Can Agents Be Better-Off with Pay Caps?

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Abstract

Imposing caps on managers' pay has been a popular way to discipline managers of companies or banks that got into trouble during the recent financial crisis. Using a small extension of the standard principal-agent model, we argue that pay caps may serve the opposite purpose because the agent can be better off with a pay cap. Specifically, we show that, given a fixed effort level to be implemented, the agent's expected utility can be decreasing in an upper bound for the agent's reward. The model also offers a characterization of the effect of pay caps on the general structure of optimal incentive contracts. While improvement of contracting information always helps the principal, it may increase or decrease the marginal cost of imposing pay caps.

1 Introduction

Caps on incentive payments are very common. For example, a large proportion of companies impose caps on managers' bonus (see, for example, Murphy [18]). On occasions, caps are brought in by governments. For example, the Clinton administration brought in the "million-dollar" cap in the 1990s. More recently, President Obama proposed to cap the compensation of executives in companies that have received financial support from the Troubled Asset Relief Program, following the financial crisis of 2007. At the same time, leaders of the G20 are also debating whether to cap executive pay. One of the issues that has been vigorously debated is whether imposing pay caps will cause the top talents of troubled companies to flee to better-performing ones, making it even more difficult for the troubled firms to survive and eventually causing more instability in important industries such as banking.[1] While the issue is at the heart of the study of incentive compensation, we are surprised to find that the very economic tool developed for such an issue – the moral hazard model – seems to have been left on the shelf. In this paper, we illustrate how a simple extension of the traditional moral hazard model can shed new light on the debate. More specifically, we extend the traditional principal agent model with limited liability by considering an upper bound on the reward of the agent (managers, CEOs) and show that, given a fixed effort level to be implemented, the expected utility of the agent can be decreasing in the cap on the agent's compensation. Although our result contradicts the popular concern that pay caps will drive managers away, it is consistent with the finding of DeVaro and Fung [6] that imposing pay caps will cause executive retention rates to increase significantly. Our result suggests that pay caps may not cause top managers to flee (because they are better-off with the caps), but may serve the opposite purpose if these pay caps are meant to limit the managers' well-being.

[1] Nanette Byrnes, "Congress Set to Curb Exec Pay," *BusinessWeek*, Feburary 13, 2009.

The intuition of our result can be explained as follows. When the agent captures a limited-liability rent, the goal of the principal's optimal contract is to minimize this rent, given the same effort to be implemented. As in standard models, the principal do so by paying more for outcomes that signal more strongly the event that the effort desired by the principal is exerted (or, more precisely speaking, outcomes with higher likelihood ratios). This is the most effective way of extracting the rent from the agent because it provides the strongest causal link between effort and reward. In this situation, the direct impact of a pay cap is to reduce the optimal payments for outcomes that deserve the most rewards, lowering the incentive for the agent to exert costly effort. If the principal wants to implement the same level of effort, the optimal payments for some other outcomes that are also worthy of reward (but not so much as the previous ones) have to be increased. Together, these decreases of high payments and increases of low payments should entail a higher expected payment from the principal because a more restrictive, binding pay cap necessarily reduces the effectiveness of rent extraction. In the case of a risk-neutral agent, this immediately means a higher expected payoff for the agent.

In the case of a risk-averse agent, a higher expected payment from the principal may not mean a higher expected utility for the agent. However, it does imply that the expected value of all the increases in payments can more than cancel that of all the decreases. Therefore, the overall change can be decomposed into i) a part that contains all the decreases and some fractions of the increases that are just enough to cancel the decreases in expected values and ii) the remaining fractions of the increases. Part i) can be referred to as the as *forced-insurance effect* because it constitutes an actuarially fair insurance to the agent. Part ii) can be referred to as the *rent-surrendering effect* because it constitutes the extra rent surrendered to the agent. Clearly, each of these effects makes the agent better off. This implies that they jointly also make the agent better off. This intuition is formalized in Proposition 1.

1.1 Related Literature

In the moral hazard literature, two early studies by Innes [12] and Mathews [19] consider both lower and upper bounds on payments. In these models, upper bounds on payments are introduced as a limited-liability constraint of the principal and the main goal is to rationalize the debt contract as the optimal contract. Recently, Poblete and Spulber [23] extend the result of Innes [12] by allowing for a larger class of outcome distributions. In addition, Jewitt *et al.* [14] offer a general characterization of an optimal incentive contract when there are both lower and upper bounds for payments, and prove the important results of existence and uniqueness. None of these studies focuses on the relationship between the agent's limited-liability rent and the upper bound, as we do in this paper. We also depart from this body of work by following the approach of Grossman and Hart [9] to address the moral hazard problem, which does not put stringent restrictions on the distribution function of the output (see Bolton and Dewatripont [3] p.152 for details).

Despite its empirical relevance, the existence of pay caps is hard to rationalize from the point of view of Arya *et al* [2] and Jensen [13]. In particular, caps may cause managers to manipulate earnings (Healy [10]). Conversely, Arnaiz and Salas-Fumás

[1] identify a particular situation in which caps can be rationalized. We join the former authors by illuminating the cost of pay caps from the moral hazard perspective.

The rest of the paper is organized as follows. Section 2 introduces the model setup. Section 3 characterizes the optimal compensation schemes. Section 4 derives the main results, and investigates the effect of upper bounds for payments on the limited-liability rent. Section 5 examines the effect of the improvement of contracting information on the cost of pay caps, and Section 6 concludes the paper.

2 The Model Setup

Consider a risk-neutral principal employing an agent with zero outside options. The agent's utility function is $u(\cdot)$, where $u'(\cdot) > 0$, $u''(\cdot) < 0$ (for risk aversion) or $u''(\cdot) = 0$ (for risk neutrality), and $u(0) = 0$. The agent chooses an effort level $e \in \{0, 1\}$, which is not observable to the principal. The agent's disutility from exerting effort is $c \cdot e$. Suppose there are N possible output levels, denoted as y_i where $i \in \{1, 2, ..., N\}$.

