Team Incentives for Managing Competition*

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This Draft: June 12, 2008

Abstract

Players in contests put forth their efforts not only to win but also not to lose. Incentives in contests are earning a winner’s gain and avoiding a loser’s loss as well. This paper explores the implications of such different incentives in competition. The nature of competition can be either offensive or defensive depending on the relative size of the winner’s gain to the loser’s loss. In addition, the winner’s gain and loser’s loss influence contestants’ equilibrium effort levels through different channels. While the loser’s loss always boosts up players’ efforts, but the winner’s gain has not only the encouraging effect but also the discouraging effect. This appealing feature allows us to analyze the optimal combination between team incentives and competition incentives in the principal’s problem to induce agents’ optimal effort levels. The proportion of team incentives relative to competition incentives should be increasing in the equilibrium probability that agents accomplish their tasks. Furthermore, when the collusive cooperation between team members is possible, the principal may prefer to put more weights on team incentives as providing the collaborative work environments.

JEL Classification: J3, J4, L1, L2

Keywords: Contest, principal-agent model, strategic complements, strategic substitutes, team incentives, competition incentives, relative or joint performance evaluation

*I am deeply grateful to my advisor, Jay Pil Choi, for his guidance and support. I would like to thank Carl Davidson and participants at the Canadian Economic Association, INFORMS Marketing Science, Midwest Economic Association conference for their helpful discussion.

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1. Introduction

Many types of competition have been analyzed based on contest models. R&D races, lobbying battles, political campaigns, and litigations are typical examples. Obviously, incentives to put forth efforts or to invest in these contests is winning a prize. However, there is another crucial incentive which has been often neglected in the previous literature. Players make efforts not only to win but also not to lose in contests.

At first sight, winning seems to be another expression of not losing. Yet, in terms of incentives, the loser’s loss could be distinguished from the winner’s gain. For example, a firm invests in innovation to earn the winner’s gain when its rival does not succeed in making the innovation. It also invests to avoid the loser’s loss when its rival succeeds. The winner’s gain does not need to be equal to the loser’s loss. For a particular game, to be a winner is more important concern to players than not to be a loser. For another type of game, not to be a loser is more important than to be a winner. I will refer to the former type of game as an offensive game and the latter as a defensive game.¹

This paper begins by exploring some implications of such different incentives in competition. First, incentives to do efforts are represented by a weighted average of winner’s gain and loser’s loss. Then I will show that the type of competition depends on the relative size of winner’s gain to loser’s loss in the sense that the task, assignment, or innovation for which players are working can be strategic complements or strategic substitutes.² The tasks are strategic complements in defensive games where not losing is more important than winning. Conversely, the tasks are strategic substitutes in offensive games where winning is more important than not losing.

Second, the winner’s gain and loser’s loss influence contestants’ equilibrium effort levels differently. While the loser’s loss always boosts up players’ equilibrium efforts, but the winner’s gain has both encouraging and discouraging effects on efforts. Thus the winner’s gain and loser’s loss has the different marginal effect on the equilibrium effort levels. The ratio of marginal effects of the loser’s loss to the winner’s gain is increasing in the equilibrium probability.

¹The game in which the loser’s penalty is enormous can be thought of as the defensive game. Likewise, the game in which the winner’s prize is huge is the offensive game. For example, the Ph. D. qualifying exam is more likely the defensive game because one who does not pass the exam is kicked out of the program. On the other hand, the third year paper contest may be the offensive game because the faculty committee selects the best paper while everyone pass the contest as long as one presents one’s paper.

²Bulow et al. (1985) defined strategic substitutes and complements by whether a more aggressive strategy by the player A lowers or raises the player B’s marginal profits.
On the basis of these findings, the novel issue to be considered is a principal or contest designer’s problem to maximize her expected revenue through inducing players’ optimal effort levels, which depends on a wage scheme. In this section, I will interpret the winner’s gain and loser’s loss differently. The winner’s gain is equivalent to competition incentives which rewards an employee who performs better than his peers. Rather, the loser’s loss is comparable to team incentives which rewards the team when every team member performs well.\footnote{The meaning of "team" is not always clearly defined in most papers. Holmstrom (1982) defines it as "a group of individuals who are organized so that their productive inputs are related". But, the team in this paper can be thought of, in more broad sense, as a group of individuals who works for the same principal.}

I find that the principal provides both team and competition incentives to players. In particular, the proportion of team incentives relative to competition incentives should be increasing in the equilibrium probability that players accomplish their tasks. In other words, she provides team incentives more as players are relatively capable or the assignment is very important. Ironically, team incentives should be more weighted as players put forth more competitive efforts. This striking result suggests the underlying reason why too much competition within a group should be managed by providing team incentives.

This result is contrasting, and unique, to the literature. There are some papers that address the team incentive scheme as a principal’s optimal strategy. Teamwork in Itoh (1991), peer pressure in Kandel and Lazear (1992), and long-term relationship in Che and Yoo (2001) explain the rationale for team incentives. Compared to these papers, I discover another important reason for which team incentives should be provided. Competition incentives has the discouraging effect which increases in the equilibrium probability of success. Therefore the relative importance of team incentives to competition incentives becomes greater as players make more efforts.

It is worthwhile to emphasize what is the technical difference in my model from the related literature on this issue. The key difference is that the incentive compatibility (IC) constraint in this paper is the equilibrium competition condition between players, while most principal-agent models with multi-agents are based on the framework with two-state and two-action. This popular approach is not able to analyze how competition between agents is characterized and how some strategic interactions between agents affect the principal’s problem.

In this line of inquiry, I will show that the principal may raise the proportion of team incentives.
tives when the strategic interaction between players are allowed. First, I study whether collusive cooperation between team members is compatible with the principal’s interest. She prefers to allow players to cooperate if team incentives are greater than competition incentives, and vice versa. Therefore team incentives should be more weighted with providing the collaborative work environments.

Second, I study how the players’ choice of timing of actions affects competition. When players are allowed to choose the order of moves to be a leader or a follower, the offensive game becomes a simultaneous move game, while the defensive game becomes a sequential move game. In particular, players exert more efforts by moving sequentially in the defensive game, given the wage scheme. This is the case that team incentives are greater than competition incentives. Thus the principal may choose more proportion of team incentives to take advantage of the effect of players’ strategic precommitment.

