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Team-Based Incentives in Problem-Solving Organizations

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Abstract

This paper investigates a repeated employment relationship between a principal and agents who he hires to solve a series of problems. Each agent works independently, but the principal can choose to pay a team incentive bonus to all agents if any one of them solves a problem.

We show that, under relational contracts, there is a range of parameter values for which the principal prefers team incentives to individual incentives. Team incentives create a problem of moral hazard, but they can also reduce the principal's commitment problem by smoothing bonus payments over time. The latter effect is particularly strong when problems are difficult to solve. If team size is endogenous, team incentives can increase efficiency by allowing the principal to motivate a greater number of agents. However, in some such cases, the principal still chooses individual incentives because they allow him to appropriate more surplus. (*JEL* J41, M52)

Keywords: team incentives; relational contracts.

1 Introduction

The last few decades have seen an increasing reliance on teams in the workplace. For instance, Lawler, Mohrman, and Ledford (1995) found that between 1987 and 1993, the percentage of Fortune 1000 companies using self-managing work teams increased from 28 to 68 percent. Teams may be used

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because they promote communication, enhance cooperation, or increase productivity.

In particular, teams have existed for many years in work organizations with an overarching goal of solving problems. For example, teams may be active in research and development, where solving a problem is equivalent to making a discovery or having a breakthrough idea. This paper aims to analyze incentive pay in these type of problem-solving teams.

Human resource management consultants often argue that team organizations are not quite effective unless accompanied by genuine team-based incentive plans, as individual performance pay can undermine team spirit. Examples of team-based pay include a commission for the sale of real estate property that is shared among members of a sales force, and a cash bonus for a product's development that is given to a team of scientists and engineers. Real team-based incentives are used in practice (see, e.g., Gross (1995)), and there is a growing interest in the adoption of team-based pay in various organizations (see, e.g., Reilly, Phillipson, and Smith (2005) for experience with team-based pay in the U.K. National Health Service).

Recently, economists have started paying attention to the complementarity between multiple human resource practices, such as team organization and team-based pay. For instance, Boning, Ichniowski, and Shaw (2007), using data from U.S. steel mills, found some evidence that problem-solving teams can increase the effectiveness of group incentive pay plans.[1] Due to the difficulty of measuring individual employee contributions, incentive pay plans in their sample were all group-based. However, there are also cases where employers can observe individual performance, but choose to reward workers based on group performance.

This paper investigates the choice between individual and team-based incentives in a repeated principal-agent framework. The principal has a sequence of problems that he wants agents to solve, and he can observe whenever an agent solves a problem. We consider both the case where this information is verifiable in court (formal contracting), and where it is not (relational contracting).

Under individual incentives, the principal promises each agent a bonus whenever that agent solves a problem. Under team incentives, the principal

[1] Similarly, Dunlop and Weil (1996) and Pil and MacDuffie (1996) found a high correlation between the percentage of workers in teams and the use of group-based incentives in the apparel and the auto industries, respectively.

promises all agents a bonus in any period where a problem is solved, regardless of who solves it. The interpretation is that the whole team is rewarded whenever the team succeeds. One can view these team incentives as a form of joint, as opposed to relative, performance evaluation, in the specific context of problem solving teams.

We restrict our attention to these two types of incentives regimes, even though an agent's bonus could in principle depend on the entire profile of individual outcomes. For instance, the bonus might depend on how many agents succeed or fail to solve a problem. We feel that the question of how team incentives compare to individual incentives is worthy of attention in its own right. These two incentives regimes are both widely used in practice and the rules specifying when bonuses are paid are straightforward, which may well help with their implementation. The increased tractability also allows us to delve further into the issue of team size.

In our setting, each agent who exerts effort solves the problem with a certain probability. This probability is independent across agents. It is generally known that production complementarities can make joint performance evaluation optimal (Itoh 1991), but that is not what we want to focus on. Rather, we are interested in how team-based pay can affect problems that the principal may have with credibility, and assuming independence helps isolate this effect. We also assume that agents are risk neutral, so the principal does not need team incentives to reduce agents' exposure to risk.