Let P_i and p_i denote the probabilities that an output level y_i is realized when the effort level is 1 or 0, respectively. We assume that there exist more than two output levels i and j with positive and distinct likelihood ratios, i.e., $\frac{P_i - p_i}{P_i} > \frac{P_j - p_j}{P_j} > 0$ (which requires that $N \geq 3$). Because a level with a higher likelihood ratio is more informative about the event that the agent works ($e = 1$), this introduces the possibility of rewarding the agent for less informative output levels when a pay cap binds the rewards for more informative output levels. Our result will not hold if there is only one output level with positive likelihood ratio, such as in the binary-output models of Demougin and Gravie [7], Demougin and Fluet [8] or Budde and Kräkel [4] because a binding pay cap will simply makes it impossible to implement $e = 1$, and hence different binding pay caps do not make any difference.

Without loss of generality, we relabeled the output levels so that the likelihood ratio $\frac{P_i - p_i}{P_i}$ is strictly increasing in i,[2] and hence the probability distribution of output realization satisfies the standard monotone likelihood ratio property (MLRP). With this index system, we will refer to any given output level y_i as a "higher" output level than another level y_j if $i > j$, even though it may be the case that $y_i < y_j$.

This construction implies that an agent who works ($e = 1$) is more likely to produce high output levels than an agent who shirks ($e = 0$). Technically, this also means that

$$P_j p_i > P_i p_j \text{ for any } j > i. \tag{1}$$

Given the assumption that the agent's effort is not observable, the principal can only compensate the agent according to the observable and verifiable output levels. Let w_i denote the compensation paid to the agent when the realized output level is y_i.

[2] If there are any two output levels i and j such that $\frac{P_i - p_i}{P_i} = \frac{P_j - p_j}{P_j}$, it is clear from Lemma 1 that the optimal payment for these two levels will be the same. This means that these two output levels can be regrouped as one without affecting the calculation of the agent's rent. Hence our main result that the agent can be better off with pay caps will not be affected by relaxing the strictness of the monotonic relationship between $\frac{P_i - p_i}{P_i}$ and i.

The principal's problem is

$$C(\overline{w}) \equiv \min_{(w_1,\ldots,w_N)} \sum_{i=1}^{N} P_i w_i, \tag{2}$$

subject to

$$\sum_{i=1}^{N} P_i u(w_i) - c \geq \sum_{i=1}^{N} p_i u(w_i), \tag{IC}$$

$$\sum_{i=1}^{N} P_i u(w_i) - c \geq 0, \tag{IR}$$

$$w_i \geq 0, \forall i \in \{1,\ldots,N\}, \tag{LB}$$

$$w_i \leq \overline{w}, \forall i \in \{1,\ldots,N\}. \tag{UB}$$

The only difference between the problem above and the standard principal-agent problem with limited-liability constraint is the addition of (UB). We follow the standard normalization in setting the lower bound for payments to zero in (LB).

For program (2) to have feasible solutions, it requires that

$$\sum_{i\in\{i|P_i-p_i<0\}} (P_i - p_i) u(0) + \sum_{i\in\{i|P_i-p_i\geq 0\}} (P_i - p_i) u(\overline{w}) = \sum_{i\in\{i|P_i-p_i\geq 0\}} (P_i - p_i) u(\overline{w}) \geq c,$$

or equivalently,

$$\overline{w} \geq \alpha \equiv u^{-1}\left(\frac{c}{\sum_{i\in\{i|P_i-p_i\geq 0\}} (P_i - p_i)}\right), \tag{3}$$

so that (IC), (LB), and (UB) will not be in conflict. If (3) fails, the principal can only implement $e = 0$, and hence the agent's expected utility will always be zero regardless of $\overline{w}$. In addition, $\overline{w}$ only affects the solution of program (2) if it is low enough that

(UB) binds. This requires that $\overline{w} < w_N^{SB}$, where w_N^{SB} is the optimal payment for the highest output level N when (UB) is excluded from the program. It is clear that the agent's expected utility is also constant for all $\overline{w} \geq w_N^{SB}$.

To illustrate that the expected utility of the agent in equilibrium can increase as $\overline{w}$ decreases, it helps to restrict attention to the current binary-effort structure because it avoids the complication of changing the optimal choice of effort by the principal. In fact, we will focus on the case in which the principal always finds it optimal to implement $e = 1$. Technically, this can be ensured by the following assumption:

Assumption 1 $\sum_{i=1}^{N} P_i y_i - \sum_{i=1}^{N} p_i y_i > C(\overline{w})$, *where* $C(\overline{w})$ *is the agency costs of implementing* $e = 1$, *defined in (2).*

Without this assumption, the decreasing relationship between agent's expected utility and $\overline{w}$ holds for decreasing $\overline{w}$ down to some point, below which the principal will prefer implementing $e = 0$, causing the expected utility of the agent to drop to zero. This assumption is likely to hold when the marginal product of effort, i.e., $\sum_{i=1}^{N} (P_i - p_i) y_i$, is large or $C(\overline{w})$ is low, which can be the case if the marginal cost of effort c is small. We discuss the importance of Assumption 1 and the setup of binary effort in section 4.1.

3 Optimal Incentive Scheme

By solving the optimization problem set up in the previous section, we obtain the following characterization of the optimal incentive scheme.

Lemma 1 *Suppose that Assumption 1 holds and $\alpha \leq \overline{w}$. The optimal contract entails that (IC) always binds and satisfies*

$$\begin{aligned} w_i^* &= 0 \text{ and } \frac{(P_i - p_i)}{P_i} u'(0) \leq \frac{1}{\lambda} \text{ for all } i \leq \underline{i}; \\ 0 &< w_i^* < \overline{w} \text{ and } \frac{(P_i - p_i)}{P_i} u'(w_i^*) = \frac{1}{\lambda} \text{ for all } \underline{i} < i \leq \overline{i}; \\ w_i^* &= \overline{w} \text{ and } \frac{(P_i - p_i)}{P_i} u'(\overline{w}) \geq \frac{1}{\lambda} \text{ for all } i > \overline{i}, \end{aligned}$$

for some Lagrangian multiplier λ associated with (IC) and some cut-off indexes $\underline{i}$ and $\overline{i}$ such that $1 \leq \underline{i} \leq \overline{i} \leq N$.

Proof. See Appendix. ■

In the following, we say that an output level i is "exploited" if the optimal payment for this level is positive, i.e., $w_i^* > 0$, and that an output level i is "exploited more" than another level j if $w_i^* > w_j^*$. We also say that an output level is "partially exploited" if $0 < w_i^* < \overline{w}$ and "fully exploited" if $w_i^* = \overline{w}$. The main message of Lemma 1 is that the exploitation of output levels is prioritized so that a higher level is never exploited less than a lower level. The driving force of this prioritization is the construction that a higher output level has a higher likelihood ratio and hence is more informative about the event that the agent works, compared with a lower output level. When the agent is risk-neutral, the prioritization is carried out in a strict way so that a level will only be exploited if all the levels above it have been fully exploited and hence there will be at most one level that is partially exploited.