The remainder of the paper is organized in the following way. Section 2 provides the basic model. In Section 3, I analyze the principal’s problem. Section 4 extends the model by incorporating players’ collusive cooperation. Section 5 studies another strategic interaction between players, which is endogenous choice of moves. Section 6 discuss applications such as joint liability group lending and joint patent system. Finally, in Section 7, concluding remarks follow.

2. Incentives in Contests: To be a Winner or Not to be a Loser

There are two players, or agents, A and B. Each player is given a task to complete. The outcome of this task can be either success or failure. The probabilities of success are \( p(I_A) \) and \( p(I_B) \), where \( I_A \) and \( I_B \) are the effort levels of A and B respectively. Two players are symmetric in that they have an identical probability function. I assume that the probability functions are concave; the probability is increasing in one’s efforts at decreasing rates, i.e., \( p'(I_i) > 0 \) and \( p''(I_i) < 0 \). This concavity ensures the existence of equilibrium. I assume also the following inequality for global stability and uniqueness of equilibrium.\(^4\)

\[
\left( \frac{\partial^2 V_A}{\partial I_A^2} \right) \left( \frac{\partial^2 V_B}{\partial I_B^2} \right) > \left( \frac{\partial^2 V_A}{\partial I_A \partial I_B} \right) \left( \frac{\partial^2 V_B}{\partial I_A \partial I_B} \right). \]

That is, the slope of firm A’s reaction curve is greater than that of firm B’s.

\(^4\)This is a sufficient condition for the following stability condition, \( \left( \frac{\partial^2 V_A}{\partial I_A^2} \right) \left( \frac{\partial^2 V_B}{\partial I_B^2} \right) > \left( \frac{\partial^2 V_A}{\partial I_A \partial I_B} \right) \left( \frac{\partial^2 V_B}{\partial I_A \partial I_B} \right) \).
As a result of efforts, four different situations can occur; both players succeed with probability \( p(I_A)p(I_B) \), the player \( A \) succeeds but the player \( B \) fails with \( p(I_A)(1 - p(I_B)) \), the player \( B \) succeeds but the player \( A \) fails with \( (1 - p(I_A))p(I_B) \), and neither player succeeds with \( (1 - p(I_A))(1 - p(I_B)) \). Corresponding payoffs of the player \( A \) and \( B \) will be represented by \( (v^S, v^S), (v^W, v^L), (v^L, v^W) \), and \( (v^O, v^O) \). The player \( A \)'s maximization problem can be written as follows.

\[
\begin{align*}
\max_{I_A} \quad & V_A = p(I_A)p(I_B)v^S + p(I_A)(1 - p(I_B))v^W \\
& + (1 - p(I_A))p(I_B)v^L + (1 - p(I_A))(1 - p(I_B))v^O - I_A
\end{align*}
\]

The player chooses the effort levels to maximize one’s expected payoffs. The first-order condition for a maximum is given by

\[
p'(I_A) \left[ p(I_B)\Delta^{SL} + (1 - p(I_B))\Delta^{WO} \right] - 1 = 0,
\]

where \( \Delta^{SL} = (v^S - v^L) \) and \( \Delta^{WO} = (v^W - v^O) \). This equation shows that incentives to make efforts depend on two terms, \( \Delta^{SL} \) and \( \Delta^{WO} \), given the other player’s effort levels. \( \Delta^{SL} \) represents the net loss that a loser must bear when one’s rival succeeds, while \( \Delta^{WO} \) indicates the net gain that a winner can earn when one’s rival fails. I will often call \( \Delta^{SL} \) the loser’s loss and \( \Delta^{WO} \) the winner’s gain. Incentives are not simply measured by the prize accruing to the winner, i.e., its post-success payoffs. When the rival succeeds, not being a loser is the main incentive. When the rival fails, being a winner is the main incentive. After all, incentives in the contest are represented by a weighted average of the loser’s loss and the winner’s gain.

The loser’s loss and winner’s gain do not need to be equal. The relative size of one to the other depends on a particular type of game. I will refer to an offensive game as the one where the winner’s gain is greater than the loser’s loss. Likewise, the game in which the loser’s loss is greater than the winner’s gain will be called a defensive game.

Before finding a Nash equilibrium, let us see the slope of reaction functions. Totally differ-
entiating equation (1), we get
\[ \frac{dI_B}{dI_A} = \frac{-p''(I_A)(p(I_B)\Delta^{SL} + (1 - p(I_B))\Delta^{WO})}{p'(I_A)p'(I_B)(\Delta^{SL} - \Delta^{WO})}. \] (2)

The numerator is negative by the second-order condition. Hence the sign of the slope of reaction functions is determined by the sign of $\Delta^{SL} - \Delta^{WO}$ in the denominator. This implies that the tasks can be strategic complements and strategic substitutes. The cutoff criteria is whether the winner’s gain is greater than or smaller than the loser’s loss.

**Proposition 1** If the loser’s loss is greater than the winner’s gain ($\Delta^{SL} > \Delta^{WO}$, defensive game), the tasks are strategic complements. Conversely, if the winner’s gain is greater than the loser’s loss ($\Delta^{SL} < \Delta^{WO}$, offensive game), the tasks are strategic substitutes.

Now, through well-known oligopoly models, I provide some examples to show different types of competition in which being a winner is more important than not being a loser, and vice versa. I consider the case that firms conduct cost reducing innovations, which reduces production costs from $c$ to $c - \lambda$. Then, in examples below, both $\Delta^{WO}$ and $\Delta^{SL}$ are functions of $\lambda$, i.e., $\Delta^{WO}(\lambda)$ and $\Delta^{SL}(\lambda)$.

**Example 1.** (Cournot Model) Let us consider an oligopoly market with a linear demand $Q(p) = a - p$. When firms involve the process innovation as described above, the corresponding profits for each case are given by $\pi^S = \frac{(a - c + \lambda)^2}{9}$, $\pi^W = \frac{(a - c + 2\lambda)^2}{9}$, $\pi^L = \frac{(a - c - \lambda)^2}{9}$, and $\pi^O = \frac{(a - c)^2}{9}$. The loser’s loss and winner’s gain are calculated easily as $\Delta^{SL} = \frac{2}{9}(a - c)\lambda$ and $\Delta^{WO} = \frac{1}{9}(a - c + \lambda)\lambda$. Note $\Delta^{SL} - \Delta^{WO} = -\frac{4}{9}\lambda^2 < 0$. In the simple Cournot model with a linear demand and constant marginal costs, in R&D competition, firms play the offensive game in which to win is more important than not to lose.

