

CEO Compensation Contract Design under Moral Hazard and Adverse Selection

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Abstract: In modern corporate governance, the separation of ownership and management rights leads to increasingly prominent principal-agent problems. Information asymmetry leads to adverse selection in advance and moral hazard after the event, which significantly increases agency costs and weakens the incentive effect of enterprises. In view of the realistic dilemma of unobservable executive ability and unverifiable efforts, the traditional single performance-linked compensation model is difficult to adapt to the differentiated needs of different types of executives. Therefore, this study focuses on the design of CEO compensation contract, and constructs a theoretical model that includes both moral hazard and adverse selection. It aims to achieve type separation and incentive compatibility through mechanism design, so as to maximize shareholders' interests under the condition of information asymmetry. Based on the principal-agent theory framework, this study sets shareholders as risk-neutral and CEOs as risk-averse agents, and constructs a single-period model including hidden ability types and hidden effort levels. By introducing a linear compensation contract and a mean square utility function, the CEO's optimal effort decision is internalized, and a contract menu is constructed based on participation constraints and incentive compatibility constraints. Aiming at the problem that the model is difficult to solve analytically, a two-stage grid search method is used for numerical optimization. Firstly, the high-yield area is located by global scanning of coarse grid, and then the optimal incentive coefficient and fixed compensation combination are determined by local fine search of fine grid. This method effectively improves the efficiency and stability of the solution, and has good expansibility. The results show that the optimal compensation contract shows significant differentiation characteristics: high-capacity CEOs correspond to high performance sensitivity coefficient ($b_H^* = 0.837$) and negative fixed compensation ($w_H^* = -0.638$), forming a 'strong incentive and high deposit' model; the CEO with low ability corresponds to a lower incentive intensity ($b_L^* = 0.327$) and a fixed salary close to zero. This design effectively compresses the information rent of high-ability CEOs, and at the same time promotes the two types of CEOs to truthfully reveal their own types and make corresponding efforts to achieve incentive compatibility and type self-selection. This study not only expands the contract theory under dual information asymmetry, but also provides theoretical basis and practical reference for enterprises to design differentiated executive compensation and regulators to formulate reasonable incentive policies. In the future, it can be further extended to continuous type setting, multi-task performance indicators and dynamic contract scenarios to enhance the realistic explanatory power of the model.

Keywords: Moral Hazard; Adverse Selection; Salary Contract Design; Principal-Agent Model

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1. Introduction

1.1 Research Background

The design of executive compensation contract is one of the core issues of corporate governance. In modern companies with the separation of ownership and management rights, due to the information asymmetry caused by principal-agent, the ex ante adverse selection (the ability information of executives is opaque and cannot choose excellent talents) and the ex post moral hazard (the behavior of executives cannot be observed, which maximizes their private interests and harms the interests of shareholders), resulting in an increase in the agency cost of the company and a reduction in the incentive effect of the company's behavior.

In theory, contract research has gradually developed from unilateral information asymmetry to bilateral information asymmetry. Early research mainly focused on the moral hazard and adverse selection problems in the case of unilateral information asymmetry, and proposed solutions such as risk sharing mechanisms and menu contracts. Subsequently, Picard et al. concerned about the contract design of two risk concurrent situations. In the case of two kinds of information asymmetry, the contract structure is more stringent and more challenging. In recent years, Chinese scholars have also begun to study the dual agency problem, and gradually try to design the corresponding incentive model for the two agency problems.

In practice, facing the dilemma of unobservable ability and unverifiable efforts, it has always been a problem to adopt which salary system or plan to deal with. Generally, the performance-linked approach (equity, bonus) is adopted, but for different levels of executives, there is no set of incentives to adapt to all executives. To this end, we must design a differentiated compensation contract. On the one hand, it is necessary to induce executives to choose their own programs, on the other hand, it is necessary to encourage executives to work as hard as possible to complete the task, which requires the design of compensation contracts to maximize the interests of shareholders and executives on the basis of ensuring this premise. Incentive compatibility.

Figure 1: Research background



1.2 Research Objectives and Significance

In view of the above background, the goal of this study is to explore the optimal design method of CEO compensation incentive contract under the framework of moral hazard and adverse selection. Specifically, this study attempts to answer: when executives have different levels of ability and their ability types are not known to the principal in advance, and the degree of effort is not observable afterwards, how should shareholders set fixed compensation and performance sensitivity coefficients to simultaneously motivate different types of executives to work hard and make them reveal their own types truthfully, so as to maximize corporate performance?

In order to achieve this goal, this study establishes a theoretical model containing 'double asymmetric information', introduces risk-averse managers and risk-neutral shareholders, and comprehensively uses principal-agent theory and numerical optimization methods to solve the optimal compensation contract and analyze its economic meaning.

The research has the following significance:

First, it enriches the theoretical analysis paradigm of executive compensation incentives. In the past, the research on executive compensation contracts mostly focused on a single information asymmetry problem or empirical correlation analysis. This study applies the mechanism design theory to executive incentive contracts, and considers both hidden information and hidden actions in the model, which has reference value for the expansion of classical contract theory in the context of corporate governance.

Second, the model solving method of this study is general and can be extended to other dual principal-agent problems. For example, in the face of multi-type employees and hidden efforts, the internal incentive design of enterprises, the phased incentive contract design of venture capitalists and entrepreneurs, etc., only need to adjust the model parameters to apply this research method to solve, which is helpful to improve the numerical stability and efficiency of solving such problems.

Thirdly, the conclusions of this study have guiding significance for practice. Through model simulation, this study clarifies the composition characteristics of optimal contracts for executives with different abilities, and provides a quantitative basis for enterprises to design differentiated compensation incentives based on managers' abilities. At the same time, the analysis of this study reveals the trade-off relationship between information rent and effort incentive in executive incentive, which can provide reference for regulators to formulate executive compensation policies and improve corporate governance.

1.3 Contributions of This Study

The main contributions of this study include :

Firstly, an executive incentive contract model with both moral hazard and adverse selection is built. Considering the heterogeneity of executive ability, the influence mechanism of the optimal contract under double information asymmetry is described. Compared with the single information asymmetry model, it is more in line with the real corporate environment and makes up for the lack of domestic analysis of the dual principal-agent theory of executive compensation.

Secondly, using the novelty of the solution method, this study combines analytical derivation and numerical search. Based on the analysis of the set of bindings under constraints, the original complex constrained optimization problem is transformed into a search problem in a limited parameter space. Then, the optimal solution is obtained by using the method of coarse grid local search and fine grid local refinement, which improves the accuracy and efficiency of the solution, and provides a new technical means for the design of similar incentive contracts.

Thirdly, combined with the results of the model, it can be seen that the optimal contract is a differentiated model of 'strong incentive and high ability, weak incentive and low ability' for different types of ability managers. Under this new model, although high ability managers obtain high performance coefficient, they get more effective information rent compression. The incentive intensity of low-ability managers is reduced, so that high-ability and low-ability managers can maintain the true type, which also shows that the incentive marginal income for low-ability managers is more stable. This part uses the method of model to expand the classical principal-agent theory, changes the traditional incentive method to a certain extent, and explains the problem of executive incentive in reality.

To sum up, the exploration of the theory and method of this study provides a certain reference significance for improving the research of executive compensation contract and guiding enterprise practice.