This bang-bang property will disappear if the agent is risk-averse. In that case, the concern for insurance provision makes it optimal for the principal to spread the intermediate rewards across several consecutive output levels (to smooth out the income differentials of the agent across different outcomes), so there will be several consecutive output levels that are partially exploited (as shown by the solid line in Figure 1). In this case, the prioritization is carried out in a weaker sense so that the partially exploited levels are exploited in a degree that is increasing in the output level, and given that both the upper and lower bounds are binding, all output levels above these output levels are fully exploited and all output levels below are completely unexploited.

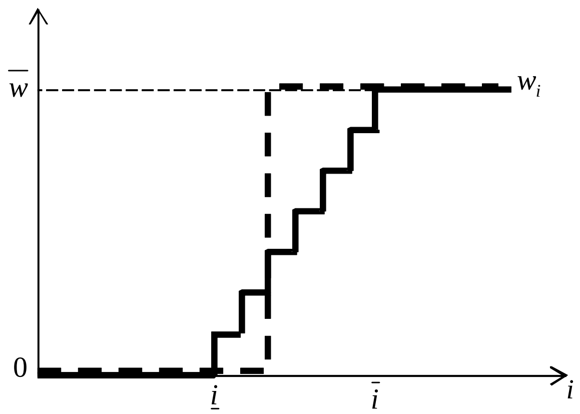

Figure 1.

4 The Effect of Pay Cap

After formulating the structure of the optimal contract, we can proceed to investigate the effect of the restrictiveness of the upper bound for payments on the optimal compensation scheme. When the upper bound decreases, optimal payments of the original contract that exceed the new upper bound are no longer feasible and hence need to be lowered for the new contract. Given that the principal always wants to implement $e = 1$ (Assumption 1), the payments for some output levels need to be raised. Lemma 2 characterizes the systematic way the optimal payment scheme changes with the pay cap.

Lemma 2 *Suppose that Assumption 1 holds and $\alpha \leq \overline{w}$. Let $\underline{i}'$ and $\overline{i}'$ respectively denote the lower and upper cut-off indexes and $(w_1', \ldots, w_N')$ denote the optimal contract when the pay cap is $\overline{w}'$; let $\underline{i}''$ and $\overline{i}''$ denote respectively the lower and upper cut-off indexes and $(w_1'', \ldots, w_N'')$ denote the optimal contract when the pay cap is $\overline{w}''$. If $\overline{w}'' < \overline{w}'$, then*

$$\underline{i}'' \leq \underline{i}', \text{ and } \overline{i}'' \leq \overline{i}', \tag{4}$$

and

$$\begin{aligned} w_i'' &= w_i' \text{ for all } i \text{ such that } i \leq \underline{i}'', \\ w_i'' &> w_i' \text{ for all } i \text{ such that } w_i' < \overline{w}'' \text{ and } i > \underline{i}'', \\ w_i'' &< w_i' \text{ for all } i \text{ such that } w_i' > \overline{w}''. \end{aligned}$$

Proof. See appendix. ■

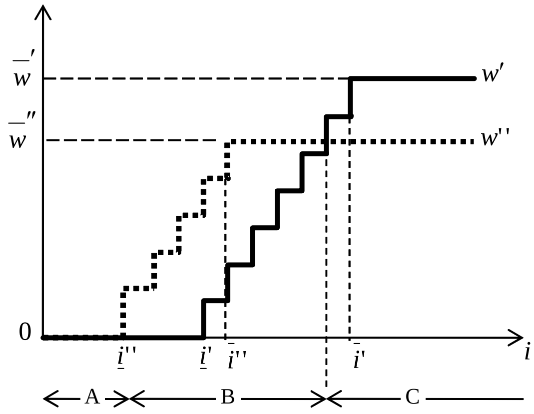

Figure 2.

Lemma 2 says that the same prioritization mentioned above will be followed in exploiting output levels in response to the decrease of $\overline{w}$. The case with a risk-averse agent is illustrated in Figure 2, in which w' and w'' denote the optimal compensation schemes when the the levels of the upper bounds are $\overline{w}'$ and $\overline{w}''$, respectively. In this case, a more stringent pay cap reduces the payments associated with the highest output levels (region C), while increasing those associated with the intermediate output levels (region B). Under the new upper bound $\overline{w}''$, the partially exploited levels are also exploited in a degree that is increasing in the output level, as discussed above.

As shown in figure 2, a more stringent pay cap will cause the payment to the agent to decrease for some output levels and increase for some other output levels, so it is not transparent why it necessarily entails a higher expected utility for the agent. However, as discussed in the introduction, this can be seen easily for the case with a risk-neutral agent. For the case with a risk-averse agent, the intuition can be illustrated by considering the special case with three output levels, i.e., $N = 3$. Assume that $\frac{P_1 - p_1}{P_1} < 0$ and $\frac{P_3 - p_3}{P_3} > \frac{P_2 - p_2}{P_2} > 0$ so that $w_1^* = 0$ and $w_3^* \geq w_2^* > 0$.

Consider two binding pay caps $\overline{w}''$ and $\overline{w}'$, where $\overline{w}'' < \overline{w}'$. The corresponding two equilibria can be represented respectively by points X and Z in Figure 3, where the binding IC constraint, i.e., $\sum_{i=1}^{3}(P_i - p_i)\,u(w_i) = c$, crosses with $w_3' = \overline{w}'$ and $w_3'' = \overline{w}''$. It is graphically clear that the agent's expected utility increases from point X (in the amount of $\sum_{i=1}^{3} P_i u(w_i')$) to point Z (in the amount of $\sum_{i=1}^{3} P_i u(w_i'')$) as the cap decreases. To understand the economic intuition, this increase can be decomposed into i) the change from X to Y and ii) the change from Y to Z. Part i) represents the forced-insurance effect: it moves the payments southeast from X along the iso-payment line, i.e., $\sum_{i=1}^{3} P_i w_i = \sum_{i=1}^{3} P_i w_i'$, for the principal, constituting an actuarially fair insurance subcontract. Part ii) represents the rent-surrendering effect: it raises the payment for y_2 and leave those for y_1 and y_3 unchanged. The joint benefit can be understood by combining these two clear positive effects.