**Example 2.** (Perfect Complements) Consider the case that two goods form a system as perfect complements. A consumer type $x \in (-\infty, 0]$ has a valuation of $V - p_A - p_B + x$ for the system. This generates the following profit function, $\pi_i = (p_i - c)(V - p_i - p_j)$. Firms have the same chance of process innovation which can reduce production costs. Then we find
\[ \pi_S = \left( \frac{V - 2(c - \lambda)}{3} \right)^2, \quad \pi_W = \pi_L = \left( \frac{V - 2c + \lambda}{3} \right)^2, \quad \pi_O = \left( \frac{V - 2c}{3} \right)^2. \] Note that the winner’s profits equal the loser’s profits \((\pi_W = \pi_L)\) by externalities in the case of perfect complement. The benefit of innovation is equally shared by two firms. This yields \(\Delta^{SL} - \Delta^{WO} = \frac{2}{9} \lambda^2 > 0\), where \(\Delta^{SL} = \frac{3 \lambda^2 + 2 \lambda (V - 2c)}{9}\) and \(\Delta^{WO} = \frac{\lambda^2 + 2 \lambda (V - 2c)}{9}\). Firms providing complements play the defensive game in which not losing is more important than winning.

**Example 3.** (Hotelling Model) Suppose that a consumer is indexed by \(\theta \in [\underline{\theta}, \bar{\theta}]\), where \(\underline{\theta} = -\bar{\theta} < 0\). The \(\theta\) represents a consumer’s relative preferences for the product \(B\) over \(A\). Consumers are distributed by cumulative distribution function \(F\) over \(\theta\). We assume \(F\) is symmetric about zero and the monotone hazard rate \(\frac{f(\theta)}{1 - F(\theta)}\) is strictly increasing in \(\theta\).\(^5\) In this simple model, consumers \(\theta < \bar{\theta} = p_B - p_A\) choose to buy \(A\), whereas consumers \(\theta \geq \bar{\theta}\) choose \(B\). Then the profit function of each firm is given by \(\pi_A = (p_A - c) F(\bar{\theta})\) and \(\pi_B = (p_B - c)(1 - F(\bar{\theta}))\) respectively. It is easy to show that the symmetric outcome of the Hotelling model displays \(\pi^S = \pi^O = \frac{F(0)^2}{f(0)} = \frac{1}{4f(0)}\). On the other hand, when only one firm, say the firm \(A\), succeeds, profit functions are written by \(\pi_A = (p_A - c - \lambda) F(\bar{\theta})\) and \(\pi_B = (p_B - c)(1 - F(\bar{\theta}))\). Each firm’s reaction function is \(p_A(p_B) = (c - \lambda) + \frac{F(\bar{\theta})}{f(\theta)}\) and \(p_B(p_A) = c + \frac{1 - F(\bar{\theta})}{f(\theta)}\) respectively. The solution must satisfy \(\theta^* = p_B - p_A = \lambda + \frac{1 - 2F(\theta^*)}{f(\theta^*)}\). With this equilibrium condition, we can represent \(\pi^W = \frac{F(\theta^*)^2}{f(\theta^*)}\) and \(\pi^L = \frac{(1 - F(\theta^*))^2}{f(\theta^*)}\), whose sign depends on the distribution of consumers. They play the defensive game when \(f(0)\) is sufficiently small as in an inverse Normal-shaped distribution. Otherwise, they play the offensive game. In this example, it should be noted that innovations can be strategic complements or strategic substitutes regardless of whether products are strategic complements or strategic substitutes.

**Example 4.** (Entry Game) Suppose that there is a monopolist in the market with a potential entrant. In order to enter the market, the entrant must be a sole winner in R&D competition to cover large fixed costs, \(K\). That is, I consider \(\frac{(a - c + \lambda)^2}{9} < K < \frac{(a - c + 2 \lambda)^2}{9}\). The entrant’s profits are \(\pi_E^W = \frac{(a - c + 2 \lambda)^2}{9} - K\) and \(\pi_E^S = \pi_E^L = \pi_E^O = 0\). The incumbent’s corresponding profits are

\(^5\)The symmetry of \(F\) then implies that the reverse hazard rate \(\frac{f(\theta)}{1 - F(\theta)}\) is strictly decreasing in \(\theta\). This assumption, together with the increasing hazard rate, ensures nice demand curves. More precisely, the second-order conditions are always satisfied in both firms’ profit maximization problem.

\(^6\)This type of analysis with non-uniform distributions in the Hotelling model is thoroughly studied by my working paper, Kim (2007).
The player $B$’s maximization problem yields the symmetric first-order condition with equation (1). Given that the model is symmetric and the condition for global stability is met, we have $I^* = I^*_A = I^*_B$ in equilibrium satisfying

$$\frac{1}{p'(I^*)} = p(I^*)\Delta^{SL} + (1 - p(I^*))\Delta^{WO}. \hspace{1cm} (3)$$

Equilibrium effort levels are represented in Figure 1. Note, importantly, that $\Delta^{SL}$ and $\Delta^{WO}$ affect the equilibrium effort levels differently. $\Delta^{SL}$ raises the slope of the right-hand term. So equilibrium efforts are increasing in $\Delta^{SL}$. On the other hand, interestingly, the increase in $\Delta^{WO}$ raises equilibrium efforts through lifting the intercept, but reduces them by lowering the slope. Put it differently, the increase in the winner’s gain not only encourages players to do efforts but also discourages them.

The intuition to understand this result is as follows. Note that the player can obtain
\(\Delta^{WO}\) when he succeeds and the rival fails. As \(\Delta^{WO}\) grows, the rival makes more efforts, and accordingly raising the probability of the rival’s achievement. In turn, this lessens the player’s probability of realizing the winner’s gain. Hence the direct effect of winner’s gain is positive, but the indirect effect is negative.\(^7\)

One natural question at this point would be which factor has a stronger effect on players’ equilibrium level of efforts. Using the implicit function theorem to equation (3), we obtain

\[
\frac{\partial I^*}{\partial \Delta^{SL}} = - \frac{p'(I^*)p(I^*)}{[(p''(I^*)p(I^*) + (p'(I^*))^2)(\Delta^{SL} - \Delta^{WO}) + p''(I^*)\Delta^{WO}]} \tag{4}
\]

and

\[
\frac{\partial I^*}{\partial \Delta^{WO}} = - \frac{p'(I^*)(1 - p(I^*))}{[(p''(I^*)p(I^*) + (p'(I^*))^2)(\Delta^{SL} - \Delta^{WO}) + p''(I^*)\Delta^{WO}].} \tag{5}
\]

The denominator is negative regardless of the sign of \(\Delta^{SL} - \Delta^{WO}\). \((p''(I^*)p(I^*) + (p'(I^*))^2)\) is negative by the stability condition. If \(\Delta^{SL} - \Delta^{WO}\) is a large negative number, there may be a possibility of having a positive denominator. But this violates the second-order condition. If we rearrange the denominator in terms of the second-order condition, we get \(p''(I^*)p(I^*)\Delta^{SL} + (1 - p(I^*))\Delta^{WO} + (p'(I^*))^2(\Delta^{SL} - \Delta^{WO}).\) For this to be positive, \(\Delta^{SL} - \Delta^{WO}\) must be a large positive number. This means that the denominator is always negative as long as both the stability condition and the second-order condition are satisfied.