2. Related Work

Due to the widespread existence of principal-agent relationship, the academic circles have carried out a lot of research on incentive contracts under the condition of information asymmetry. According to the different types of information asymmetry, the relevant literature can be divided into the following aspects :

(1) Research on incentive contract with only moral hazard. This kind of research assumes that the agent's private information is only an after-action, that is, the effort is unobservable, but its ability type, task difficulty, etc. are known in advance. For example, Holmstrom (1979) established a single-period hidden action model to prove that the optimal contract needs to balance risk sharing and incentive provision, usually manifested as allowing the agent to bear part of the output risk^[1]. Shavell (1979) further analyzed the form of optimal incentive compensation, such as linear contract can achieve suboptimal incentive effect under certain conditions. Domestically, Wang Xianyu and Yan Jinjiang discussed the combination of incentives and supervision, and Hong Jianqiao compared the incentive effects of the compensation scheme based on budget indicators and

the linear compensation scheme. These studies focus on how to promote the agent's diligent work through contract design in the case of unobservable efforts, forming a perfect theoretical system of 'type I agency problem'.

(2) Only discuss the incentive contract of adverse selection. This kind of literature analyzes how the principal designs a mechanism to encourage the agent to voluntarily disclose the true type of information when some of the agent's private information (such as ability, high-quality opportunities) is not known to the principal before the contract is signed. Spence (1973) pioneered the study of adverse selection by giving the classical signal transmission model. Based on the mechanism design framework, Myerson (1982) theoretically gave the optimal auction and contract under adverse selection. In the principal-agent environment, Mirrlees (1976), Maskin and Riley (1984) and others studied the optimal incentive compatibility contracts of single continuous type and multiple continuous types respectively. It is found that when there is a high type of high information rent, it is in line with the optimal contract requirements to sacrifice some low types in order to expose the identity of the high type, which can also be regarded as 'the information rent obtained by high-ability executives'. This corresponds to the incentive mechanism of executives in the optimal contract mentioned above. It is similar to the research conclusion of domestic scholar Zhang Xinli^[2] and others on venture capital contract, that is, the optimal separation contract can induce entrepreneurs with different abilities to self-select; in general, the 'menu' contract design is only applicable to a single implicit information situation.

(3) Research on incentive contract with moral hazard and adverse selection. When the agent has both pre-hidden information and post-hidden action, the incentive contract design needs to meet two types of incentive compatibility conditions at the same time^[3], and the problem becomes more complicated. There are relatively few studies on this situation and most of them analyze special cases in theory. One idea is to find sufficient conditions to ensure that both types of constraints are satisfied. For example, the first-order rule proposed by Rogerson (1985) can be applied to the coexistence of adverse selection and moral hazard under certain conditions. Picard (1987) is one of the important works in this field. He analyzed the general properties of the optimal incentive mechanism in the presence of both hidden information and hidden actions. Later, Theilen (2003) and Sung (2005) extended the model situation, including the dual information asymmetry problem under continuous time and dynamic settings. Ding Yuanyao^[4], a domestic scholar, proposed the "dual incentive and restraint mechanism" earlier, while Zhang Wei^[5] focused on the linearization and simplification of the contract form, so as to obtain an enforceable linear incentive contract when the ability difference induces double information asymmetry. Niu Xiaoqin et al. further considered the influence of the agent's social justice preference factor on the incentive contract. Generally speaking, these literatures provide ideas for understanding contracts under dual information asymmetry, but they often assume that the model is simple to obtain analytical solutions, or use numerical examples to verify specific conclusions. There is still a lack of systematic solution to the optimal contract under general parameters^[6]. This study has made efforts in this regard. This study will use numerical methods to solve the optimal contract in general situations, and apply the theory to the specific scenario of CEO compensation design, which will form a useful supplement to related research.

3. Theoretical Model and Setting

3.1 Economic Environment and Information Structure

This study considers a single-period principal-agent model including shareholders (principals) and CEOs (agents). Shareholders own the ownership of the company and care about the company's profits, and the CEO is responsible for business decisions and efforts. The information structure of the two sides is asymmetric: CEO has two types of capabilities, denoted by $\theta \in \theta_L, \theta_H$, which represent 'low ability' and 'high ability' types, respectively. In the case of high ability, $\theta_H > \theta_L > 0$. θ determines the efficiency or marginal output capacity of CEO's efforts to transform into performance. The adverse selection is that θ is only known to the CEO himself before the contract is signed, and shareholders can only know a prior probability $P(\theta = \theta_H) = p$ (the proportion of high-capacity managers), but they cannot directly identify the true type of a CEO candidate. In addition, the CEO chooses the level of effort $e \geq 0$ to operate the company during the execution of the contract, and the effort cannot be observed by shareholders, reflecting moral hazard. CEO's effort will affect the company's final operating performance or profit, expressed as a random variable. In order to simplify the analysis, this study assumes that the company's final profit Π satisfies the following production function:

$$\Pi = \theta \cdot e + \varepsilon \quad (3-1)$$

where ε represents independent random noise, reflecting the uncertainty of the operating environment. Let $E[\varepsilon]=0, \text{Var}(\varepsilon)=\sigma^2$. This hypothesis implies that the contribution of CEO effort to expected profit is θe , and the equal effort of high-capacity CEO will bring higher expected performance. At the same time, due to the noise, the actual performance contains uncontrollable components. In order to highlight the core of the problem, this study assumes that shareholders are risk-neutral, while CEOs are risk-averse and satisfy the mean square deviation preference structure. Specifically, let the CEO's utility function be $U(w)$, where w is the actual monetary income. This study assumes that $U(w)$ is an augmented concave function, and the risk cost can be represented by mean-variance equivalence (such as exponential utility brings linear variance penalty). This setting is often used to analyze the optimization problem of linear contracts under risk aversion conditions.

Based on the above settings, there are two types of information asymmetry : pre-hidden information about θ (adverse selection) and post-hidden action about e (moral hazard). The transaction sequence is as follows : First, the shareholders propose a compensation contract menu for the CEO to choose, and each contract corresponds to a set of payment options ; the CEO chooses to accept one of the contracts or rejects according to his own ability type (if rejected, the income of both parties is an exogenous reserve value) ; after the contract is signed, the CEO chooses the effort level e according to the terms of the contract ; subsequently, the profit Π is realized and allocated to both parties according to the contract. The goal of this study is to solve the optimal compensation contract design that maximizes shareholder returns in such an environment.

3.2 Technology and Preference

Output and Cost : CEO's effort e will bring personal costs. This study assumes that the cost function is

$$C(e) = \frac{1}{2} k e^2 \quad (3-2)$$

Where $k > 0$ denotes the effort cost coefficient, and the larger k means the higher cost per unit effort. The production (profit) function is $\Pi = \theta e + \varepsilon$ as described above. A high ability θ_H means that the same effort can produce a higher expected output. The noise ε obeys a distribution with a mean value of 0 and a variance of σ^2 (e.g. normal distribution), independent of θ and e .

Contract form: This study considers linear compensation contracts, which have a certain realistic correspondence in executive compensation (such as basic annual salary plus performance bonus). Let the contract be (w, b) , where w is the fixed salary, and b is the bonus coefficient (or incentive intensity) linked to performance. When the actual profit is Π , the CEO gets $w + b \Pi$, and the shareholders get $\Pi - (w + b \Pi) = (1 - b)\Pi - w$. Since $0 \leq e \leq e_{\max}$ and the output is bounded, this study limits $0 \leq b \leq 1$ to avoid over-reliance on performance ratio in contract payment. It is worth noting that if w is negative, it means that the manager invests or guarantees, which is equivalent to the performance deposit mechanism ; if $1 - b < 0$, the shareholders need to pay extra, this extreme case is not considered here.