We assume that agents who do not exert effort never solve a problem, so there is no issue of moral hazard under individual incentives. Even though the principal cannot observe effort, each agent knows that he will never receive a bonus unless he exerts effort. If there are no issues of credibility, then the principal can offer an individual bonus that is just high enough to make an agent's participation constraint bind. Agents will then work, and the principal will capture all surplus.

Compared with individual incentives, offering team incentives has two effects. First, team incentives give each agent the opportunity to free ride on the work of others. An agent knows that he may receive a bonus even if he does not work, because one of his teammates may solve the problem. Moral hazard is then an issue, so the principal must offer an expected bonus that is strictly higher than the cost of effort to convince agents to work. The extent of the free-rider problem is limited by agents' ability to monitor each others' effort, and punish those who shirk with a grim trigger strategy. However, this type of work norm cannot eliminate the free-rider problem altogether,

and the principal must share some surplus with agents. This effect of team incentives reduces firm profits.

Second, team incentives can allow the principal to smooth bonus payments over time. Agents may be willing to work for a lower bonus than under individual incentives, because they expect to receive a bonus more often. This will be the case as long as agents are sufficiently patient, so that mutual monitoring between agents makes free-riding unattractive.

Under formal contracting, the firm is only concerned with the expected payment that it must make to agents. The size of the bonus itself does not matter, since having to pay a smaller bonus more often does not necessarily represent any cost savings for the firm. That means the only impact of team incentives is through morale hazard, which decreases profits. The principal will therefore always use individual incentives if formal contracts are available.

In contrast, the size of the bonus can play an important role under relational contracting. As is well-known, the key issue in relational contracting is how large a bonus the agents can trust the principal to pay. The principal can promise to pay a bonus, but may prefer to renege on his promise once a problem is solved. He will do so if the size of the bonus is greater than the expected future benefit of sustaining the productive relationship with the agents. A larger bonus increases the principal's immediate gain from reneging, so that agents may be unwilling to work because of the principal's credibility problem.

We show that under relational contracts, the principal will use team incentives whenever they are credible but individual incentives are not. This will be the case when problems are difficult to solve, and the cost of effort is moderate relative to the project value. The two effects of team incentives both have an impact on the principal's credibility. Free-riding makes the principal's promise of a bonus less credible, because it decreases the expected profits from continuing the productive relationship. Smoothing bonus payments over time makes the principal's promise more credible, because it decreases his immediate benefit from reneging. When problems are difficult to solve, the effect of payment smoothing dominates and team incentives will help with credibility. The principal will then use team incentives if the cost of effort takes on an intermediate value for which team incentives are credible, but individual incentives are not.

We then let team size be endogenous, and show how team size relates to the type of contract and the choice of incentive scheme. Team size is limited

by the number of agents that the principal can motivate to work, which is determined by his credibility constraint.

We show that, with formal contracts, the principal can always motivate more agents under individual incentives than under team incentives. However, with relational contracts, the principal may be able to motivate more agents under team incentives. That means the optimal team size is only higher under team incentives if the firm uses relational contracts.

Moreover, the principal uses team incentives less often than would be optimal from a social point of view. For some parameter values, the principal will use individual incentives even though team incentives would allow him to motivate more agents. Team incentives are then more efficient, but would force the principal to give agents strictly positive rents to overcome the free-rider problem.

The remainder of the paper is organized as follows. Section 3.2 briefly discusses the relevant literature. Section 3.3 lays out the basic model, and Section 3.4 analyzes individual and team incentives under formal as well as relational contracting. Section 3.5 considers the optimal team size, and Section 3.6 discusses hybrid individual-team incentives. Section 3.7 concludes.