Hence, by comparing \(\frac{\partial I^*}{\partial \Delta^{SL}}\) to \(\frac{\partial I^*}{\partial \Delta^{WO}}\), we find that the loser’s loss has a higher marginal effect on players’ equilibrium effort levels than the winner’s gain if the probability of success is greater than \(1/2\), and vice versa. That is to say, a stick (loser’s loss) is better motivator than a carrot if players are more likely to succeed. Conversely, a carrot (winner’s gain) is a better motivator if players are less likely to succeed. More importantly, note how the ratio of marginal effects is changing.

**Proposition 2** \(\frac{\partial \Delta^{WO}}{\partial \Delta^{SL}} \big|_{I^*} = \frac{\partial I^*}{\partial \Delta^{SL}} / \frac{\partial I^*}{\partial \Delta^{WO}} = \frac{p'(I^*)}{1 - p(I^*)}.\) The ratio of marginal effects of the loser’s loss to the winner’s gain is increasing in the equilibrium probability \(p(I^*)\).

As the probability of accomplishing the task increases, the discouraging effect of the winner’s

\(^7\)In this stochastic model, the positive effect is always greater than the negative effect because the probability functions are nondecreasing. See equation (5).
gain becomes larger. On the contrary, the loser’s loss strengthens players’ beliefs on each other’s success.

3. Optimal Team and Competition Incentives

3.1 Preliminaries

Before analyzing the principal’s problem, I will discuss some preliminary results. Now let \( v = (v^S, v^W, v^L, v^O) \) describe the wages that the principal offers to players in each situation. I assume that the principal cannot impose negative wages on players.

Following the literature, I define a wage scheme \( v \) exhibits joint performance evaluation (JPE) if \((v^S, v^L) > (v^W, v^O)\), independent performance evaluation (IPE) \((v^S, v^L) = (v^W, v^O)\), and relative performance evaluation (RPE) if \((v^S, v^L) < (v^W, v^O)\). In fact, players feel that their works are complementary under JPE, while their works are substitutable under RPE, irrespective of whether tasks are truly complementary or substitutable. "Conventional substitutes and complements are distinguished by whether a more aggressive strategy by player A lowers or raises player B’s payoffs."\(^8\)

My model displays

\[
\frac{\partial V_i}{\partial I_j} = p'(I_j) [p(I_i)(v^S - v^W) + (1 - p(I_i))(v^L - v^O)]
\]

\[ > 0 \text{ under JPE} \]

\[ < 0 \text{ under RPE.} \] \( (6) \)

It is immediately observed that JPE makes the tasks complements, whereas RPE makes them substitutes. This implies that even if each player’s task is identical and perfectly substitutable, players perceive that they are working on complementary jobs under JPE.\(^9\)^\(^10\)

**Proposition 3** The agents perceive that the tasks are complements under JPE, while the tasks are substitutes under RPE.

\(^8\)I quote this sentence from Bulow et al. (1985) with a slight change.

\(^9\)Also, we can say that RPE makes the competitive relationship, while JPE makes cooperative relationship. Under RPE, to succeed alone is best and to fail alone is worst. However, under JPE, to succeed together is best and to fail together is worst.

\(^10\)The literature, for example Che and Yoo (2001) and Kvaløy and Olsen (2006), likes to state that a player’s work yields positive externalities under JPE and negative externalities under RPE.
Following Bulow et al (1985) and Fudenberg and Tirole (1984), we can explain the effect of precommitment in contests. If \( I_i \) can be precommitted, its effect is represented by \( \frac{\partial V}{\partial I_i} = \frac{\partial V}{\partial I_i} + \frac{\partial V}{\partial I_j} \frac{dI_j}{dI_i} \). The first term is zero by the envelope theorem. Note that the second term is the product of (2) and (6). The following proposition summarizes the strategic effect of precommitment in contests.

**Proposition 4** The sign of the strategic effect on profits is as follows.

<table>
<thead>
<tr>
<th></th>
<th>JPE</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offensive game</td>
<td>+ (lean and hungry)</td>
<td>+ (top dog)</td>
</tr>
<tr>
<td>Defensive game</td>
<td>+ (fat cat)</td>
<td>- (puppy dog)</td>
</tr>
</tbody>
</table>

Indeed, this is the main issue that Dixit (1987) studies. He argues that the symmetric players have no incentive to precommit in the contest model. However, my model describes that the incentive and effect of precommitment depends on (a) whether they play the offensive or defensive game and (b) whether team incentives are greater or smaller than competition incentives.

In fact, most contest models are based on a unique winner without allowing multiple winners. In these models, reaction functions are upward sloping at low effort level and downward sloping at high effort level. This implies that the game is defensive for a lower level of effort, while it is offensive for a higher level. However, the symmetric equilibrium arises always on the effort level where the slopes of reaction functions are infinite for player 1 and zero for player 2. This property is considerably general irrespective of the way of modelling contests.\(^{11}\)

### 3.2 Principal’s Problem

In this section, I consider a risk neutral principal’s problem deliberately. But players are risk averse: each player’s utility function is \( u(x) \) with \( u'(x) > 0 \) and \( u''(x) < 0 \). To have an

\(^{11}\)For example, there are two well-known functional forms to model contests. One is the additive form employed by Tullock (1980). The player \( i \)'s winning probability is represented by \( p(I_i, I_j) = \frac{f(I_i)}{f(I_i) + f(I_j)} \). The other is the way of Lazear and Rosen (1981). Each player’s output is \( q_i = I_i + \epsilon_i \) and \( q_j = I_j + \epsilon_j \) respectively, with a random shock \( \epsilon_i \) and \( \epsilon_j \) which are i.i.d. Then the winning probability of player \( i \) can be written as \( \Pr(q_i > q_j) = \Pr(I_i - I_j > \epsilon_j - \epsilon_i) = G(I_i - I_j) \), where \( G(\cdot) \) is the cumulative distribution function of \( (\epsilon_j - \epsilon_i) \) which is symmetric with mean 0. In both functional forms, Dixit’s argument holds.
interior solution, I assume \( u'(0) = \infty \). Consider that there is a common environmental shock.