Agent utility: CEO is risk-averse and faces random income. Certainty Equivalent (CE) can be expressed as expected income minus risk cost. In the form of mean square error, when CEO chooses effort e under contract (w, b) , its utility is determined as follows:

$$U^{CE} = w + b \cdot E[\Pi] - C(e) - \frac{1}{2} \gamma b^2 \text{Var}(\Pi) \quad (3-3)$$

Where $\gamma > 0$ is the CEO's absolute risk aversion coefficient. Since $E[\Pi] = \theta e$, $\text{Var}(\Pi) = \sigma^2$, the output expectation and variance are substituted, and the above equation can be written as:

$$U^{CE}(e; w, b, \theta) = w + b \theta e - \frac{1}{2} k e^2 - \frac{1}{2} \gamma b^2 \sigma^2 \quad (3-4)$$

The formula shows that the expected utility of CEO is affected by fixed income w , performance coefficient b , own ability θ , effort decision e and risk cost. CEO will maximize U^{CE} when choosing efforts; shareholders will consider the CEO's optimal response and willingness to participate under different contracts when providing contracts.

Agent's effort decision : Under the given contract parameters (w, b) and its own type θ , the CEO chooses effort e to maximize $U^{CE}(e)$. The optimal effort response function can be obtained by solving the first derivative of the above formula with respect to e and making it zero:

$$\frac{\partial U^{CE}}{\partial e} : b \theta - k e = 0 \implies e^*(b, \theta) = \frac{b \theta}{k} \quad (3-5)$$

This means that the CEO 's optimal effort level increases proportionally with the incentive intensity b and the ability θ , and decreases with the increase of the cost coefficient k . When $b=0$ (pure fixed wage contract), $e=0$, that is, the lack of incentive will make the CEO choose zero effort ; when θ is higher and b is larger, the marginal revenue $b\theta$ of CEO 's per unit effort is higher, so he is willing to invest more effort. It should be noted that the result is the connotation solution obtained under the assumption of quadratic cost and utility mean square error. If e exceeds a certain physical upper limit, e can be constrained in the model, but this problem does not occur under the benchmark parameters of this study.

From the above analysis, it can be seen that shareholders can foresee the CEO 's effort response $e^*(b,\theta)$ when designing contracts. Therefore, in the subsequent solution, this study can substitute the CEO 's effort selection and directly replace e with the optimal effort. Specifically, for a CEO of type θ , the utility after accepting the contract is determined to be equivalent to :

$$U_{\theta}^{CE}=w+\frac{1}{2}\frac{b^2\theta^2}{k}-\frac{1}{2}\gamma b^2\sigma^2 \quad (3-6)$$

In this study, $e^*=\frac{b\theta}{k}$ is substituted and simplified to obtain $U_{\theta}^{CE}=w+\frac{b^2\theta^2}{2k}-\frac{\gamma b^2\sigma^2}{2}$. This expression clearly decomposes the

source of CEO utility : w is deterministic income, $\frac{b^2\theta^2}{2k}$ is the benefit of effort (net gain after deducting the cost of effort), and

$-\frac{\gamma b^2\sigma^2}{2}$ is the cost of risk. When $\gamma=0$ (CEO risk neutral), the risk cost is zero, and the CEO utility is simplified to $w+\frac{b^2\theta^2}{2k}$.

When $\gamma>0$ and b is large, the risk cost will significantly reduce the utility, which reflects that too high performance incentive is detrimental to the utility of risk-averse managers in high-risk situations.

Figure 2: Modeling code

```
# ----- 核心函数 -----
def CE(theta, w, b, k, sigma, gamma): 3 usages
    return w + (b**2)*(theta**2)/(2.0*k) - 0.5*gamma*(b**2)*(sigma**2)

def e_star(theta, b, k): 2 usages
    return (b*theta)/k

def wL_from_binding(bL, theta_L, k, sigma, gamma, U0): 2 usages
    return U0 - (bL**2)*(theta_L**2)/(2.0*k) + 0.5*gamma*(bL**2)*(sigma**2)

def wH_from_binding(bL, bH, theta_H, k, sigma, gamma, U0, theta_L): 1 usage
    wL = wL_from_binding(bL, theta_L, k, sigma, gamma, U0)
    return wL + ((bL**2 - bH**2)*(theta_H**2))/(2.0*k) + 0.5*gamma*((bH**2 - bL**2)*(sigma**2))

def profit_type(theta, w, b, k): 2 usages
    return ((1.0 - b)*b*(theta**2))/k - w
```

3.3 Contract Space and Constraints

Under the dual information asymmetry, shareholders can consider designing a contract menu $(w_L, b_L), (w_H, b_H)$ for CEOs who claim to be low-capacity type (θ_L) or high-capacity type (θ_H). Here, we assume that there are only two types of executive capabilities, in order to highlight the nature of mechanism design ; the model can be extended to continuous types but the analysis will be more complex. Now, this study lists the constraints that contract design needs to meet :

Rational Constraint (IR) : The contract must ensure that all types of CEOs are willing to accept and not to reject the contract. The CEO 's retention utility U_0 (external opportunity utility) is normalized to 0. Then for CEOs of type θ_i , the assigned contract (w_i, b_i) must satisfy:

$$U_{\theta_i}^{CE}(w_i, b_i) \geq U_0 = 0 \quad (3-7)$$

Since the U^{CE} expression of this study has been substituted into the optimal effort, the IR constraint is actually:

$$w_i + \frac{b_i^2 \theta_i^2}{2k} - \frac{\gamma b_i^2 \sigma^2}{2} \geq 0, \quad i \in L, H \quad (3-8)$$

This means that the contract should give this type of CEO at least zero utility. Usually, in the optimal contract, the IR constraint of the low-type CEO happens to be equal, that is, the low-type participation constraint is bound. The reason is that in order to save costs, shareholders tend not to leave excess rent for low-capacity managers, only to provide just the remuneration that they are willing to participate. High-type CEOs may obtain certain excess utility (information rent) because of information advantage, and their IR constraints can be strictly satisfied by inequality.

