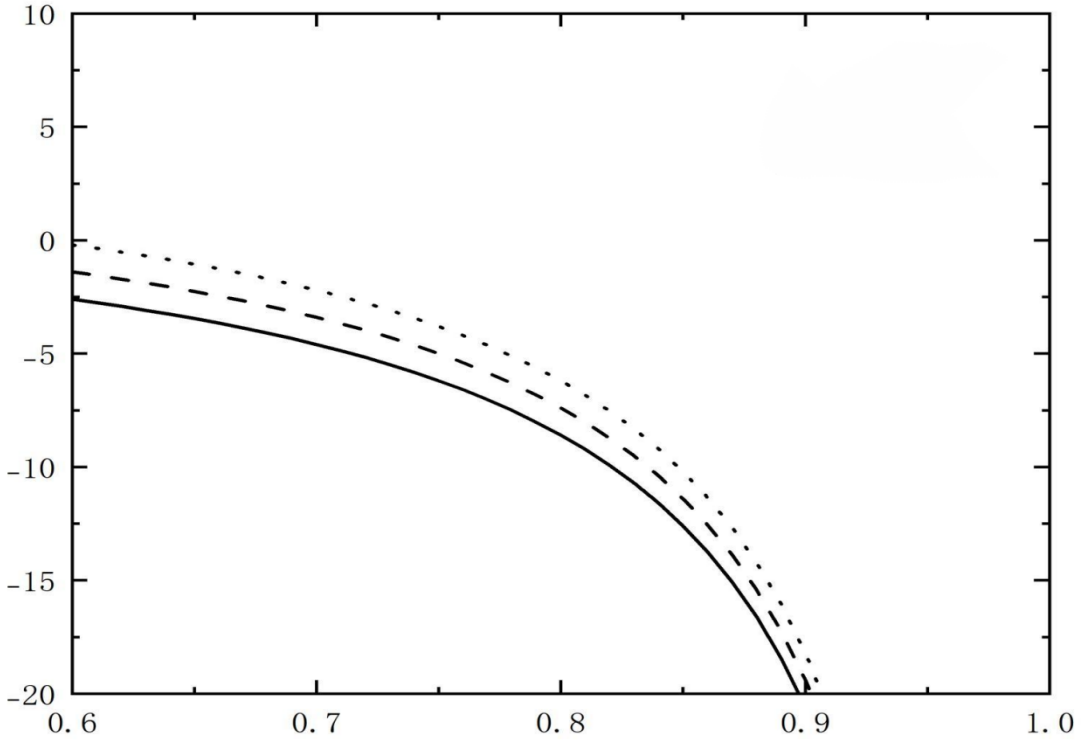


**Figure 3: Relationship between Discount Factors under Different Carbon Price Scenarios and the Incremental Expected Returns from Non-Compliant Disclosure by Unethical Firms**

Simulation results indicate that as carbon prices rise, the excess profits from non-compliant carbon disclosure increase for unethical firms. However, due to regulatory oversight and market penalties, the expected value of non-compliant disclosure ($E(\Delta R(n=1,m=0))>E(\Delta R(n=1,m=1))$) remains below the expected value of compliant disclosure, leading firms to choose compliance. Nevertheless, the expected incremental profit from non-compliant disclosure is relatively high under high carbon price scenarios, suggesting that sufficiently high carbon prices may strengthen firms' incentives to take risks.

### 6.4.3 Scenario of Regulatory Intensity Changes

Changes in regulatory intensity directly affect the probability of firms being detected and penalized, thereby influencing their carbon disclosure strategy choices. We simulate firms' carbon disclosure strategy selections under different regulatory intensity scenarios by adjusting the parameters: the probability of detection and penalty by regulators ($P_{fT}$) and the loss incurred upon detection and penalty ($L_f$). Regulatory intensity scenarios are categorized into three levels: moderate (baseline), weak regulation, and strong regulation. Specific parameter settings are detailed in Table 3:

**Table 3: Detailed Parameter Settings for Different Regulatory Intensity Scenarios**

| Regulatory | Probability of Detection by Regulatory Authorities $P_{fT}$ | Penalty Loss $L_f$ |
|---|---|---|
| **Intensity** | 0.4 | 8 |
| **Moderate (Baseline)** | 0.2 | 6 |
| **Weak regulation** | 0.6 | 10 |