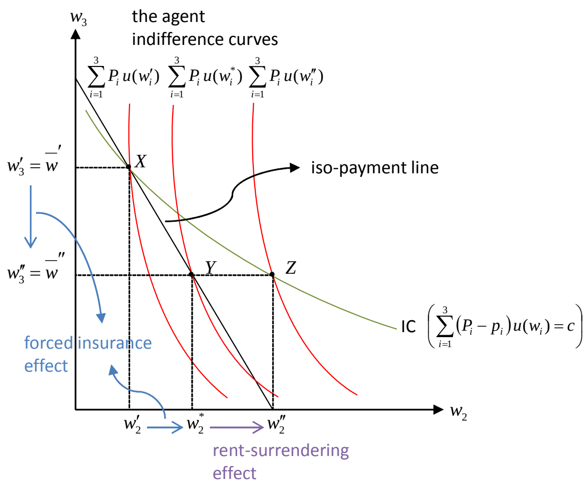

Figure 3.

In the following proposition, we formalize the intuition for the general case.

Proposition 1 *Suppose that Assumption 1 holds.*

- *For $\alpha \leq \overline{w} \leq w_N^{SB}$ (so that $e = 1$ is implementable and the pay cap binds), the expected utility of the agent is strictly decreasing in $\overline{w}$. More specifically, the change of optimal contract caused by a decrease of $\overline{w}$ in this range can be decomposed into the following two beneficial effects for the agent:*
  - *a forced-insurance effect that constitutes a actuarially fair insurance to the agent*
  - *a rent-surrending effect that constitutes weakly positive payments to the agent across all states.*
- *For $\overline{w} > w_N^{SB}$ (so that $e = 1$ is implementable and the pay cap does not bind) or $\overline{w} < \alpha$ (so that $e = 1$ is not implementable), the expected utility of the agent is constant with respect to $\overline{w}$.*

Proof: See appendix.

One can see from Lemma 2 that as the cap on payment becomes more stringent, the optimal compensation scheme has a higher insurance element because payments across different output levels become more homogenized. While this homogenization does not exactly entail a less risky contract in the regular sense, Proposition 1 shows that it does so in a weak sense, that is, this homogenization can necessarily be decomposed into a forced-insurance component and a rent-surrendering component. Therefore, one interpretation of the effect of lowering the cap is that it forces the principal to lower the risk imposed on the agent, and then to make up for the resultant incentives loss by increasing the reward for $e = 1$. Both of these effects increase the expected utility of the agent.

The result of Proposition 1 can also be illustrated as in Figure 4. As $\overline{w}$ approaches 0 from the right, it has no effect until it starts to bind the payment for level N (at the point $\overline{w} = w_N^{SB}$). As $\overline{w}$ decreases beyond this point, the agent's expected utility $R(\overline{w})$ will increase, according to Proposition 1, and may have kinks in the curve as $\overline{w}$ hits $\overline{w}_{n-1}$, $\overline{w}_{n-2}$, ..., and so on, because different sets of constraints are binding before and after these points. $R(\overline{w})$ will continue to increase in a similar fashion until $\overline{w}$ hits α, beyond which $R(\overline{w})$ will drop to zero.

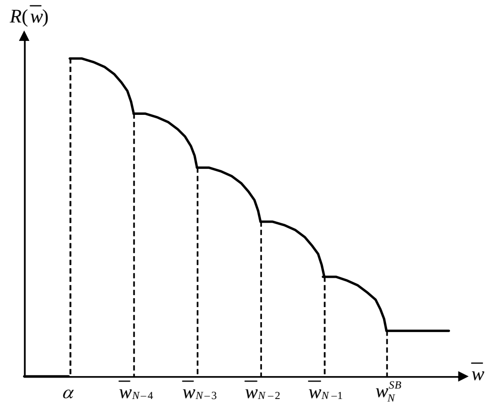

Figure 4.

In the empirical literature, Currie and McConnell [5] and Piekkola and Haaparanta [22] found a rather surprising *positive* relationship between the financial constraints faced by firms and the wage levels of their employees. Because it is natural to assume that more financially constrained firms should be more limited in paying employees bonuses, Proposition 1 offers a plausible explanation for these findings.

The result that the agent can benefit from the pay cap is specific to a particular type of principal-agent problem. In the current model, both (i) the trade-off between insurance provision and incentive provision, and (ii) the trade-off between limited-liability rent extraction and incentive provision are present. As the following result shows, the result holds only under (ii) but not under (i).

Proposition 2 *Suppose that there is no lower bound for the payments. The agent's rent will always be zero, no matter how low the pay cap is.*

Proof. See Appendix. ■

The result of Proposition 2 shows that the increased expected utility of the agent caused by the lowered pay cap should be viewed as augmented limited-liability rent because it depends crucially on the existence of a lower bound (i.e., the limited-liability constraint). In the literature, modeling the principal-agent problem as the trade-off between incentive provision and insurance provision, or the trade-off between incentive provision and limited-liability rent extraction, seems to have been viewed as an innocuous choice of modeling in applied works. In many models, one version is often chosen over the other without justifying its suitability for the given context. Our result highlights an important difference between the two versions that may qualitatively affect the results of applied models.

4.1 Limitations and Extensions

Assumption 1 helps deliver our result by ensuring that even the marginal agency cost of effort $C(\overline{w})$ increases as the upper bound $\overline{w}$ decreases, the marginal revenue of the effort $\sum_{i=1}^{N} P_i y_i - \sum_{i=1}^{N} p_i y_i$ always dominates and hence the principal will not prefer to distort the effort to zero, which causes the agent's expected payoff to drop to zero, as discussed after Assumption 1. If this assumption is relaxed, the result that the agent is better off with more stringent pay caps will hold for a smaller range of the parameter values $\overline{w}$.

One can imagine that this restrictive version of the result with effort distortion (from $e = 1$ to $e = 0$) can be extended to a model with more than two levels of effort as follows. As the upper bound decreases, the agent's expected utility increases for a interval of the upper bound (as the principal maintains the same effort) and then drops discontinuously to a certain level (as the principal distorts the effort downward by one level). This pattern may repeat several times until the expected utility of the agent drops to zero. This non-monotonicity between the upper bound and the agent's expected utility may also arise in the extreme case with continuous effort.