Incentive compatibility constraint (IC) : In order to achieve type separation, it is necessary to ensure that all types of CEOs choose the ' contract designed for their own type ' in the contract menu to be optimal, that is, the honest report type is higher than the false report income. For high-capacity CEOs, it is necessary to prevent them from pretending to be low-capacity to obtain different contracts ; for CEOs with low ability, it is necessary to prevent them from falsely claiming high ability. Formally, these two types of IC constraints are:

$$U^{CE}\theta_H(w_H, b_H) \geq U^{CE}(w_L, b_L) \quad (3-9)$$

$$U^{CE}\theta_L(w_L, b_L) \geq U^{CE}(w_H, b_H) \quad (3-10)$$

Substituting the utility to determine the equivalent formula can be further written as:

$$w_H + \frac{b_H^2 \theta_H^2}{2k} - \frac{\gamma b_H^2 \sigma^2}{2} \geq w_L + \frac{b_L^2 \theta_H^2}{2k} - \frac{\gamma b_L^2 \sigma^2}{2} \quad (3-11)$$

$$w_L + \frac{b_L^2 \theta_L^2}{2k} - \frac{\gamma b_L^2 \sigma^2}{2} \geq w_H + \frac{b_H^2 \theta_L^2}{2k} - \frac{\gamma b_H^2 \sigma^2}{2} \quad (3-12)$$

The right side of the above inequality represents the utility of high-capacity CEOs when they choose a contract designed for low-capacity (the utility of subscript mismatch), and the utility of low-capacity CEOs when they choose a high-capacity contract. Incentive compatibility requires that the utility of each type under their own contract is not lower than that under the other party 's contract. Usually, in the optimal solution, the IC constraint of the high-capacity type is bound and the IC constraint of the low-capacity type is relaxed. That is to say, the optimal contract arrangement will make the high-capacity CEO have no difference in impersonating the low-capacity CEO, so that shareholders can minimize the information rent given to the high-capacity CEO ; due to capacity constraints, low-capacity CEOs may be less effective even if they are given high-capacity contracts because they fail to meet performance requirements (that is, the left side is significantly larger than the right side), so there is no special constraint on low-capacity to choose high-capacity contracts. Mathematically, a high-capacity IC binding means that the above equation takes an equal sign, which can be used to eliminate a contract parameter.

3.4 Expression of the Optimal Problem

After the model setting and constraint conditions are clear, this study can express the optimal contract design problem of shareholders. The goal of shareholders (principals) is to maximize their expected returns, that is, the company 's profits minus the remuneration paid to the CEO. Under the uncertainty of the two types of managers, their expected returns are:

$$E[\Pi - (\text{CEO compensation})] = (1-p)[(1-b_L) E[\Pi|\theta_L] - w_L] + p[(1-b_H) E[\Pi|\theta_H] - w_H] \quad (3-13)$$

Since $E[\Pi|\theta_i] = \theta_i$, $e^*(b_i, \theta_i) = \theta_i$, $\frac{b_i \theta_i}{k} = \frac{b_i \theta_i^2}{k}$, we can get:

$$\text{Shareholder expected return} = (1-p)[(1-b_L) \frac{b_L \theta_L^2}{k} - w_L] + p[(1-b_H) \frac{b_H \theta_H^2}{k} - w_H] \quad (3-14)$$

Sorting out each item, the shareholder 's income is composed of profit sharing and salary reduction payment in each type of situation. In this study, they are recorded as π_L and π_H respectively to represent the benefits of low-capacity and high-capacity types to shareholders:

$$\pi_i = (1-b_i) \frac{b_i \theta_i^2}{k} - w_i, \quad i=L, H \quad (3-15)$$

The problem of maximizing shareholders is:

Maximization : $(1-p) \pi_L + p \pi_H$

Variables: w_L, b_L, w_H, b_H

Constraints:

$$w_L + \frac{b_L^2 \theta_L^2}{2k} - \frac{\gamma b_L^2 \sigma^2}{2} \geq 0 \quad (3-16)$$

$$W_H + \frac{b_H^2 \theta_H^2}{2k} - \frac{\gamma b_H^2 \sigma^2}{2} \geq 0 \quad (3-17)$$

$$W_H + \frac{b_H^2 \theta_H^2}{2k} - \frac{\gamma b_H^2 \sigma^2}{2} = W_L + \frac{b_L^2 \theta_L^2}{2k} - \frac{\gamma b_L^2 \sigma^2}{2} \quad (3-18)$$

$$W_L + \frac{b_L^2 \theta_L^2}{2k} - \frac{\gamma b_L^2 \sigma^2}{2} \geq W_H + \frac{b_H^2 \theta_H^2}{2k} - \frac{\gamma b_H^2 \sigma^2}{2} \quad (3-19)$$

The above constraints correspond to IR (L), IR (H), IC (H), IC (L) in turn. Based on the above analysis, this study expects that in the optimal solution, IR (L) and IC (H) will be tightly bound (equal sign), IR (H) will be relaxed (high capacity has positive rent), and IC (L) will be relaxed (low capacity has no power to pretend to be high capacity). Based on this, the two decision variables W_L and W_H can be eliminated by using the equality conditions of IR (L) and IC (H), and then the problem is transformed into the optimization of the two incentive coefficients b_L and b_H . Intuitively, the contract compensation w_L of low-capacity managers will be lowered by shareholders to a level that they are willing to accept, and the contract of high-capacity managers is designed to make them have no income from posing as low-capacity, so as to choose truthful reports without difference. After this treatment, shareholders only need to determine the optimal combination of (b_L, b_H) . Although manual derivation is feasible, it is difficult to directly solve the explicit solution due to the complexity of the equation. In the next section, this study will use numerical methods to solve the optimal b_L^*, b_H^* and further give the corresponding w_L^*, w_H^* and other optimal quantities. It is worth mentioning that in order to ensure the global optimality of the solution, this study will combine coarse-grained global search and local fine search to scan the entire (b_L, b_H) parameter space to avoid falling into the trap of local extremum.

4. Solving Method and Modeling Route

4.1 Binding Set

According to the analysis of Section 3.4, this study gives priority to the case where the low-type participation constraint and the high-type incentive compatibility constraint are equal signs, and simplifies the solution process accordingly. The specific steps are as follows : First, the IR constraints of low-capacity CEOs are equalized, that is:

$$W_L = \frac{b_L^2 \theta_L^2}{2k} - \frac{\gamma b_L^2 \sigma^2}{2} - U_0 \quad (4-1)$$

Since $U_0=0$, the above formula gives the functional relationship of w_L with respect to b_L . It shows that the fixed salary paid by shareholders for low-capacitated managers just makes its utility to zero. It can be seen that w_L may be positive or negative with the increase of b_L : when b_L is small, $\frac{b_L^2 \theta_L^2}{2k}$ is dominant, w_L is positive and increases; when b_L is large, the risk cost $\frac{\gamma b_L^2 \sigma^2}{2}$ increases faster, and w_L may decrease or even become negative. Intuitively, this means that if low-capacity CEOs are given too high a performance coefficient b_L , their required retention fixed wage w_L will be reduced or even turned into a requirement for them to pay a deposit to compensate for the loss of utility caused by risk. Similarly, taking the equal sign of the IC constraint of the high-capacity type can be solved:

$$W_H = W_L + \frac{(b_L^2 - b_H^2) \theta_H^2}{2k} - \frac{\gamma (b_H^2 - b_L^2) \sigma^2}{2} \quad (4-2)$$

This formula is derived from the expression of w_H about w_L, b_L, b_H by making the utility of high-capacity CEO equal in two contracts. Substituting the previous $w_L(b_L)$, the functional relationship between w_H and b_L, b_H can be obtained. Thus, the four variables of the contract (w_L, b_L, w_H, b_H) are reduced to two b_L, b_H . Next, only $w_L(b_L)$ and $w_H(b_L, b_H)$ are substituted into the shareholder income function and residual constraints for optimization. At this time, it is necessary to check whether the remaining low-type IC constraints are naturally satisfied, that is, to verify that the low-capacity CEO does not have the motivation to impersonate the high-capacity contract under the optimal solution. If it is found that low-type ICs have a tendency to default, it is necessary to adjust the binding constraint set to re-solve. However, under most parameters, the constraint binding pattern assumed in this study will appear. This study will test this after solving. The whole process is actually the process of assuming the constraint binding set first, then simplifying and solving the problem by back substitution elimination, and then verifying the hypothesis. Due to the complexity of the double asymmetry problem, this study adopts

this simplified solution path based on theoretical inference, which greatly reduces the difficulty of numerical optimization.