The common shock is good with probability \( \sigma \). In this case, both players can succeed the tasks without exerting any effort. By contrast, it is bad with probability \( 1 - \sigma \). Then the probabilities of success are \( p(I_A) \) and \( p(I_B) \) as before. The designer is not able to observe players’ effort level, but she can observe whether task is accomplished or not.

In this model, there is no reason that the principal has to reward the player who does not perform well. The principal set \( v^L = v^O = 0 \). Thus players play the offensive game under the RPE, while they play the defensive game under the JPE. Then, the player A’s objective function can be rewritten as

\[
\max_{I_A} V_A = [\sigma + (1 - \sigma)p(I_A)p(I_B)]u(v^S) + (1 - \sigma)p(I_A)(1 - p(I_B))u(v^W) - I_A.
\]

The equilibrium condition becomes

\[
\frac{1}{(1 - \sigma)p'(I^*)} = p(I^*)u(v^S) + (1 - p(I^*))u(v^W).
\]

(7)

Obviously, as \( \sigma \) increases, the equilibrium effort level \( I^* \) falls. This condition is the incentive compatibility (IC) constraint for the principal’s problem.\(^{12}\)

When the players achieve the task, the principal can realize the revenue, \( R \). Here, I consider the most unfavorable case for the principal to provide team incentives to players, which is the situation where the tasks undertaken by players are perfectly substitutable with each other.\(^{13}\)

Thus the problem of the principal is

\[
\max_{v^S, v^W} \left[ \sigma + (1 - \sigma)p(I^*)(2 - p(I^*)) \right] R - 2[\sigma + (1 - \sigma)p(I^*)^2]v^S - 2(1 - \sigma)p(I^*)(1 - p(I^*))v^W
\]

s.t. equation(7).

The revenue is realized when at least either of players achieves the task, thereby with probability \( \sigma + (1 - \sigma)p(I^*)(2 - p(I^*)) \). The principal has to pay \( v^S \) to both players when both

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\(^{12}\)The individual participation (IP) constraint in this model is always satisfied. Each player’s equilibrium payoff is \( V^* = \sigma u(v^S) + (1 - \sigma)\left[ p(I^*)p(I^*)u(v^S) + (1 - p(I^*))u(v^W) \right] - I^* \). This can be rewritten as \( \sigma u(v^S) + p(I^*)p'(I^*) = I^* \) using the constraint (7). Even if \( v^S = 0 \), we must have \( p(I^*)p'(I^*) > I^* \) because \( p'(I^*) < 0 \).

\(^{13}\)Suppose that the players undertake independent tasks and that the success of each task yields the same revenue \( R \) to the contest designer. Then, according to the analysis below, team incentives must be provided more.
accomplish with probability \[\sigma + (1 - \sigma)p(I^*)^2\], and \(v^W\) to the player who achieves the goal with probability \((1 - \sigma)p(I^*)(1 - p(I^*))\) with two possible cases.

As in Grossman and Hart (1983), it is convenient to think of this problem in two stages. First, given the effort level, the principal finds the best wage scheme, which is the optimal combination of \((\bar{v}^S, \bar{v}^W)\). Second, for the choice of \((\bar{v}^S, \bar{v}^W)\), she chooses the players’ optimal level of efforts, \(\bar{I}^*\).

\(\bar{I}^*\) can be induced by various combinations of \((v^S, v^W)\) which satisfy the IC constraint (7), where \(I^* = \bar{I}^*\). Then we have to find the optimal combination of \((\tilde{v}^S, \tilde{v}^W)\) whose marginal rate of substitution must be equal to the slope of the IC constraint (7). This is represented by

\[
MRS(v^S, v^W) = \frac{\sigma + (1 - \sigma)p(I^*)^2}{(1 - \sigma)p(I^*)(1 - p(I^*))} = \frac{p(I^*)}{1 - p(I^*)} \frac{u'(v^S)}{u'(v^w)} = \left. -\frac{dv^W}{dv^S}\right|_{r^*},
\]

\[
i.e., \quad \frac{\sigma}{(1 - \sigma)p(I^*)} + 1 = \frac{u'(v^S)}{u'(v^w)} \tag{8}
\]

This suggests that the principal provides both team and competition incentives. Most interestingly, recall that the ratio of marginal effect of team incentives to competition incentives is increasing in equilibrium probability \(p(\bar{I}^*)\). As a result, the principal wants to provide team incentives more and more as \(p(\bar{I}^*)\) increases.

**Proposition 5** \(\tilde{v}^S/\tilde{v}^W\) is increasing in \(\bar{I}^*\). The proportion of team incentives relative to competition incentives should be increasing in the equilibrium probability that players accomplish their tasks successfully.

Another interpretation is that team incentives are more weighted as competition is more aggressive. Many people believe that too much competition within a team may hurt the team performance. The result implies that this conventional wisdom can be partially, and marginally, true. As competition increases, the marginal effect of competition incentives diminishes. Hence the relative importance of team incentives should be greater.\(^{14}\)

Nevertheless, note that the optimal wage scheme is RPE in this model as long as \(\sigma\) is positive. Since the left-hand side in (8) is greater than 1, we must have \(\bar{v}^S < \bar{v}^W\). As is

\(^{14}\)We should be cautious in interpreting this argument. One may think competition hinders teamworks between team members. In my model, team production is not incorporated.
well-known, the superiority of RPE is that it exposes players to less risk by filtering out the common shock. However, in the next sections, we will show that the JPE can be the optimal wage scheme by allowing strategic interactions between players.