5 The Effect of Improved Contracting Information

In this section we try to further understand the agent's rent generated by the pay cap by analyzing its relationship with the quality of contracting information. For clarity, we focus on the special case of a *risk-neutral* agent. Let F denote the distribution function of the output when $e = 1$, and f be the corresponding probability mass function (i.e., $P_i = f(y_i)$ for $i = 1, \ldots, N$). Suppose that an improvement in the quality of information has the distribution function of the output when $e = 1$ become G, with $G(z) \leq F(z)$ for all $z \in \{y_1, \ldots, y_N\}$ and $G(z) < F(z)$ for some z. That is, we assume that the G first-order-stochastic strictly dominates F. Let $P_i' = g(y_i)$ for $i = 1, \ldots, N$, where g is the corresponding density function of G. Let $\mathbf{w} = (w_1, \ldots, w_N)$ be the optimal contract and $R = \sum_{i=1}^{N} P_i w_i - c$ the limited-liability rent when the distribution function is F. Let $\mathbf{w}' = (w_1', \ldots, w_N')$ be the optimal contract and $R' = \sum_{i=1}^{N} P_i' w_i' - c$ the limited-liability rent when the distribution function is G. In the literature of efficiency of signals in moral hazard, such as in Holmstrom [11], Grossman and Hart [9], and Kim [15], the general finding is that an increase in the informativeness of the principal's signal reduces the agency cost.[3]

The following proposition extends a version of this informativeness principle adopted to the framework with limited liability by Tirole [30] (p. 123, footnote 23) with the additional consideration of pay caps.

Proposition 3 *Given the assumption that the agent is risk-neutral, if the G first-order-stochastic strictly dominates F, then $R' < R$. In other words, an improvement in contracting information decreases the limited-liability rent of the agent.*

Proof. See Appendix. ■

In the following, we analyze how the improvement in contracting information affects the marginal cost of pay caps. To concentrate on the most instructive framework, we further specialize the model to focus on the case in which there are three output levels, y_i, $i \in \{1, 2, 3\}$. We also assume that $P_1 - p_1 < 0$, $P_2 - p_2 > 0$, and $P_3 - p_3 > 0$. This allows the rent of the agent to be written as

$$R = P_2 \left[\frac{c - (P_3 - p_3)\, \overline{w}}{P_2 - p_2} \right] + P_3 \overline{w}.$$

[3] Schmitz [27] made a case against monitoring based on the reason that the rent extraction may reduce the total surplus of the principal and agent. Demougin and Fluet [8] identified an exception to this situation by considering costly monitoring.

Although simple, this specialized setup is rich enough to encompass three representative types of improvement in information quality:

Case 1 *P_2 decreases to $P_2 - t$ and P_3 increases to $P_3 + t$.*

Case 2 *P_1 decreases to $P_1 - t$ and P_2 increases to $P_2 + t$*

Case 3 *P_1 decreases to $P_1 - t$ and P_3 increases to $P_3 + t$*

While improved contracting information always benefits the principal, the following result shows that lowering pay caps and improved information can be substitutes in some cases and complements in others.

Proposition 4 *When the quality of the contracting information improves in Case 1 and 3, the marginal cost of the pay cap ($-\frac{\partial R}{\partial \overline{w}}$) increases; when the quality of the contracting information improves in Case 2, the marginal cost of the pay cap ($-\frac{\partial R}{\partial \overline{w}}$) decreases.*

Proof. Under case 1, the limited-liability rent is

$$R_1 = (P_2 - t)\left[\frac{c - ((P_3 + t) - p_3)\,\overline{w}}{(P_2 - t) - p_2}\right] + (P_3 + t)\,\overline{w}.$$

Differentiating R_1 with respect to t and $\overline{w}$ gives

$$-\frac{\partial^2 R_1}{\partial t \partial \overline{w}} = \frac{-p_2\left[(P_2 - p_2) + (P_3 - p_3)\right]}{\left[(P_2 - t) - p_2\right]^2} > 0.$$

Under case 2, the limited-liability rent is

$$R_2 = (P_2 + t)\left[\frac{c - (P_3 - p_3)\,\overline{w}}{(P_2 + t) - p_2}\right] + P_3\overline{w}.$$

Differentiating R_2 with respect to t and $\overline{w}$ gives

$$-\frac{\partial^2 R_2}{\partial t \partial \overline{w}} = \frac{p_2\,(P_3 - p_3)}{[(P_2 + t) - p_2]^2} < 0.$$

Under case 3, the limited-liability rent is

$$R_3 = P_2\left[\frac{c - ((P_3 + t) - p_3)\,\overline{w}}{P_2 - p_2}\right] + (P_3 + t)\,\overline{w}.$$

Differentiating R_3 with respect to t and $\overline{w}$ gives

$$-\frac{\partial^2 R_3}{\partial t \partial \overline{w}} = \frac{-p_2}{P_2 - p_2} > 0.$$

■

Given the intuitive, positive role of improved contracting information shown in Proposition 3, it seems curious that improved information may increase the marginal cost of pay caps, as shown for Cases 1 and 3 in the previous result. The reason is that under these two cases, the improvement in contracting information makes output 3 more important and thus enhances the influence of pay caps. When contracting information improves in Case 2, the importance of high output decreases and the importance of output 2 increases. This alleviates the effect of pay caps.

6 Conclusion

By minimally extending the standard moral hazard model, we illustrate the effect of imposing a binding pay cap on incentive contracts. Contrary to the popular belief that pay caps penalize managers, we show that managers' expected utility can increase as the pay cap becomes more stringent. We characterize the effect of pay caps on the optimal contract and illustrate that the increased payoff of the agent is essentially the limited-liability rent augmented by the pay cap. We further examine the effect of improved contracting information on the cost of the pay cap and find that although improved contracting information always reduces the cost of the pay cap, it may increase the marginal cost of it. Our result should provide a new perspective for considering numerous issues discussed in the literature that arise under limited liability, such as monitoring in Demougin and Fluet [8] and Schmitz [27], task scheduling in Mylovanov and Schmitz [20], the form of optimal contract in Innes[12], Kim [16], and Poblete and Spulber [23], or performance standards in Sherstyuk [29].