2 Related Literature

This paper aims to contribute to the burgeoning literature on relational contracts (which we do not attempt to survey here).[2] Levin (2003) provides a definitive treatment of a repeated agency framework with self-enforcing, relational contracts, the most distinguishing feature of which is a constraint that limits the principal's promise of credible payments. What distinguishes our work is that we analyze relational team-based incentives in problem-solving teams. Levitt (1995) is an earlier work that analyzes optimal contracts when only the agents' best outcome matters and the principal can choose between one versus two agents, but it does not consider team incentives.

One of our key findings is that team incentives can help the principal

[2]While we abstract from the interaction between formal and relational contracts, the literature includes such papers as MacLeod and Malcomson (1989), Baker, Gibbons, and Murphy (1994), Schmidt and Schnitzer (1995), and Pearce and Stacchetti (1998). Recently, Rayo (2007) considers the joint use of implicit and explicit incentives in teams, where the focus is on showing that the relational contracts can affect the allocation of profits shares, giving rise to an endogenously chosen principal.

by relaxing his credibility constraint. This complements the findings in the existing literature. For instance, Auriol, Friebel, and Pechlivanos (2002) explain why a principal will use more collectively oriented incentives when he cannot commit to long-term contracts. That is, when workers have career concerns, the principal uses group compensation to reduce sabotage incentives. Corts (2007) provides yet another reason to use team-based incentives. He finds that although individual incentives reduce workers' exposure to risk, team incentives are desirable for multi-task problems.

Traditional incentive theories with multiple agents have evolved around the use of relative performance evaluation, which has the advantage of allowing the principal to filter out common noise in the workers' performance measures (e.g., Holmstrom (1982)). However, a number of authors have also pointed out that incentive schemes which reward agents when their peers perform well can sometimes be optimal. For instance, Itoh (1993) shows that, when agents can side contract on effort, the principal can be better off adopting a group incentive scheme. This is despite the fact that one agent's output does not contain any information on the other agent's effort.

Che and Yoo (2001) establish similar results in a repeated game where agents cannot exchange side payments, but can instead engage in implicit contracting. Their insight is that under joint performance evaluation, an agent who shirks can be punished by the subsequent shirking of others agents. They show that joint performance evaluation can be optimal when the principal only observes a signal on performance, since peer monitoring then reduces moral hazard. Specifically, an agent only receives a bonus if the principal receives a positive signal both about his work, and about the work of the other agent. This joint performance evaluation is very different than our concept of team incentives, where a bonus is paid to everyone whenever any agent solves a problem. The latter has an intuitive interpretation in our setting, the idea being that everyone receives a bonus whenever the team succeeds. Another difference is that Che and Yoo assume there are two agents, and only consider formal contracting with the principal.

Conceptually, the closest paper to our work is Kvaloy and Olsen (2006). They modify Che and Yoo by assuming output is non-verifiable, and solve for the optimal relational contract. Just as in our paper, they look at relational contracts in a principal-agent setting, with implicit contracting between agents. Their main finding is that when the productivity of effort is relatively high, credibility problems lead the principal to choose relative performance evaluation. They also show that the optimal contract never pays

an agent a bonus in a period where his output is low. The principal would never use what we define as team incentives, where an agent is paid whenever the team succeeds, regardless of his own contribution to that success. If the principal had credibility problems, he would instead use a cleverly designed relative performance evaluation scheme.

We do not consider the possibility of relative performance evaluation for a number of reasons. First and foremost, as mentioned above, both individual and team incentives are widely used in practice, and we believe it is instructive to show when one scheme outperforms the other. Moreover, there are a number of features of relative performance evaluation that can make it unattractive in practice, by hurting morale and discouraging cooperative behavior. Relative performance evaluation can encourage agents to sabotage each other's work, particularly if they are often in contact with one another. It can also induce agents to engage in collusive shirking, and distort their incentives to work with more able colleagues (Gibbons and Murphy 1989)

A common feature of the above two papers is that moral hazard is already an issue under individual incentives. The principal may therefore want to use a specific type of joint performance evaluation to take advantage of peer monitoring, regardless of whether credibility is an issue. This is in sharp contrast to our paper, where moral hazard plays no role under individual incentives. Here, moral hazard only becomes a problem if agents can free-ride on the work of others, which can occur precisely because the principal uses team incentives. It is then only partially mitigated by implicit contracting. If the principal uses team incentives, it is despite their impact on moral hazard, not because of it.