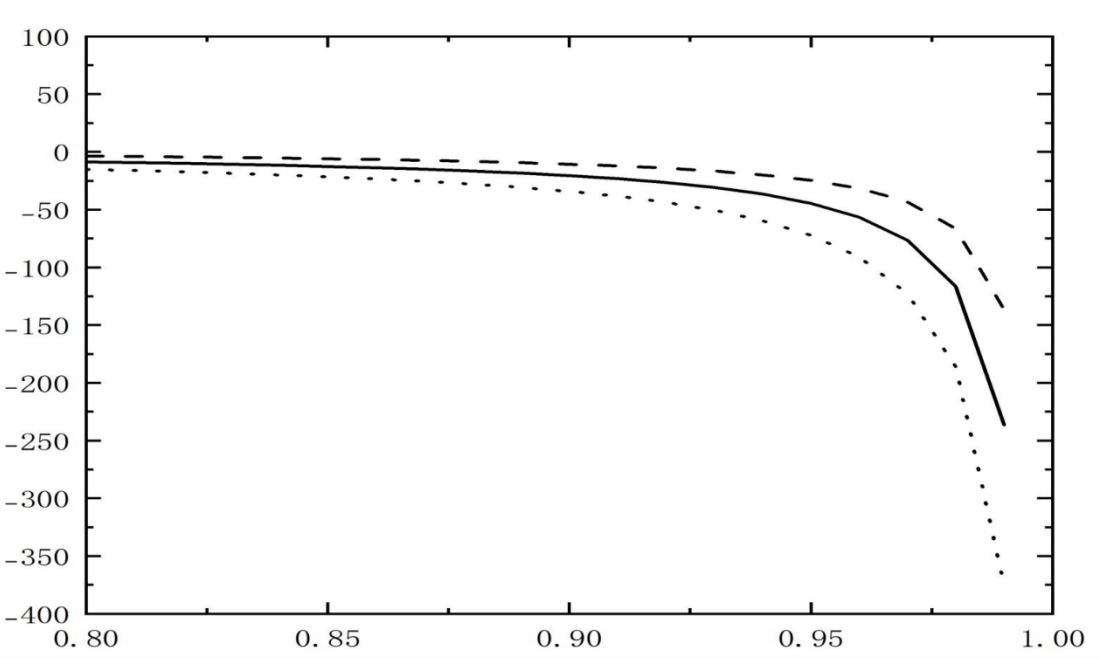


**Figure 4: Relationship between Discount Factors under Different Regulatory Scenarios and the Incremental Expected Returns from Non-Compliant Disclosure for Unethical Firms**

Simulation results indicate that changes in regulatory intensity significantly influence firms' strategic choices. Under weak regulation, the expected incremental profit from non-compliant disclosure remains relatively high but negative, leading firms to still opt for compliant disclosure. Under strong regulation, however, the expected incremental profit from non-compliant disclosure declines substantially, making firms more inclined toward compliant disclosure. This demonstrates that strengthening regulatory enforcement can effectively curb firms' non-compliant behavior.

## 7. Conclusion

By constructing a KMRW reputation model between firms and regulatory bodies, this paper investigates the dynamic strategic choices concerning corporate carbon information disclosure. Through theoretical derivation and numerical simulation, it is possible to predict how corporate disclosure practices are influenced by reputation concerns and, in turn, how such behaviour affects a firm's long-term value.

The study reveals that: (1) In a single-stage game, rational, moral firms should opt for truthful carbon information disclosure to cultivate a favourable reputation. (2) Over a multi-stage game, a firm's disclosure actions in each period have cascading effects on its future reputation and utility. Establishing a strong reputation in one period yields greater utility in subsequent periods. Conversely, amoral firms will choose not to disclose information truthfully in the final stage T, capitalising on their established reputation to maximise short-term gains. Prior to stage T, however, they will engage in truthful disclosure to build that reputation. (3) For amoral firms, while rising carbon prices increase the excess benefits of non-compliant disclosure, the presence of regulatory and market sanctions ensures they will continue to comply. Furthermore, the stringency of regulation is found to be a significant determinant of a firm's strategic choices.

Therefore, based on the above findings, this paper derives the following insights: (1) When conducting carbon information disclosure, enterprises must consider the long-term impact of their actions on corporate reputation. Although in certain cases, incomplete or delayed disclosure may bring some benefits in the short term, such practices may damage the company's long-term reputation, thereby affecting its overall utility in long-term games. (2) In the actual market, if an enterprise truthfully discloses carbon information, although it may cause some short-term investors to sell off due to the disclosure of adverse information such as high emissions or difficulties in emission reduction, leading to a short-term decline in stock price, in the long run, market forces sensitive to ESG factors and optimistic about the company's long-term sustainable development potential will drive the stock price to rise. Moreover, truthful disclosure helps to reduce policy and reputational risks, stabilize market expectations, and provide positive support for the stock price. At the customer level, truthful disclosure helps to attract environmentally conscious consumers, and corporate clients are more inclined to choose such enterprises when selecting suppliers, thereby acquiring new customers. Although some price-

sensitive customers may be lost due to increased costs, this impact will gradually weaken in the long term. Regarding partner trust, truthful disclosure reflects integrity and transparency, which can enhance the confidence of partners such as suppliers and research institutions, consolidate cooperative relationships, and promote green innovation cooperation. Especially for long-term stable partners, it can further deepen trust. (3) If an enterprise falsifies carbon information disclosure, in the short term, the stock price may initially rise due to misleading investors, but once exposed, it will inevitably lead to a collapse of investor trust, causing a sharp drop in stock price, a significant reduction in corporate market value, and a deterioration of financing and debt-servicing capabilities. In terms of customers, consumers will be disgusted by the company's deceptive behavior and permanently leave, corporate clients will terminate cooperation to avoid reputational damage, and the company will also face difficulties in acquiring new customers, with hindered market promotion and sales channels. In terms of partner trust, once a company is found to have falsified disclosure, partners will fundamentally doubt its integrity and responsibility, reduce supply, decrease sales promotion efforts, terminate cooperative projects, and the company may also suffer industry exclusion, a decline in its status within the industry, loss of development opportunities, and ultimately fall into a predicament in market competition. (4) In addition, corporate reputation, as a market signal, regulatory supervision can improve the transparency of corporate information disclosure, thereby positively influencing the company's carbon information disclosure strategy choices. At the same time, regulatory authorities can reduce the agency costs between enterprises and stakeholders through information dissemination, mitigate the negative impact of carbon information disclosure on short-term corporate interests, and at the same time enhance its positive impact on market valuation. As rational participants, enterprises should choose to truthfully disclose carbon information to maximize utility and have a positive impact on their reputation. This will help improve the evaluation of their reputation by regulatory authorities and the public, thereby promoting the enhancement of corporate market value.

Limitations of this paper: In the model derivation part, this paper did not introduce enterprise type heterogeneity, which can be further improved in the future; in the numerical simulation part, this paper only considered the energy industry, and future research can try to explore the dynamic selection of carbon information disclosure strategies for enterprises in other industries.

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