Appendix

Proof of Lemma 1

Given Assumption 1, the first order conditions are

$$P_i - \lambda (P_i - p_i) u' (w_i) - \mu_i + \gamma_i = 0, \forall i \in \{1, \ldots, N\}, \tag{5}$$

$$\lambda \left[\sum_{i=1}^{N} (P_i - p_i) u (w_i) - c \right] = 0, \tag{6}$$

$$\mu_i w_i = 0, \forall i \in \{1, \ldots, N\}, \tag{7}$$

$$\gamma_i (w_i - \overline{w}) = 0, \forall i \in \{1, \ldots, N\}, \tag{8}$$

$$\mu_i \geq 0, \forall i \in \{1, \ldots, N\}, \tag{9}$$

$$\gamma_i \geq 0, \forall i \in \{1, \ldots, N\}, \tag{10}$$

and

$$\lambda \geq 0, \tag{11}$$

where λ, μ_i, and γ_i are the Lagrangian multipliers associated respectively with (IC), (LB), and (UB).

Note that Kuhn-Tucker conditions are necessary and sufficient here because problem (2) can be transformed into a convex programming problem simply by replacing $u(w_i)$ with u_i and w_i with $u^{-1}(u_i)$. With this transformation, the principal's objective function will be strictly convex and all of the constraints are linear. See Laffont and Martimort [17] (p. 158) for details.

In the following, we first prove that (IC) always binds in optimum. Next, we show that there exist two cut-off indexes, $\underline{i}$ and $\overline{i}$, that divide the optimal incentive scheme into three parts. Finally, we show that for each part of the optimal incentive scheme, the corresponding (in)equality holds.

If (IC) is slack, then $\lambda = 0$ by (6), and for those i such that $w_i > 0$ (the existence of such i is guaranteed by (IC) and (LB)), $\mu_i = 0$ by (7). It follows that for such i, $\gamma_i = -P_i < 0$ by (5), which contradicts (10).

We establish the existence of $\underline{i}$ and $\overline{i}$ through three simple observations.

Observation 1. $w_i = 0$ for all $i \in \left\{\widehat{i} \in \{1, \ldots, N\} \mid P_{\widehat{i}} - p_{\widehat{i}} < 0\right\}$. If $w_i > 0$ for such i, then $\mu_i = 0$ by (7). Consequently, $\lambda = (P_i + \gamma_i) / (P_i - p_i) u'(w_i) < 0$ by (5), which violates (11).

Observation 2. If $0 < w_i < \overline{w}$ for some i, then $w_j \geq w_i$ for all $j > i$. Since $0 < w_i < \overline{w}$, $\mu_i = \gamma_i = 0$ by (7) and (8). Consequently, $\lambda = P_i / (P_i - p_i) u'(w_i)$ by (5). If $w_j < w_i$ for some $j > i$, then $\gamma_j = 0$ by (8). It then follows that

$$\begin{aligned}
\mu_j &= P_j - \lambda (P_j - p_j) u'(w_j) \\
&= P_j - \frac{P_i}{(P_i - p_i) u'(w_i)} (P_j - p_j) u'(w_j) \\
&= \frac{(P_j P_i - P_j p_i) u'(w_i) - (P_j P_i - P_i p_j) u'(w_j)}{(P_i - p_i) u'(w_i)} \\
&< 0,
\end{aligned}$$

since $u''(\cdot) < 0$ and $P_j p_i > P_i p_j$ by (1). This contradicts (9).

Observation 3. If $w_i = \overline{w}$ for some i, then $w_j = \overline{w}$ for all $j > i$. Since $w_i = \overline{w}$, $\mu_i = 0$ by (7). Consequently, $\lambda = (P_i + \gamma_i) / (P_i - p_i) u'(\overline{w})$ by (5). If $w_j < \overline{w}$ for some $j > i$, then $\gamma_j = 0$ by (8). It then follows that

$$\begin{aligned}
\mu_j &= P_j - \lambda (P_j - p_j) u'(w_j) \\
&= P_j - \frac{P_i + \gamma_i}{(P_i - p_i) u'(\overline{w})} (P_j - p_j) u'(w_j) \\
&= \frac{(P_j P_i - P_j p_i) u'(\overline{w}) - (P_j P_i - P_i p_j) u'(w_j) - \gamma_i (P_j - p_j) u'(w_j)}{(P_i - p_i) u'(\overline{w})} \\
&< 0,
\end{aligned}$$

since $u''(\cdot) < 0$, $P_j p_i > P_i p_j$ and $P_j - p_j \geq 0$ by (1), $\gamma_i \geq 0$ by (10). This contradicts (9).

Observation 1 indicates that there is at least one $w_i = 0$, and (IC) and (LB) ensure that there is at least one level i such that $w_i > 0$ in the optimal incentive scheme. Thus, Observations 2 and 3 imply that there exists a cut-off index $\underline{i}$ such that $w_i = 0$ for all $i \leq \underline{i}$ and $w_i > 0$ for all $i > \underline{i}$. When the upper bound binds, i.e., $\overline{w} \leq w_N^{SB}$, Observation 3 implies that there exists a cut-off index $\overline{i} \geq \underline{i}$ such that $w_i = \overline{w}$ for all $i > \overline{i}$ and $w_i < \overline{w}$ for all $i \leq \overline{i}$.[4]

Furthermore, for all $i \leq \underline{i}$, $w_i = 0$, and therefore $\gamma_i = 0$ by (8). It follows that $\mu_i = P_i - \lambda (P_i - p_i) u' (0)$ by (5). Consequently, $(P_i - p_i) u' (0) / P_i \leq 1/\lambda$ by (9). For all $\underline{i} < i \leq \overline{i}$, $0 < w_i < \overline{w}$, and hence $(P_i - p_i) u' (w_i) / P_i = 1/\lambda$ by (5), (7), and (8). For all $i > \overline{i}$, $w_i = \overline{w}$, and therefore $\mu_i = 0$ by (7). It follows that $\gamma_i = \lambda (P_i - p_i) u' (\overline{w}) - P_i$ by (5). As a result, $(P_i - p_i) u' (\overline{w}) / P_i \geq 1/\lambda$ by (10).