Our contribution lies in looking at a widely used type of team incentives, and deriving conditions under which a particular feature, smoothing bonus payments over time, can be enough to make them preferable to individual incentives. This will be the case whenever the effect of payment smoothing outweighs the problem of moral hazard. Focusing on the ranking of these two incentive regimes also allows us to address the issue of team size. When team size is endogenous, our work generates novel, testable implications regarding the relationship between team size, the type of contract, and the choice of incentive scheme. It also shows that the principal's choice of incentive scheme may be inefficient.

3 The Model

We consider a repeated employment relationship between a principal and a team of agents hired to solve a series of problems. Problems must be solved one at a time, in that the team must solve one problem before they begin work on the next one. The problems can be interpreted as sequential in nature, as in a team of engineers that builds on previous projects to make further progress. They can also be interpreted as independent of each other, as in a team of consultants that deals with one client after another.

Time is discrete, infinite, and indexed by $t = 0, 1, \ldots$. In period 0, the principal chooses how many agents to employ, $N \geq 0$. In period 1, the N agents all go about solving the first problem, and they continue working in subsequent periods until at least one agent solves it. The principal then gives the agents a second problem to work on in the following period, and so forth.

Following the literature, all parties are risk neutral, and the agents are subject to limited liability. This means that the principal cannot impose negative wages on the agents.

In each period, each agent decides whether to work or shirk. If an agent works, the probability he solves the problem is $p > 0$. If he shirks, the probability is zero. An agent who works incurs effort cost $c > 0$. We assume that an agent's probability of solving a problem does not depend on the effort choice of other agents or the size of the team. This focuses attention on the role of team-based incentives, rather than production complementarities, which we believe would reduce tractability without substantially changing our results.

The principal obtains profits $K > 0$ in each period where a problem is solved, regardless of how many agents solve it.[3] An agent's decision to work or shirk is observed by all other agents but not by the principal. The principal can observe, however, whenever an agent solves a problem. We consider both cases where this information is verifiable in court and where it is not. In the former case, the principals can offer a formal, binding contract. In the later case, the principal must try to motivate the agents through relational

[3] In reality, the principal's profits could depend on the number of agents who solve the problem, if that corresponds to a "better" solution. The important point is that expected profits should be concave in the number of agents who exert effort. Our framework is particularly tractable, as expected profits do not involve binomial probabilities. It allows us to derive explicit expressions for the values of p for which team incentives can increase profits.

contracts. He promises each agent a bonus b to be paid at the end of the period, conditional on whether a problem was solved in that period. The promise is non-binding, so the principal can always renege and not pay the bonus. In our set-up, agents are identical, so the principal offers an identical contract to all N agents.

Before period 1, the principal chooses between one of two incentive schemes. Under individual incentives, he promises an agent a bonus each time the agent solves a problem. Under team incentives, the principal promises all agents a bonus in each period where a problem is solved, regardless of which one of them solves it. We assume that contracting between the principal and the agents is multilateral. An agent considers the principal to have deviated if the principal reneges on a bonus that any agent was promised. The intuition is that once the principal breaks any kind of promise, agents regard him as untrustworthy.

All parties play grim trigger strategies when information is non-verifiable. If the principal reneges on a bonus to an agent, then the productive relationship with all agents ends. The agents shirk in all subsequent periods, and the principal offers a bonus of zero. Moreover, each agent observes every other agent's choice of effort, and engages in implicit contracting with them. Agents have a work norm which specifies they will impose the worst possible self-enforcing punishment on an agent who shirks. No side payments are allowed between agents. Optimal relational contracts with risk neutral agents are stationary (Levin 2003), so we can restrict attention to equilibria where players' behavior does not change along the equilibrium path.