It is worthwhile to point out how my model is corresponding to the related literature. If players are risk neutral, the principal’s optimal wage scheme is very extreme in that only competition incentives are provided, i.e., \( \bar{v}^S = 0 \), as in Che and Yoo (2001). One can easily see that \( MRS(v^S, v^W) \) is always greater than the slope of the IC constraint. In addition, with the absence of the common shock \( (\sigma = 0) \), \( MRS(v^S, v^W) \) coincides with the slope of the IC always. Hence, the principal is indifferent between any combination of \( (v^S, v^W) \).\(^{15}\) This is the result of Kvaløy and Olsen (2006).

On the other hand, with risk averse players and the absence of the common shock, the IPE \( \bar{v}^S = \bar{v}^W \) is the optimal scheme. In other words, a reward scheme based on individual performance is best to the principal as in Mookherjee (1984). This special case is also comparable to the study of Green and Stockey (1983). They compare the rank order tournaments with individual contracts. They show that piece rates may dominate tournaments when agents are risk averse, while the dominance can be reversed by incorporating a common shock as seen in our model.

I believe that all these papers can be thought of as a special case of my model. On top of that, I fill in the intermediate cases, and discover the significant implication that the team reward serves the purpose of managing competition. Now consider what effort level the principal should induce. The first-order condition of the principal’s problem with respect to \( I^* \) is simplified by

\[
(1 - p(I^*))R = 2p(I^*)v^S + (1 - 2p(I^*))v^W. 
\]

The optimal effort level \( \bar{I}^* \) is increasing in \( R \). It also increases as players are more capable in the sense that the success function \( p(I) \) shifts in a first-order stochastic dominance sense. Therefore the principal provides team incentives more as \( R \) increases or as players are more capable.

\(^{15}\)Indeed, substituting the constraint into the objective function, the reduced problem can be rewritten as

\[
\max_{I^*} p(I^*)(2 - p(I^*))R - 2 \frac{p(I^*)}{p(I^*)}. \]

It becomes the unconstrained maximization problem. This means that \( I^* \) can be induced by various combinations of \( (v^S, v^W) \) which satisfy the constraint (7), where \( I^* = \bar{I}^* \).
4. Strategic Interaction Between players

In the previous section, I have suggested a new perspective on team rewards, which is that team incentives manage competition between group members within a team. Yet, the principal still prefers the RPE wage scheme in which competition incentives are greater than team incentives so long as there is a positive common shock. However, in this section, I will show how strategic interactions between players lead the principal to choose the JPE wage scheme.

The strategic interactions between agents have not been paid attention to in the principal-agent model with multiple agents. The reason is that the most papers adopt the popular framework in which agents are allowed to make a binary effort decision, particularly, between only two actions. This approach has a significant limitation in analyzing how players are interacting and responding to each other’s actions. However, my model will display that players’ strategic interaction such as collusion, and the choice of timing can change the principal’s wage scheme.

4.1 Collusive Cooperation between players

I consider the possibility that players cooperate completely in choosing ones’ effort levels. We can think of some possible scenarios for cooperation to take place. First, if players interact over a long period, they are able to collude by grim trigger strategies. Second, the principal allows players to sign side contracts to coordinate their actions. Third, alternatively, the principal can contracts with the team of players that coordinate their action choices. To make the problem simple, irrespective of how they cooperate, I assume that the players’ collusion emerges voluntarily as long as it is beneficial to themselves.

Indeed, RPE is associated with the offensive game with downward sloping reaction functions, while JPE accompanies the defensive game with upward sloping reactions function. In addition, players’ isopayoff curves are convex and concave in each case respectively. This can be easily verified by inspecting the slope of isopayoff curves in the space of $I_i$ and $I_j$ as follows.

\[
\left. \frac{dI_j}{dI_i} \right|_{P_i} = \frac{(1 - \sigma)p'(I_i)\left[p(I_j)u(v^S) + (1 - p(I_j))u(v^W)\right] - 1}{(1 - \sigma)p'(I_j)p(I_i)\left(u(v^S) - u(v^W)\right)}
\]
Their equilibrium payoffs are greater as isopayoff curves move down under RPE, whereas isopayoff curves move up under JPE. Therefore, given $v^S$ and $v^W$, the symmetric collusive level of efforts is smaller than non cooperative equilibrium level of effort under RPE, but it is greater under JPE. Formally, to find the collusive outcome, we need to maximize the following collusive payoff function, $V^C = [\sigma + (1 - \sigma)p(I)^2]u(v^S) + (1 - \sigma)p(I)(1 - p(I))u(v^W) - I$. Then the collusive level of efforts $I^C$ satisfies

$$\frac{1}{(1 - \sigma)p'(I^C)} = 2p(I^C)(u(v^S) - u(v^W)) + u(v^W).$$

(9)

Proposition 6 $I^C \succeq I^*$ if and only if $v^S \succeq v^W$. The symmetric collusive level of efforts is greater than non cooperative equilibrium level of efforts under JPE, but it is smaller under RPE.

The proof can be shown promptly by comparing (9) to (7). Compared to the non-cooperative equilibrium, players collusively make more efforts under JPE and less efforts under RPE. Under JPE, players feel like working on complementary tasks. Thus they face the classical double marginalization problem of complements. However, through collusion, the agents are able to internalize the externality of one’s effort on each other’s payoff, thereby avoiding this double marginalization problem. This is the reason why players exert more efforts by collusion under JPE.

Again, this result is in sharp contrast to the literature, for example, Che and Yoo (2001) and Laffont and Martimont (1998).\textsuperscript{16} In their models only with two actions or two states, work and shirk, collusion involves with both players’ shirking regardless of whether a wage scheme follows RPE or JPE. However, in my model, collusion under JPE makes players do more efforts and is better for the principal. This difference is precisely showing the restrictive weakness of the principal-agent model formulated with two actions.

There are a few papers which also shows that collusion between players can make it possible for the principal to be better off. For example, Holmström and Milgrom (1990), Itoh (1993), and Varian (1990) study the related issue. However, the mechanism to make the principal

\textsuperscript{16}Che and Yoo (2001) argue that the cost of using the RPE scheme rises when the players are allowed to collude, while that of the JPE scheme remains unchanged. I come to the same result for RPE, but the players’ collusion makes the principal better off under JPE.
better off is very different. In these papers, collusion reduces the agents’ total risk exposures by risk sharing or increases the agents’ peer monitoring through information sharing.

Now let us show that the JPE scheme can be adopted under the players’ collusion. The

\[ MRS \] of the principal’s indifference curve should be equal to the collusive IC constraint (9). Then the optimal combination of \((v^S, v^W)\) must satisfy

\[
\frac{\sigma + (1 - \sigma)p(I^*)(1 - 2p(I^*))}{2(1 - \sigma)p(I^*)(1 - p(I^*))} = \frac{u'(v^S)}{u'(v^W)}.
\]

If \(u'(v^S)/u'(v^W)\) is less than 1, the JPE is the optimal scheme, and vise versa.