Proof of Lemma 2

According to Lemma 1,

$$(P_i - p_i) u' (w_i^*) \lambda = P_i \tag{12}$$

for all of those output levels i with an interior-solution payment, i.e., for all $\underline{i} < i \leq \overline{i}$. The right-hand-side of (12) can be viewed as the marginal cost of raising w_i because one unit of it increases the minimized cost by P_i, and the left-hand-side of (12) can be viewed as the marginal benefit of raising w_i because one unit of it eases the restriction on the IC constraint by $(P_i - p_i) u' (w_i^*) \lambda$, where λ is the shadow price of the IC constraint. If λ increases as $\overline{w}$ decreases, w_i^* also has to increase to maintain

[4] When the upper bound does not bind, i.e., $\overline{w} > w_N^{SB}$, $\overline{i} = N$.

the equality in (12). This means that the w_i^* for some high level $i \leq \bar{i}$ may hit the new upper bound, causing $\bar{i}$ to decrease, and the w_i^* for some low level $i \leq \underline{i}$ may become positive, causing $\underline{i}$ to decrease. Thus, to show (4), it suffices to show that $\lambda'' > \lambda'$, where λ'' and λ' are the Lagrangian multipliers for (IC) when the levels of upper bounds are $\overline{w}''$ and $\overline{w}'$ respectively, reflecting that the IC constraint becomes more stringent as $\overline{w}$ decreases from $\overline{w}'$ to $\overline{w}''$. In the following, we establish that neither $\lambda'' = \lambda'$ nor $\lambda'' < \lambda'$ can be optimal.

If $\lambda'' = \lambda'$, then $\underline{i}'' = \underline{i}'$ and $\bar{i}'' \leq \bar{i}'$ according to Lemma 1. Thus, we have $w_i'' = w_i'$ for $i = 1, \ldots, \bar{i}''$ and $w_i' > w_i'' = \overline{w}''$ for $i \in \left\{ \widehat{i} \mid \widehat{i} > \bar{i}'' \text{ and } w_{\widehat{i}}' > \overline{w}'' \right\}$. In addition, Lemma 1 indicates that (IC) always binds; hence, to keep (IC) binding, there must be some $i \in \left\{ \widehat{i} \mid \widehat{i} > \bar{i}'' \text{ and } w_{\widehat{i}}' < \overline{w}'' \right\}$ such that w_i increases to $\overline{w}''$. However, for those w_i that increase to $\overline{w}''$,

$$\frac{1}{\lambda''} = \frac{1}{\lambda'} = \frac{P_i - p_i}{P_i} u'\left(w_i'\right) > \frac{P_i - p_i}{P_i} u'\left(\overline{w}''\right),$$

which cannot be optimal according to Lemma 1.

If $\lambda'' < \lambda'$, we have $\underline{i}'' \geq \underline{i}'$, while $\bar{i}''$ can be less than, equal to, or larger than $\bar{i}'$. First, consider the case in which $\bar{i}'' \geq \bar{i}'$. In this case, $w_i' = w_i'' = 0$ for $i = 1, \ldots, \underline{i}'$, $w_i' > w_i'' = 0$ for $i = \underline{i}' + 1, \ldots, \underline{i}''$, $w_i' > w_i'' > 0$ for $i = \underline{i}'' + 1, \ldots, \bar{i}'$, $w_i' = \overline{w}' > \overline{w}'' > w_i''$ for $i = \bar{i}' + 1, \ldots, \bar{i}''$, and $w_i' = \overline{w}' > \overline{w}'' = w_i''$ for $i = \bar{i}'' + 1, \ldots, N$. As w_i'' is either equal to or strictly less than w_i' for all i, (IC) cannot bind in this scenario.

Next, consider the case in which $\bar{i}'' < \bar{i}'$. In this case, $w_i' = w_i'' = 0$ for $i = 1, \ldots, \underline{i}'$, $w_i' > w_i'' = 0$ for $i = \underline{i}' + 1, \ldots, \underline{i}''$, $w_i' > w_i'' > 0$ for $i = \underline{i}'' + 1, \ldots, \bar{i}''$, and $w_i' > w_i'' = \overline{w}''$

for $i \in \left\{\widehat{i} \mid \widehat{i} > \overline{i}'' \text{ and } w'_{\widehat{i}} > \overline{w}''\right\}$. Therefore, to keep (IC) binding, there must be some $i \in \left\{\widehat{i} \mid \widehat{i} > \overline{i}'' \text{ and } w'_{\widehat{i}} < \overline{w}''\right\}$ that $w_i$increases to $\overline{w}''$. However, for such i,

$$\frac{1}{\lambda''} > \frac{1}{\lambda'} = \frac{P_i - p_i}{P_i} u'\left(w'_i\right) > \frac{P_i - p_i}{P_i} u'\left(\overline{w}''\right),$$

which cannot be optimal according to Lemma 1.

Proof of Proposition 1

If $\alpha \leq \overline{w} \leq w_N^{SB}$, the IC constraint will always bind (according to Lemma 1) and Lemma 2 applies. In this case, consider $\overline{w}'' < \overline{w}'$, and let $\mathbf{w}'' \equiv (w''_1, \ldots, w''_N)$ and $\mathbf{w}' \equiv (w'_1, \ldots, w'_N)$ denote the optimal contracts when the upper bounds are $\overline{w}''$ and $\overline{w}'$, respectively. From Lemma 2, we know that there exists an index value i_0 such that $w''_i \geq w'_i$ for $i = \underline{i}'' + 1, \ldots, i_0$, and $w''_i < w'_i$ for $i = i_0 + 1, \ldots, N$. Given the strict concavity of $u(\cdot)$, the solution is unique (Grossman and Hart [9]) and hence $\overline{w}'' < \overline{w}'$ implies that $\sum_{i=1}^N P_i w''_i > \sum_{i=1}^N P_i w'_i$. This implies that there exists a vector $\left(w^*_{\underline{i}''+1}, \ldots, w^*_{i_0}\right)$ such that $w'_i \leq w^*_i \leq w''_i$ for $i = \underline{i}'' + 1, \ldots, i_0$, where both the first and second inequalities are strict for at least some i, and

$$\sum_{i=1}^{\underline{i}''} P_i w''_i + \sum_{i=\underline{i}''+1}^{i_0} P_i w^*_i + \sum_{i=i_0+1}^{N} P_i w''_i = \sum_{i=1}^{N} P_i w'_i. \tag{13}$$

That is, we can construct a compensation structure

$$\mathbf{w}^* \equiv \left(w''_1, \ldots, w''_{\underline{i}''}, w^*_{\underline{i}''+1}, \ldots, w^*_{i_0}, w''_{i_0+1}, \ldots, w''_N\right)$$

with the same mean as $\mathbf{w}'$.