Players have a common discount factor $\delta \in (0, 1)$, or equivalently the employment relationship terminates at the end of each period with probability $1 - \delta$. Each agent's outside option gives a pay-off of zero, and we assume that an agent who is indifferent will work. The optimal base salary for the principal to offer is the lowest salary sufficient to induce the agents to join the firm, which is zero as long as the agents cannot post bonds. Hence, we abstract from base wages.

In terms of notation, we use the small scripts i and t to refer to individual and team incentive schemes, respectively. For example, b_i is the bonus under individual incentives, while π^t is the expected discounted flow of profits under team incentives.

4 Analysis

In this section, we treat team size as exogenous. We are only interested in cases where it is efficient for all agents to work, rather than shirk:

$$Nc \leq (1 - (1 - p)^N)K. \tag{1}$$

The left-hand side is the total effort cost when all agents work. It must be no higher than the right-hand side, which is the project value times the probability at least one agent solves the problem. The ratio of effort cost to project value must therefore not be too large.

When output is verifiable, the principal's problem is to minimize the expected wage payments subject to the constraint that the agents must be induced to work (e.g., Grossman and Hart (1983)). When output is non-verifiable, there is an additional constraint, as the principal must prefer to pay the agents the promised bonus rather than renege. That is, relational incentive contracts must be self-enforcing (Bull 1987).

There are four incentive regimes to consider: formal individual incentives, formal team incentives, relational individual incentives, and relational team incentives. We show that under formal contracts, individual incentives are optimal even though team incentives allow the agents to engage in implicit contracting. Under relational contracts, individual incentives are also optimal as long as the principal's credibility constraint is met. If that is not the case, however, the principal may choose team incentives. In Section 3.6, we show that these results are robust to considering hybrid incentives, which include both an individual and team bonus.

4.1 Formal Individual Incentives

Suppose the principal motivates each agent to work by offering individual incentives. The optimal formal contract in this setting is actually the same as what would arise with a single agent. The differences appear later, in Section 3.5, when the principal chooses team size.

The principal offers a bonus b_i to an agent whenever that agent solves a problem. That can induce agents to work in each period as a subgame-perfect Nash equilibrium if

$$pb_i - c \geq 0.$$

Hence, the principal can motivate each agent to work with:

$$b_i^* = \frac{c}{p}. \tag{2}$$

This can be interpreted as an equilibrium spot contract, or as an optimal long-term contract that the principal can commit to.

4.2 Formal Team Incentives

For given parameter values, the principal's problem is again to minimize the cost of motivating the agents. Recall that under team incentives, each agent gets paid an equal bonus whenever any one of them solves a problem.

With team incentives, an agent's work generates a positive payoff externality on the other team members. It now becomes possible to sustain a subgame-perfect equilibrium with implicit contracting between agents. We consider the worst possible punishment strategy: if one agent shirks, then all other agents shirk forever after. An agent who expects others to follow through on their punishment will work if

$$\frac{1}{1-\delta}\left[(1-(1-p)^N)b_t - c\right] \geq (1-(1-p)^{N-1})b_t.$$

The left-hand side is the present-discounted expected payoff from working, given that all other agents work. The right-hand side is the expected payoff from unilaterally shirking for one period and being subsequently punished by the teammates' grim trigger strategy. Rearranging gives the optimal team bonus, which minimizes the principal's cost:

$$b_t^* = \frac{c}{\delta - (\delta - p)(1-p)^{N-1}}. \tag{3}$$

We have implicitly assumed an agent will want to shirk in each period where he is being punished. For this to hold, we must have $pb_t^* < c$. The expected bonus from being the only one to work must be less than the cost of effort, where the inequality is strict because an agent will work when indifferent. This is the exact same condition for the other agents to want to follow through on their punishment, and so is sufficient for a subgame-perfect equilibrium. Substituting b_t^* from (3), it is equivalent to

$$\delta > p,$$

which we assume for the rest of the paper. Our first result is the following:

Proposition 1. Suppose $N \geq 2$ and $\delta > p$, and the principal uses formal contracts. The optimal team bonus is lower than the optimal individual bonus, $b_t^* < b_i^*$. However, the expected per-period payment is larger under team incentives, so the principal uses individual incentives.