**Proposition 7** The principal prefers JPE if \(I^* > \hat{I}^*\) and RPE if \(I^* < \hat{I}^*\), where \(p(\hat{I}^*) = \sigma/(1 + \sigma)\).

When \(\sigma = 0\), the JPE scheme is always optimal. But, as \(\sigma\) rises, the region in which the JPE scheme is optimal shrinks. The reason is that the merit of RPE, which is filtering out the common shock, becomes greater as \(\sigma\) rises.

The result implies that the principal had better supplying collaborative work environments under JPE. In this sense, the conventional wisdom favoring team incentives becomes more than marginally true. When the principal puts more weights on team incentives in the wage scheme, she prefers to provide other non-monetary rewards to motivate players’ cooperation.

### 4.2 Endogenous Timing of Actions

Let us consider another strategic interaction between players. Now, players are allowed to choose the order of moves to be a leader or a follower in competition. As in Hamilton and Slutsky (1990), I add the stage in which players select the timing of their moves before choosing the level of effort. The players have to choose to play the first or to play the second. If players make the same decision, the simultaneous game proceeds. If they make different decisions, the typical Stackelberg game follows, where the follower can observe the action chosen by the leader.
To make the problem simple, I assume that players are risk neutral and there is no common shock. Then we have already known that the principal is indifferent between any combination of \((v^S, v^W)\), without any strategic interaction between players. Without loss of generality, let us assume that player \(A\) moves first and \(B\) follows. Then we solve the stackelberg game, and so player \(A\)’s problem is maximizing his payoff function under player \(B\)’s first-order condition as follows.

\[
\max_{I_A} V_A = p(I_A)p(I_B)v^S + p(I_A)(1 - p(I_B))v^W - I_A \\
\text{s.t. } p'(I_B) [p(I_A)v^S + (1 - p(I_A))v^W] - 1 = 0
\]

**Proposition 8** \(I_A^1 > I^* > I_B^2\) in the offensive game (under RPE). \(I_A^1 > I^*\) and \(I_B^2 > I^*\) in the defensive game (under JPE).

**Proof.** The first-order condition is summarized by

\[
p'(I_A) [p(I_B)v^S + (1 - p(I_B))v^W] + \frac{dI_B}{dI_A} p'(I_B)p(I_A)(v^S - v^W) = 0. \tag{10}
\]

Note that the second term is always positive by Proposition 1. That is, we have \(\frac{dI_B}{dI_A} < 0\) as \(v^S \geq v^W\). Now, let us compare this to equation (1). Given \(I_B, I_A\) is always greater in the Stackelberg game than in the simultaneous game. Thus, at the equilibrium, \(I_B\) is lower than the symmetric equilibrium effort levels \(I^*\) in the offensive game because the reaction function is downward sloping. Similarly, \(I_B\) should be lower than \(I^*\) in the defensive game.

Denote the expected payoffs in the simultaneous-move subgame by \((V^N_i, V^N_i)\) and those in the leader-follower subgame by \((V^1_i, V^2_i)\). The superscripts 1, 2, and \(N\) indicate the first-mover, the second-mover, and the simultaneous-mover respectively. The subscript \(i\) is \(O\) or \(D\) which represents the offensive game and the defensive game respectively. Then, the normal-form representation of the first stage game is as follows.
The following lemma summarizes the comparison of expected payoffs in each case.

**Lemma 9**

1. **Offensive game (RPE):** \( V^1_O > V^N_O > V^2_O \)
2. **Defensive game (JPE):** \( V^2_D > V^N_D \) and \( V^1_D > V^N_D \).

The proof of this lemma is immediate from equation (6). The player \( i \)'s payoff is decreasing in the player \( j \)'s effort level \( I_j \) in the offensive game, and vice versa in the defensive game. In fact, it is well-known that the players have the first-mover advantages in the (offensive) game with downward sloping reaction functions, while the potential second-mover has disadvantages compared to the simultaneous move.\(^17\) Thus, there exists the dominant strategy which is to choose the first, and so two firms play simultaneously in choosing the level of efforts.

In the (defensive) game with upward sloping reaction functions, players have the second-mover advantages.\(^18\) Yet it does not mean that the first-mover becomes worse-off than simultaneous mover because one's expected payoff is greater than when it moves simultaneously. Hence they do not have a dominant strategy. There are two pure subgame perfect Nash equilibria. Given that one player chooses the first (the second), the other player chooses the second (the first). One becomes the leader and the other becomes the follower.\(^19\)

**Proposition 10** *(Hamilton and Slutsky; 1990)*

1. **RPE (strategic substitutes):** Both players choose the first at the unique equilibrium, so they move simultaneously in choosing the level

\(^17\)See Gal-Or (1985) to see first-mover and second-mover advantages in an oligopoly model.

\(^18\)In this sense, the offensive game can be thought of a race, while the defensive game can be thought of a waiting game.

\(^19\)For the game between the offensive player and defensive player, we get \( V^1_O > V^N_O > V^2_O \), \( V^1_D > V^N_D \) and \( V^2_D > V^N_D \). In this case, the offensive player still has the dominant strategy, which is choosing the first. Given the offensive player’s choice, the defensive player chooses the second. Recall, in Example 4 above, the incumbent firm plays defensively because not losing is more important, while the entrant plays offensively because winning is more important. If we apply our finding to this example, the entrant starts to develop innovation first and then the incumbent follows. Indeed, we often observe that new technologies are announced by entrants. Similarly, we can predict who brings the lawsuit in litigations and who starts early on campaign trail in political elections. The offensive players do.
of efforts. (2) JPE (strategic complements): There are multiple equilibria in which one player chooses the first and the other chooses the second.

Two propositions together suggest that it could be better for the principal to adopt the JPE scheme. Under JPE, players voluntarily plays the sequential move game, thereby exerting more effort levels. Similarly to the case of players’ collusion, the strategic interaction between players regarding the order of moves favors the JPE scheme.