4.2 Numerical Optimization Implementation

Because the analytical solution is extremely complex, this study mainly uses computer-aided numerical methods to solve the optimal contract. Since the objective function (shareholder expected return) is defined on a two-dimensional space, there may be multiple local extreme points in this space. Therefore, the author uses a two-stage grid search method : In the first stage, a coarse grid search is performed on (b_L, b_H) in the entire $[0, 1] \times [0, 1]$ interval to find the global high value area of the expected return ; in the second stage, on the basis of the first stage, a fine grid search is performed on the above high-value areas to obtain the optimal point. Through this method, the corresponding optimal contract can be quickly found when the coefficient value is certain.

Figure 3: Numerical optimization implementation

```
# ----- 粗网格 -----
b_grid = linspace_grid(a: 0.0, b: 1.0, coarse_step)
EP_grid = np.zeros((len(b_grid), len(b_grid)))
best_coarse = None

for i, bL in enumerate(b_grid):
    for j, bH in enumerate(b_grid):
        out = objective_and_components(bL, bH, params)
        EP_grid[i, j] = out["EP"]
        key = (out["EP"], bL, bH, out)
        if (best_coarse is None) or (key[0] > best_coarse[0]):
            best_coarse = key

EP_best_coarse, bL_c, bH_c, out_c = best_coarse

# ----- 细网格 -----
bL_min = max(0.0, bL_c - fine_radius)
bL_max = min(1.0, bL_c + fine_radius)
bH_min = max(0.0, bH_c - fine_radius)
bH_max = min(1.0, bH_c + fine_radius)

bL_fine = linspace_grid(bL_min, bL_max, fine_step)
bH_fine = linspace_grid(bH_min, bH_max, fine_step)

EP_fine = np.zeros((len(bL_fine), len(bH_fine)))
best_fine = None
for i, bL in enumerate(bL_fine):
```

Rough grid global search: Set the step size to a larger value Δ_1 (for example, 0.01), and generate b_L, b_H as a grid point set from 0 to 1 ; enumerate all (b_L, b_H) combinations, use the formula and binding constraints in Chapter 3, Section 4 to obtain W_L and W_H , and then obtain the shareholder 's expected return $EP(b_L, b_H)$; the grid point corresponding to the maximum benefit of the record is the coarse search optimization. Due to the large step size, the whole optimal position range is mainly found at this stage.

Figure 4 Heat map of shareholders ' expected return EP with respect to (b_L, b_H) under coarse grid. The brighter the color, the greater the profit, and the blue dots mark the maximum value obtained by the rough search (rough optimal). It can be seen that EP has unimodality in the parameter space, and the color is the brightest near the optimal solution, indicating that there is a unique global optimal contract combination.

Fine grid local search : take a smaller range around the b_L^c and b_H^c obtained by the coarse search, δ (for example 0.05), then the grid search can be carried out with a finer step size Δ_2 (for example 0.001) in the region, and the corresponding $b_L \in [b_L^c - \delta, b_L^c + \delta], b_H \in [b_H^c - \delta, b_H^c + \delta]$, and then calculate the EP of each grid one by one and find the maximum value (b_L, b_H) . At this time, the selected area and step size range will be much smaller than before, so the points determined in this

interval can be used as the position of more accurate target points.

Figure 4: Heat map of shareholders' expected return EP with respect to (b_L, b_H) under coarse grid

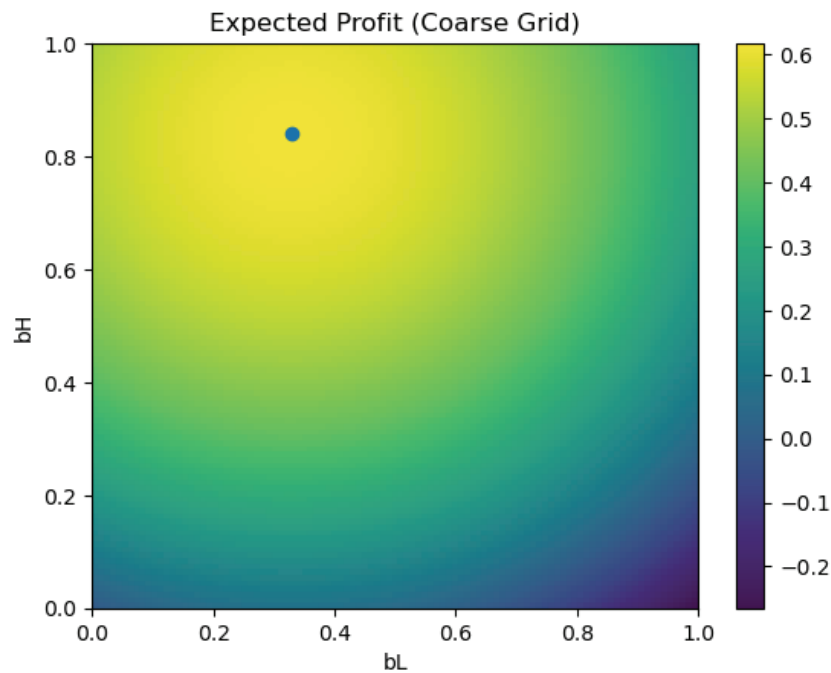


Figure 5: Local heat map of shareholders' expected return EP under fine grid conditions

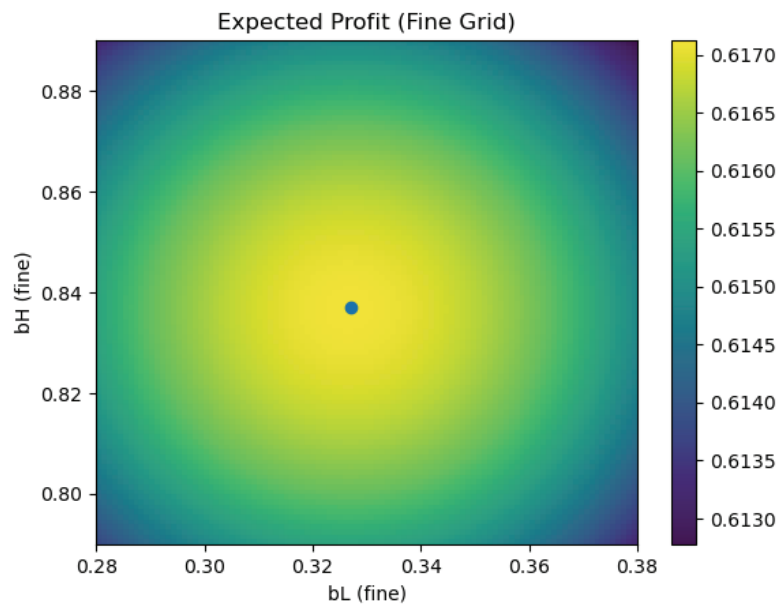
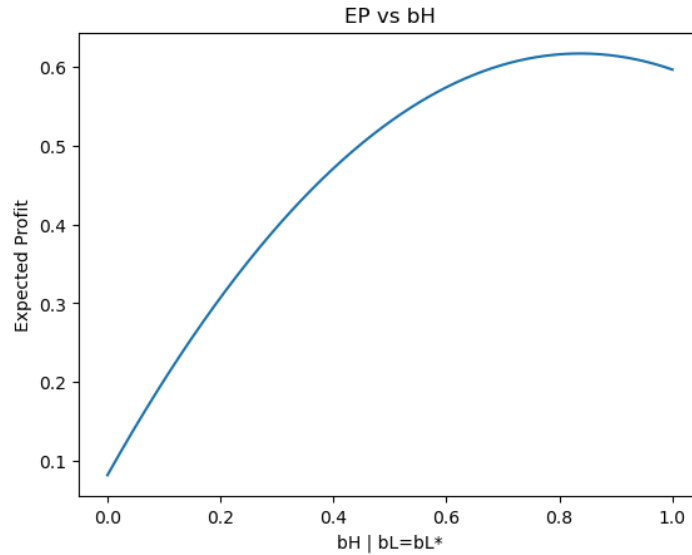