Proof. We require $pb_t^* < c$, which with $b_i^* = c$ implies $b_t^* < b_i^*$. For a given set of parameter values, the principal chooses whichever incentive scheme induces the agents to work at minimum cost. With the optimal individual bonus from (2), the principal's expected per-period payment is

$$Npb_i^* = Nc,$$

whereas, with the optimal team bonus from (3), the expected payment is

$$(1-(1-p)^N)Nb_t^* = \left[\frac{1-(1-p)^N}{\delta-(\delta-p)(1-p)^{N-1}}\right]Nc.$$

Since $\delta > p$, the expression in square brackets is strictly greater than 1 for all $N \geq 2$. Thus, the expected bonus payment per period is larger under team incentives than under individual incentives. □

The intuition behind the proposition is as follows. Under team incentives, the principal can offer a lower bonus and still cover the agents' cost of effort, because agents expect to receive a bonus more often. In this way, team incentives allow the principal to smooth the payment out over many periods. However, the firm's profits depend on its expected payment per period, which depends on both the size of the bonus and how often it will be paid. Under team incentives, the increased frequency of payments dominates the smaller size of the bonus, so that the principal's expected payment increases. The culprit here is moral hazard. Team incentives introduce a free-riding problem which, combined with the principal's inability to observe effort, constrains how low the team bonus can be.

It is also straightforward to show that without implicit contracting between agents, team incentives would give the worst of both worlds. The principal would not only have to pay a bonus more often than under individual incentives, but because of the free-riding problem the bonus would also have to be larger. As we show below, such a bonus will never lead the principal to choose team incentives under either form of contracting. Thus,

employee peer pressure, or a work norm, is critical to the success of a team-based incentive plan.

4.3 Relational Individual Incentives

The key issue with relational contracts is the principal's lack of commitment. He can promise to pay an agent a bonus but then renege once a problem is solved. Contracting is multilateral, so this would cause all agents to shirk in future periods. A principal who reneges will therefore do so against all agents simultaneously.

Formally, this adds the following constraint to the principal's cost minimization problem:

$$Nb_i \leq \delta \pi_N^i, \tag{4}$$

where the left-hand side gives the immediate gain from reneging against all agents, and the right-hand side gives the loss in future profits. The bonus must not exceed the average contribution of each agent to the expected value of the project.

The principal's present-discounted expected payoff from using individual incentives to motivate the agents is

$$\pi_N^i = \frac{1}{1-\delta}\left[(1-(1-p)^N)K - Npb_i\right], \tag{5}$$

where the probability that at least one of the N agents solves a problem in any given period is $1-(1-p)^N$. Substituting π_N^i into the credibility constraint (4), gives

$$b_i \leq \frac{\delta(1-(1-p)^N)}{1-\delta(1-p)}\frac{K}{N}. \tag{6}$$

If b_i from (2) satisfies this constraint, then the optimal incentive scheme with relational contracting is the same as that with formal contracting. In both cases, the principal motivates each agent with an individual bonus. Otherwise, individual incentives are simply not feasible with relational contracting because any credible bonus payment falls short of the cost of effort.

4.4 Relational Team Incentives

The analysis continues in a similar way as above, writing out the principal's credibility constraint under team incentives

$$Nb_t \leq \delta \pi_N^t, \tag{7}$$

The principal's present-discounted expected payoff from using team incentives is

$$\pi_N^t = \frac{1}{1-\delta}(1-(1-p)^N)(K - Nb_t). \tag{8}$$

Substituting π_N^t into the credibility constraint (7) and rearranging gives

$$b_t \leq \frac{\delta(1-(1-p)^N)}{1-\delta(1-p)^N}\frac{K}{N}. \tag{9}$$

If the optimal team bonus from (3) satisfies this constraint, then it can also be used with relational contracting. If not, then team incentives are not feasible with relational contracting because no credible bonus is large enough to convince agents to work. This may be the case even if the bonus covers the cost of effort, because each agent is tempted to free-ride on the work of others

Note that the right-hand side of (9) is strictly less than the right-hand side of (6). Keeping the size of the bonus fixed, credibility is more of a problem under team incentives. The principal must share surplus with agents under team incentives, and therefore loses less if the productive relationship ends.