Let F and G denote the distribution functions of the payment given $\mathbf{w}'$ and $\mathbf{w}^*$, respectively, and $e = 1$. It is clear that

$$F(z) - G(z) \geq (\leq)\, 0 \text{ when } z \leq (\geq)\, w^*_{i_0}, \tag{14}$$

that is, the difference between F and G satisfies the single crossing property. It follows from (13) and (14) that the potential payment received by the agent under $\mathbf{w}'$ is a mean-preserving spread of that under $\mathbf{w}^*$, and hence $\sum_{i=1}^{N} P_i u(w^*_i) \geq \sum_{i=1}^{N} P_i u(w'_i)$ (according to Rothschild and Stiglitz [25]). Therefore, the change from $\mathbf{w}'$ to $\mathbf{w}^*$ constitutes the forced insurance effect that makes the agent better off.

In addition, $w''_i - w^*_i \geq 0$ by construction and $\mathbf{w}'' - \mathbf{w}^*$ represents the rent surrendering effect (and hence $\sum_{i=1}^{N} P_i u(w''_i) > \sum_{i=1}^{N} P_i u(w^*_i)$). Hence, it is clear that the overall change from $\mathbf{w}'$ to $\mathbf{w}''$ also makes the agent better off. More specifically,

$$R'' \equiv \sum_{i=1}^{N} P_i u(w''_i) - c > \sum_{i=1}^{N} P_i u(w^*_i) - c \geq \sum_{i=1}^{N} P_i u(w'_i) - c \equiv R',$$

where R'' and R' represent the agent's rents when the upper bounds are $\overline{w}''$ and $\overline{w}'$, respectively.

If $\overline{w} > w^{SB}_N$, the pay cap does not have any impact and hence the expected utility of the agent will not vary with $\overline{w}$. On the other hand, if $\overline{w} < \alpha$, then the principal will choose to implement $e = 0$ and hence leave no rent for the agent.

Proof of Proposition 2

When there is no lower bound for payments, the principal's cost-minimizing problem is

$$\min_{(w_1,\ldots,w_N)} \sum_{i=1}^{N} P_i w_i, \tag{U}$$

subject to (IC), (IR), and (UB). The first-order conditions of problem U are (6), (8), (10), (11), and

$$P_i - \lambda \left(P_i - p_i\right) u'(w_i) - \nu P_i u'(w_i) + \gamma_i = 0, \forall i \in \{1, \ldots, N\}, \tag{15}$$

$$\nu \left[\sum_{i=1}^{N} P_i u\left(w_i\right) - c \right] = 0,$$

$$\nu \geq 0,$$

where ν is the Lagrangian multiplier associated with (IR). Rearranging the terms in (15) yields $\left(P_i + \gamma_i\right)/u'(w_i) = \lambda \left(P_i - p_i\right) + \nu P_i$. Summing over i generates

$$\sum_{i=1}^{N} \frac{P_i + \gamma_i}{u'(w_i)} = \lambda \left(\sum_{i=1}^{N} P_i - \sum_{i=1}^{N} p_i \right) + \nu \sum_{i=1}^{N} P_i = \nu > 0,$$

which implies that (IR) is binding, or, in other words, the agent cannot capture any rent in the absence of lower bound for payments.

Proof of Proposition 3

Since the G first-order-stochastic strictly dominates F, and w_i is increasing in i, we know that $\sum_{i=1}^{N} P_i' w_i > \sum_{i=1}^{N} P_i w_i$. Using the fact that (IC) is binding in optimum, we immediately obtain

$$\sum_{i=1}^{N} P_i' w_i - c > \sum_{i=1}^{N} P_i w_i - c = \sum_{i=1}^{N} p_i w_i. \tag{16}$$

(16) indicates that $\mathbf{w}' \neq \mathbf{w}$, because otherwise (IC) cannot bind.

After ruling out the possibility that $\mathbf{w}' = \mathbf{w}$, only two cases remain to be considered: case 1. $w_i' \geq w_i$ for all i, and the inequality is strict for some i; and case 2. $w_i' \leq w_i$ for all i, and the inequality is strict for some i. To see why, let $\underline{i}_d$ and $\overline{i}_d$ respectively denote the lower and upper cut-off indexes when the probability mass function is $d = f, g$, and recall that when the agent is risk-neutral, either $\overline{i}_d = \underline{i}_d$ or $\overline{i}_d = \underline{i}_d + 1$ for $d = f, g$. This means that we can rule out the possibilities that $\underline{i}_f < \underline{i}_g \leq \overline{i}_g < \overline{i}_f$ and $\underline{i}_g < \underline{i}_f \leq \overline{i}_f < \overline{i}_g$, and the remaining possibilities consist of case 1 and case 2. If $\underline{i}_g \leq \underline{i}_f$, $\overline{i}_g \leq \overline{i}_f$, and at least one of the inequalities is strict, then case 1 arises. If $\underline{i}_g \geq \underline{i}_f$, $\overline{i}_g \geq \overline{i}_f$, and at least one of the inequalities is strict, then case 2 arises. If $\underline{i}_g = \underline{i}_f$, $\overline{i}_g = \overline{i}_f$, and $\overline{i}_d = \underline{i}_d$ for $d = f, g$, then $\mathbf{w}' = \mathbf{w}$, which cannot be optimal as shown above. If $\underline{i}_g = \underline{i}_f$, $\overline{i}_g = \overline{i}_f$, and $\overline{i}_d = \underline{i}_d + 1$ for $d = f, g$, then either case 1 or case 2 arises, because otherwise $\mathbf{w}' = \mathbf{w}$.

If case 1 arises, then

$$\begin{aligned}
\sum_{i=1}^{N} \left(P_i' - p_i\right) w_i' - c &> \sum_{i=1}^{N} \left(P_i' - p_i\right) w_i - c \\
&> \sum_{i=1}^{N} \left(P_i - p_i\right) w_i - c \\
&= 0,
\end{aligned}$$

where the second inequality and the third equality are due to (16), and the first inequality holds because for those i such that $w_i' > w_i$, it must be that $P_i' - p_i > 0$. Case 1 thus cannot arise in optimum, because otherwise (IC) will be slack.

Therefore, $w_i' \leq w_i$ for all i, and the inequality is strict for some i at the optimum. Hence,

$$R' = \sum_{i=1}^{N} P_i' w_i' - c = \sum_{i=1}^{N} p_i w_i' < \sum_{i=1}^{N} p_i w_i = \sum_{i=1}^{N} P_i w_i - c = R.$$

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