5. Discussions

5.1 Profit-sharing

The preceding analyses give some implications about profit-sharing in a firm. Profit-sharing plans can be thought of as team incentives in our model. One essential problem regarding profit-sharing is that free-rider problem undermines providing proper incentives in organizations. This is the main issue that Marino and Zábojnšk (2004) addresses. They show that profit-sharing with internal competition can solve the free-rider problem because the individual teams plays a role of each other’s budget breakers, which is shown by Holmström (1982) as a solution of moral hazard problem in teams.

This paper holds the opposite view. While they center on the intrinsic problem in team incentives and propose competition as a solving method, I divulge a problem of competition and suggest supplying team incentives as a solution. That is, profit-sharing can manage the discouraging effect of competition in organizations. Both papers together may imply that there is a complementary effect between competition incentives and team incentives.

5.2 Joint Patent System

Another perspective to see the model in this paper is that our model allows for dual winners, which is different from most contest models. Hence the principal can offer a more elaborate wage scheme, which enables her to induce the optimal effort level at lower costs. This result
implies that selecting the sole and exclusive winner may not be a best way in contests. In this sense, we can pose a question about the conventional patent system which does not allow dual patent holders for the same technology.

There are only a few research about nonexclusive patents or independent invention. Leibovitz (2002) argues in depth that a nonexclusive patent system would work in practice. Manna et al (1989) suggests a simple way of implementing it by accepting all applications up to the date in which the first inventor is awarded the patent, with the provision that the Patent Office keeps the technical details of patents secret. Theoretically, the reason why they propose such a different patent system is that nonexclusive patents can realize the efficiency gain from the ex post market after patents have issued. For example, more competition will follow among rival patent holders and more reasonable licensing will increase. In addition, in R&D competition, the winner-takes-all feature of the current system makes firms choose a risky research strategy.

One important concern in the nonexclusive patent system would be whether or not granting patents to independent inventors can provide enough incentives for innovation. Maurer and Scotchmer (2002) attempts to answer this question. In their model, they assume that a new innovation can be developed by investing the fixed costs. They show that a possibility of duplication does not jeopardize the first inventor’s ability to recover R&D costs as long as the costs of duplication is not substantially low.

On top of that, this paper suggests that the nonexclusive patent system can increase innovation incentives. More specifically, the Patent Office can give different rewards in the case of having a single inventor and of having dual or more independent inventors. That is, the Office can set different patent length.

5.3 Group Lending with Joint Liability

Recently group lending programs such as the Grameen Bank work successfully to lend to poor people without any collateral. One distinctive feature of these programs is asking borrowers to form a group in which all borrowers are jointly liable for each other’s loans. The literature found that joint liability can play roles of peer monitoring (Varian; 1990), self-selection (Ghatak; 1999), and screening mechanism (Tassel; 1999, Ghatak; 2000). In addition
to these benefits, I provide another rationale for joint liability, which is choosing the optimal combination of team and competition incentives.

I use the simple set-up following Ghatak and Guinnane (1999). A person must borrow capital from a bank to perform a project. If the borrower succeeds in the given projects, he can make revenue \( Y \). The bank asks two borrowers to form a group.\(^{20}\) Borrowers have to pay an interest rate \( r \) by a standard loan contract. A condition of joint liability specifies that a borrower must pay an additional amount \( c \) to the bank if his partner is unable to repay his loan.\(^{21}\) Again, I assume that players are risk averse and that there is a common shock. Then a borrower’s expected payoff is represented by

\[
\max_{I_A} V_A = \left[ \sigma + (1 - \sigma) p(I_A) p(I_B) \right] u(Y - r) + (1 - \sigma) p(I_A) (1 - p(I_B)) u(Y - r - c) - I_A.
\]

Also we can define the bank’s problem similarly as the principal’s. It is not difficult to see that the analysis will be equivalent to our previous model. One can interpret \( Y - r \) as \( \nu^S \) and \( Y - r - c \) as \( \nu^W \) respectively. A slight difference of this model from the previous one is that the principal’s choice variables are the source of income for herself which reduces players’ incentives for effort, whereas she has chosen, in the previous case, her own costs which increase players’ incentives for effort. In addition, in this model, the positive joint liability \((c > 0)\) means that the bank uses the JPE scheme.

As a result, \( \bar{I}/c \) is decreasing in \( \bar{I}^* \). As lenders are more capable or the revenue of the project is greater, the bank should offer a contract with a lower interest rate and higher joint liability. In fact, interestingly, increasing joint liability in this model is lessening competition incentives, not strengthening team incentives. But the relative importance of team incentives increases.

The result also reinforces the findings of the literature of joint liability. When borrowers know each other’s characteristics, the voluntary group formation results in groupings of the same type of borrowers under joint liability. Based on this self-selection, the bank is able to

\(^{20}\)I assume that two borrowers in a group are identical. Indeed, the literature found that self-selection leads to that the same type of borrowers are matched when they know the characteristics of each other.

\(^{21}\)In fact, the typical form of joint liability is denying future loans to all group members if a group member is default. Thus Ghatack and Guinnane (1999) justifies the model in the way of that "this c can be interpreted as the net present discounted value of the cost of sacrificing present consumption in order to pay joint liability for a partner."
screen a group of safe or capable borrowers by offering the contract low interest rates and high joint liability. Now, the result of this paper suggests that this contract not only solves the adverse selection problem but it may also provide the optimal incentive mechanism.

6. Concluding Remarks

In this article, I have examined incentives in a simple contest model with distinguishing the loser’s loss from the winner’s gain. I dug up various interesting findings. The task can be either strategic complements or strategic substitutes by the relative size of the winner's gain to the loser’s loss; strategic complements in the defensive game and strategic substitutes in the offensive game. Two different incentives affect players’ incentives to work through different channels. Thus their marginal effect on the equilibrium effort levels is crucially different depending on the equilibrium probability of success.

In fact, the winner’s gain and loser’s loss are converted to competition incentives and team incentives respectively in the principal-agent model. Basically, the principal provides both types of incentives together, but the proportion of team incentives becomes greater as equilibrium probability increases. In this sense, team rewards play a role of managing competition within a team. Moreover, the importance of team incentives becomes much greater when we consider strategic interactions between players such as collusion and the choice of timing of actions.

I believe that it would be interesting to extend the paper in several ways. If the model incorporates team production, two issues should be analyzed in my framework. When a technological synergy in cooperation exists in team production, what incentive scheme is the best to take advantage of this externality? How does the principal mitigate players’ free-riding incentives in team production? Also, we have just focused on the symmetric outcome. There may be new interesting findings in the competition between players with different abilities. For example, the principal must provide different level of carrots and sticks to different players.

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