Under either incentive regime, for all parameter values such that a bonus is credible, the principal would actually like agents to work. That is, a bonus can only be credible if $\pi > 0$. We can now state the following result.

Proposition 2. Suppose $N \geq 2$, and the principal uses relational contracts. Define the critical value $p^* = \delta/(1+\delta)$.

Then for $p \geq p^*$, the principal never uses team incentives. For $p < p^*$, the principal uses team incentives for intermediate values of c/K: for any $p < p^*$ there exist values A_p and B_p, with $0 < A_p < B_p$, such that the principal uses team incentives if and only if $c/K \in (A_p, B_p]$.

Proof. Substituting b_i^* from (2) into (6) gives the condition for individual incentives to be credible

$$\frac{c}{K} \leq \left[\frac{\delta(1-(1-p)^N)p}{1-\delta(1-p)}\right]\frac{1}{N}. \tag{10}$$

Substituting b_t^* from (3) into (9) gives the condition for team incentives to be credible

$$\frac{c}{K} \leq \left[\frac{\delta(1-(1-p)^N)\left(\delta-(\delta-p)(1-p)^{N-1}\right)}{1-\delta(1-p)^N}\right]\frac{1}{N}. \tag{11}$$

Define A_p as the right-hand side of (10), and B_p as the right-hand side of (11). Both are strictly positive.

Suppose $c/K \leq A_p$, so that b_i is credible. Then, from Proposition 1, it follows that the individual incentive scheme minimizes the principal's expected average per-period payment, so the principal uses individual incentives. If $c/K > max\{A_p, B_p\}$, then agents will not work under either incentive regime, even though working is efficient when $c/K - max\{A_p, B_p\}$ is sufficiently close to zero.

The only occasion where the principal uses team incentives is when $c/K \in (A_p, B_p]$, so when b_t is credible but b_i is not. It remains to show that $B_p > A_p$ if and only if $p < \delta/(1+\delta)$.

Cross multiplying and canceling terms shows $B_p - A_p > 0$ is equivalent to

$$(1-\delta(1-p))(\delta-(\delta-p)(1-p)^{N-1}) - p(1-\delta(1-p)^N) > 0$$

Rearranging gives

$$\delta - p(1+\delta) - (1-p)^{N-1}(\delta - p(1+\delta)) > 0$$

$$(\delta - p(1+\delta))[1-(1-p)^{N-1}] > 0$$

Since $N \geq 2$, this inequality holds if and only if $p < \delta/(1+\delta)$. □

The proposition says that the principal will use team incentives for problems that are difficult to solve, if the cost of effort is moderate relative to the project value. For any $p < \delta/(1+\delta)$, team incentives soften the principal's credibility constraint, whereas for all larger values of p they actually make his credibility problem worse.

One might wonder why team incentives don't unambiguously help with credibility, at least for all $p < \delta$. After all, team incentives smooth payment out over many periods, and when $p < \delta$ this gives rise to a smaller bonus. A smaller bonus, in turn, reduces the principal's incentive to renege.

The reason is that the size of the bonus is only one part of the credibility constraint. From (6) and (9), what matters is how this bonus compares to an agent's average contribution to expected profits. Under team incentives, the principal has to deal with moral hazard. He must give each agent strictly positive surplus to motivate him to work rather than free-ride on the work of others. Each agent's contribution to expected profits is therefore lower than under individual incentives, which is why the right-hand side of (9) is strictly less than the right-hand side of (6).