Figure 5 is the local heat map of the shareholder's expected return EP under the fine grid condition (the parameter range has been scaled to the vicinity of the coarse optimal point), and the blue point represents the optimal point obtained by the fine search (b_L, b_H) . In this local range, EP is a smooth unimodal function, so the peak point at the optimal point can be found by fine search.

After the above steps, the global optimal contract incentive coefficient combination (b_L, b_H) is obtained, and then the corresponding (w_L, w_H) , (e_L, e_H) and all derivatives are calculated by substituting 3.4 binding constraints. This algorithm ensures that the optimal solution that satisfies the constraint conditions can be finally found, and it can effectively avoid falling into the local extremum. As long as there is a real global optimal value point in the fine search area, it is only necessary to ensure that δ is selected small enough, and at the same time ensure that there is sufficient margin near several coarse advantages. This study has verified the correctness of this method in the above way. On this basis, this study can construct a

cluster of numerical relationship curves between different factors based on different benchmark situations by adjusting the parameters.

Figure 6: The change of shareholders' expected return EP with b_H (b_L, b_H)



As shown in Figure 6, when $b_L = b_L^*$ is fixed, the shareholder's expected return EP changes with the change of b_H , that is, when $b_H = b_H^*$ (vertical line), the EP is the largest; on the contrary, once b_H deviates from b_H^* , EP will drop sharply, indicating that shareholder returns are highly sensitive to b_H near the optimal high-capacity incentive intensity point, and the corresponding curve is also unimodal.

Figure 7: The cross-sectional view of the change of the shareholder's expected return EP with b_L when $b_H = b_H^*$ is fixed

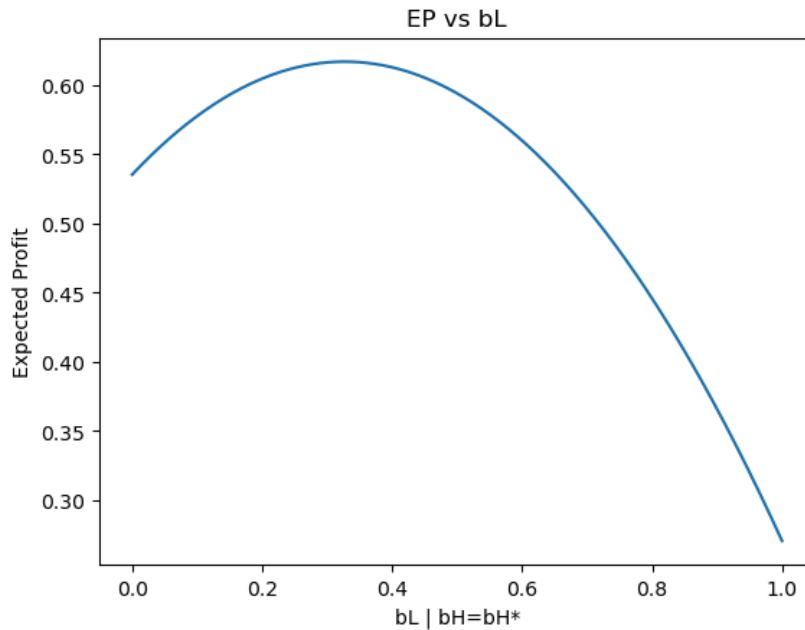


Figure 7 is a cross-sectional view of the change of the shareholder's expected return EP with b_L when $b_H = b_H^*$ is fixed. Similarly, when $b_L = b_L^*$, the profit is the largest, and the deviation from the optimal point will lead to a decrease in EP. This shows that the optimal low-capacity incentive coefficient is also the only peak point of the income function. Combined with Figure 5, it can be seen that the second derivative of EP to parameter changes near (b_L^*, b_H^*) is negative, and the gain function at the optimal point satisfies a certain concavity.

Through the cross-sectional view, it can be seen more intuitively that the optimal contract parameter is the 'mountain top' of the revenue function. This means that the (b_L^*, b_H^*) found in this study is indeed globally optimal, and shareholder returns are

quite sensitive to the deviations of these two parameters, which need to be accurately adjusted to achieve maximum. This also confirms the importance of designing differentiated contracts for different types of capabilities : if the incentive coefficient of high-capacity managers is set too low, the company 's earnings cannot fully tap its potential ; if the incentive coefficient of low-capacity managers is too high, the company 's income will also be damaged by ineffective incentives, and the optimal contract can balance the two.

4.3 Expandable Design

The solution path of the above model has good scalability and can be extended to different contract design situations. First, at the parameter level, the sensitivity of the model to some main parameters can be considered. For example, by changing the probability p of high and low ability types, the influence of the proportion of low ability of different proportion of manager groups on the optimal contract is simulated. Studies have shown that when the proportion of low-ability managers is greater, the value of distinguishing incentives is greater, and there are two kinds of contract design ; when the proportion of high ability is larger, shareholders can choose to give only a single type of contract to high-ability managers, that is, to carry out ' high-type ' incentives, without distorting the incentives of all managers for a very small number of low-ability managers. This study can test whether this statement is correct by adjusting the p , and find the condition value corresponding to the contract inflection point. Second, at the level of model construction, it can be extended from two types to continuous types. Although the solution of the continuous type requires more numerical algorithms, the existing model solving process in the two-type case can be extended by discretizing $b(\theta)$ into a finite number of parameters. Thirdly, other factors are added, such as long-term incentive, multi-task, agent fairness preference, etc. In this process, as long as the corresponding utility or constraint part is added to the model, the optimal contract combination can still be found by numerical method, and the solution algorithm of this study is insensitive to the form of constraint conditions and objective function, so the solution algorithm is very general. Of course, as the model increases more complexity, it will bring higher computational requirements, and the scheme proposed in this study can also further use more advanced optimization algorithms such as genetic algorithm and simulated annealing to assist it in searching for better optimal solutions. The scheme proposed in this study is actually an affordable framework for analyzing complex contract design problems. When it cannot be directly analyzed, the results can still be obtained by calculation.

5. Baseline Results and Policy Implications

5.1 Evaluation Caliber and Comparison Benchmark

In order to clearly interpret the optimal compensation contract, this study first clarifies the evaluation criteria and comparison criteria. In terms of evaluation caliber, shareholders are concerned about the company 's expected profit EP and its changes relative to different contractual arrangements. The CEO is concerned about their own utility, and the realization of utility is mainly affected by participation constraints and information rent. In the model of this study, because the utility is used to determine the equivalent form and the participation constraint is set to zero utility, if the CEO is low, its utility is ultimately 0 ; if it is high capacity, its utility is the size of information rent ($IR(H)$ relaxation). Therefore, this study focuses on the excess utility of high-capacity CEOs and the difference in the effort level of the two types of CEOs. In terms of comparative benchmarks, there are two cases with reference significance : one is the complete information contract, that is, shareholders know the type of CEO ability in advance, and can formulate contracts for different types without information constraints. In this case, shareholders do not need to give high-capacity information rents, and incentives that meet the first-order optimal conditions can be set for each type ; the second is a single contract (regardless of type), that is, shareholders do not distinguish between CEO types and provide a unified contract for both types of people to accept. This is equivalent to giving up the use of adverse selection mechanism, only to solve the problem of moral hazard. These two benchmarks represent the ideal case under information symmetry and the sub-optimal case without separation mechanism, respectively. This study will compare the optimal contract with these two benchmarks when discussing the results to highlight the impact of information asymmetry on contract distortions. Since the complete information contract can be regarded as an extreme case of p taking 0 or 1, and the single contract is equivalent to the constraint condition of forcing $b_L = b_H$, the effect of the two can be observed by adjusting the model parameters and constraints. It should be noted that the solution of this study focuses on the separation contract,

because under reasonable parameters, when the two types coexist and p is moderate, the separation contract can bring higher shareholder returns. However, in extreme cases (such as high capacity probability is very large or very small), a single contract may become a sub-optimal choice for shareholders. This study will discuss this policy implication in Section 5.3.

5.2 Baseline Solution Results

Based on the baseline parameters ($\theta_L=1.0$, $\theta_H=1.6$, $p=0.5$, $k=1.0$, $\sigma=1.0$, $\gamma=0.5$, $U_0=0$) proposed above, the optimal contract parameters and corresponding performance indicators are obtained. The main results are summarized as follows: $b_L^*=0.327$, $b_H^*=0.837$, $w_L^*=-0.027$, $w_H^*=-0.638$ (Amount units can be understood as a standard currency, such as millions of dollars). The CEO 's effort level is calculated as $e_L^*=\frac{b_L^*\theta_L}{k}=0.327$, $e_H^*=\frac{b_H^*\theta_H}{k}=1.3392$. The expected profit obtained by shareholders is $\pi_L^*=0.247$, $\pi_H^*=0.987$, and the comprehensive expected return $EP^*\approx 0.617$ (the same unit as above, which can be understood as million yuan). In addition, the verification of the constraint conditions shows that the relaxation of the high-capacity CEO 's participation in the constraint $IR_H=0.0834$, which is the information rent it obtains ; the incentive compatibility relaxation of low-capacity CEOs $IC_L=0.463$, indicating that the utility of high-capacity contracts is much lower than that of staying in their own contracts, proving that low-type IC constraints are stress-free, which is in line with the previous judgment of this study on constraint binding.

Figure 8: The elements of the optimal contract and the corresponding effort level histogram

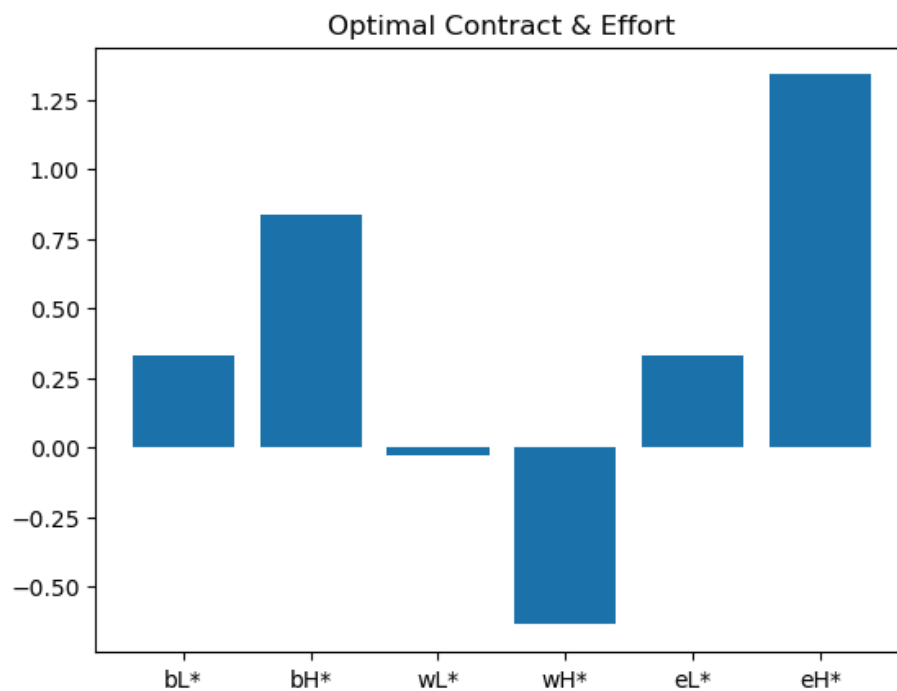


Figure 8 is a histogram of the elements of the optimal contract and the corresponding effort level. It can be seen from the figure that the optimal bonus coefficient b_L^*, b_H^* , fixed salary w_L^*, w_H^* and effort level e_L^*, e_H^* corresponding to low / high-capacity CEOs, the bonus coefficient of high-capacity CEOs is much higher than that of low-capacity CEOs, and the fixed salary is lower than that of low-capacity CEOs, and is negative, that is, high-capacity CEOs are required to pay a certain deposit or make corresponding investments after the contract is signed. In this way, the scheme of 'substantial high reward and low guarantee' has the characteristics of stronger incentive and risk sharing for employees with stronger ability. On the contrary, the performance sensitivity of CEOs with low ability is low, and the fixed salary is only slightly less than 0 (if it is a small negative number, it requires a small amount of investment). There is also a big difference in the degree of effort between the two types of CEOs: the high-ability CEO 's effort is about 4.1 times that of the low-ability CEO, that is, under the design of the optimal contract, the high-ability CEO will be more motivated to work hard and create more performance. From the above results, it can be seen that the optimal compensation contract adopts different incentives for different types of capabilities: high-capacity CEOs bear greater performance risks and obtain income mainly through performance, while low-capacity CEOs bear less performance risks and their income is more guaranteed by fixed parts. Specifically, $b_H^*\approx 0.837$

means that for every unit of profit generated by a high-capacity CEO, 0.837 units can be extracted as bonuses, which is almost a ' high commission ' incentive ; correspondingly, $1-b_H^* \approx 0.163$ means that shareholders only retain 16.3% of their profits, but because of the high output efficiency of high-capacity CEOs, shareholders can still profit from the larger base brought by their efforts. $b_L^* \approx 0.327$ gives a moderate incentive intensity to low-capacity CEOs to share about 30% of marginal profits, and $1-b_L^* \approx 0.673$ guarantees shareholders ' large share of profits in low-capacity sectors. It is worth noting that both W_H^* and W_L^* are negative, especially the fixed salary $W_H^* \approx -0.638$ absolute value of high-ability CEO is larger. In theory, this means that high-capacity CEOs need to pay a certain amount (such as buying company shares or paying performance bonds) at the time of signing the contract to qualify for high performance bonuses. $W_L^* \approx -0.027$ is close to 0, indicating that low-capacity CEOs can hardly get a fixed salary, but they do not need to pay as much as high-capacity ones. This negative fixed wage may be understood in real contracts as executives voluntarily deferred part of their compensation or put it into the company to show confidence and bound interests. In fact, there are indeed arrangements for senior executives to hold company stocks, options, etc., which can be regarded as a disguised negative wage (senior executives use cash to purchase company equity, and future earnings depend entirely on the quality of operation). The results of this study theoretically support the necessity of this approach for high-capacity managers - by requiring their own deposit or shareholding, high-capacity managers can be fully motivated and their information rents are partially grabbed by shareholders.

5.3 Mechanism Interpretation and Governance Enlightenment

The above characteristics of the optimal contract are derived from the trade-off mechanism between incentives and rents under information asymmetry. In terms of high-capacity CEOs, in order to encourage their efforts, the contract gives a high proportion of revenue sharing b_H^* , which enables them to obtain a good return for every additional effort, so that they are willing to invest in the effort level of those with far ultra-low capabilities (1.3392 vs.0.327). At the same time, because of the strong ability, the high-ability CEO can easily overfulfill the low-ability contract and obtain more efficient use. In order to prevent it from doing so, shareholders must reduce the risk compensation of high-capacity contracts, that is, reduce the fixed salary W_H , until the high-capacity CEO does not benefit from the impersonation. The solution of this study shows that this process even puts the W_H value at a negative value, that is, letting the high-ability CEO 's own ' out of pocket ' to indicate their identity. At this time, there is no difference in the utility of high-capacity CEOs between the two contracts, and their information rent is just compressed to the extent that it is almost unprofitable to defraud low-capacity contracts (this model calculates that the high-capacity CEO still has about 0.083 utility excess, but it is very small relative to its effort output). On the other hand, for low-capacity CEOs, the contract provides a smaller performance incentive b_L^* has a double meaning: first, considering that the marginal output of low-capacity CEOs is not high, too strong incentives cannot effectively improve performance, but increase their risk burden ; second, more importantly, reducing b_L makes it difficult for high-capacity people to obtain higher returns than in high-capacity contracts because of the small proportion of bonuses, even if they consider posing as low-capacity to take such contracts. Similarly, a slightly higher fixed salary (or a smaller negative W_L) for low-capacity people can increase the attractiveness of low-capacity contracts to high-capacity people, but that would violate IC_H requirements. Therefore, shareholders also tend to set W_L at the lowest possible level when designing low-capacity contracts (until the lower limit of its IR_L is 0). The final result is that low-capacity contracts contain almost no rent and high incentives, so that high-capacity people have no incentive to fake, while low-capacity people can accept them themselves. As a result, two types of CEOs with different abilities are self-screened : high-ability CEOs choose high-incentive, high-risk and high-return contracts and work hard, while low-ability CEOs choose low-incentive and low-security contracts to fulfill their duties. Shareholders obtain the highest expected profit through this mechanism design, while minimizing the efficiency loss caused by information asymmetry.

The above mechanism has certain implications for the actual corporate governance and compensation design : First of all, the company should consider the differences in executive ability when formulating executive compensation, and cannot use the same structure of compensation to motivate everyone. The model of this study shows that a high proportion of performance bonuses should be provided to capable CEOs and fixed compensation can be reduced accordingly (even performance deposit or stock purchase requirements are set) to fully stimulate their talents and prevent efficiency losses caused by adverse

selection. This is a bit similar to the practice of 'high performance sensitivity contract' or 'heavy performance, light bottom' incentive scheme. On the contrary, for executives with relatively general capabilities, excessive performance sensitivity is not appropriate. Fixed compensation guarantees should be appropriately increased and performance appraisal efforts should be reduced so as not to give up or be negative because they cannot meet high indicators (this corresponds to low-capacity contracts in the model. Incentives are weak to ensure their participation). Such hierarchical incentives help to achieve pay for ability and do their best in the team. Secondly, the existence of information rent means that high-capacity executives tend to receive additional benefits beyond their retained wages, which may be reflected in the fact that excellent CEOs get generous equity incentives or bonuses. This is not detrimental to shareholders-it is precisely to pay a certain amount of information rent in exchange for executives to create greater value for the company. Therefore, when formulating executive compensation restriction policies, regulators should recognize that moderate executive excess returns under information asymmetry may be an incentive compatibility cost, and should not simply "one-size-fits-all" depress executive performance income, otherwise it may dampen the enthusiasm of high-ability people or drive them to conceal their talents. Finally, the analysis of this study also suggests that another strategy that companies can adopt when hiring executives is type screening: if they can screen out low-capacity candidates through assessment and only retain high-capacity CEOs when hiring, then p actually approaches 1. At this time, shareholders do not necessarily need to provide two types of contracts, and can directly give a unified strong incentive contract (equivalent to only designing contracts for high-capacity). Conversely, if the majority of low-capacity (p is significantly lower than 0.5), shareholders may also choose not to hire or eliminate high-capacity (because it is rare) and only design simple contracts for most low-capacity. However, in most cases, high and low abilities coexist and are difficult to be completely screened, so differentiated compensation contracts are still necessary. The above ideas reflect that the design of the optimal compensation contract should be combined with the ability structure of the executive group. This is consistent with the concept of formulating personalized incentive plans according to the characteristics of managers in management practice.

6. Conclusion and Prospect

6.1 Research Conclusions

This study studies the design of CEO's compensation contract in the presence of moral hazard and adverse selection, and draws the following main conclusions:

- (1) Type separation: Different CEOs are given different 'pay menu' salary schemes, so that they can decide what kind of contract to choose according to their own talents. High-energy CEOs will choose high-incentive-intensity contracts, while low-energy CEOs will choose the opposite, in order to solve the problem of adverse selection.
- (2) Incentive intensity differentiation: The optimal contract increases the performance sensitivity and risk tolerance of high-capacity CEOs to the highest, and gives corresponding high returns, while for low-capacity CEOs, it intentionally lowers incentives. This strategic distortion is not the real optimal, but it is still efficient in the context of serious information asymmetry between the two parties.
- (3) Compression of information rent: contract design minimizes the information rent of high-capacity CEOs, while low-capacity CEOs only get retained utility. This contract design minimizes the additional compensation that needs to be paid to executives due to information asymmetry.
- (4) Improve shareholder returns: on the contrary, the 'one-size-fits-all' single contract will reduce the expected return of shareholders compared to the separation contract, which indicates the importance of differentiated incentives, especially when the proportion of high-capacity and low-capacity executives is relatively balanced.

In conclusion, the study finds that the differentiated contract of 'high energy and high incentive, low energy and low guarantee' can make executives self-screening and incentive compatibility, and maximize the interests of shareholders under the guarantee of minimum information rent.

6.2 Future Prospects

This study still has limitations and can be expanded from the following aspects in the future:

- (1) Model hypothesis: We can consider extending the executive ability from two types to different continuous distribution types, and design the corresponding dynamic contract model on this basis to make it more in line with the actual situation.

(2)Governance environment: Since the model does not consider the contradiction between shareholders and the CEO of the board, if these corporate governance factors are taken into account, it will help to better explain the reality of incentive anomalies.

(3)Performance indicators: In the future, we can explore how to design the optimal incentive contract with multi-dimensional (not only financial) indicators under the dual information asymmetry.

(4)Empirical test: the data of listed companies can be used to empirically verify the core predictions of the model (such as the high-capacity CEO prefers high-incentive intensity contracts and their impact on shareholder returns).

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No

Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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