Whether team incentives help with credibility depends on which of the two effects dominates, payment smoothing or moral hazard. Here, the value of p is of particular importance. When problems are difficult to solve, the payment smoothing effect is strong and team incentives help with credibility.

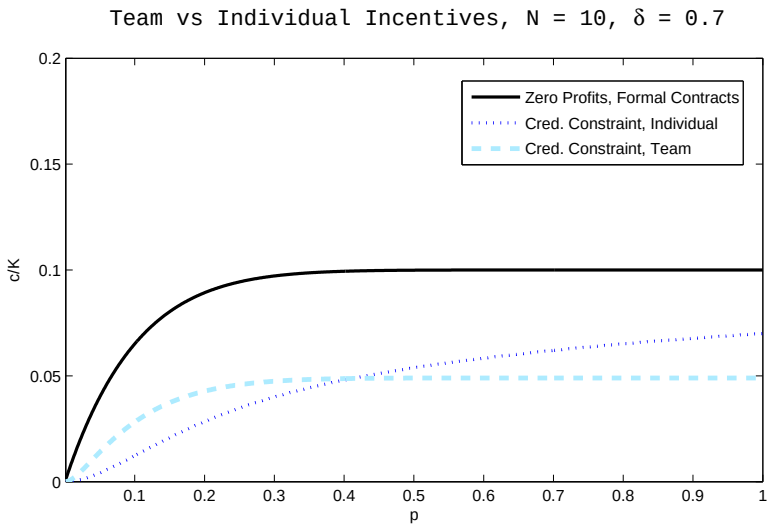
If $p < \delta/(1+\delta)$, then there are values of c/K for which team incentives are credible but individual incentives are not. The proposition shows that these are intermediate values of c/K. If c/K is small, then individual incentives are optimal because relational contracts do not impose a binding constraint. Credibility is not an issue, since the benefit of honoring the relational contracts dominates the short-term gain from defection. The principal can credibly offer b_i^* and capture all surplus. If c/K is large, then the principal cannot motivate agents under either incentive regime. No bonus is credible, even for some values of c/K for which working is efficient. The principal therefore uses team incentives if the cost of effort is moderate relative to the project value.

The critical value $p^* = \delta/(1+\delta)$ is increasing in δ. More patience increases the range of p for which team incentives can be profitable, to include some problems that are easier to solve. This is the case even though increased patience relaxes the principal's credibility constraint under individual incentives, and team incentives can only be useful when that constraint is violated.

The intuition is that an increase in δ has a direct effect under both incentive regimes, since a principal who is patient is less tempted to renege, but also has an added indirect effect under team incentives. When agents are patient, they are less inclined to shirk because they want to avoid the punishment from the grim trigger strategy. Moral hazard is less of a problem,

which increases profits and helps again with credibility.[4]

The following graph illustrates the result for particular values of N and δ.



The graph plots c/K, the ratio of effort cost to project value, versus p, the probability of solving a problem. The principal can earn positive profits with formal contracts in the region below the solid curve. Since formal contracts allow the principal to capture all surplus, this is also the region where it is efficient for agents to work.

The optimal team bonus is credible in the region below the curve represented with larger dashes, while the optimal individual bonus is credible in the region below the curve represented with smaller dots. The parameter values lying below the solid curve but above both the dotted and dashed curves are those where work is efficient, but the principal cannot motivate agents because of a lack of credibility.

The principal will use team incentives for parameter values such that a team bonus is credible, but an individual bonus is not. In the graph, this is

[4]An increase in δ does not unambiguously make team incentives more attractive. The range of p for which team incentives can be profitable does increase. However, for a given p, the range of c/K for which team incentive are profitable may decrease. For example, for any p, $B_p - A_p$ tends to zero as δ tends to 1.

the region above the dotted and below the dashed curve. For team incentives to be profitable, p should be less than 7/17, and then c/K should take on an intermediate value.

5 Optimal Team Size

The previous section considered individual and team incentives when team size was exogenous, so that the basic mechanism at work could be clearly shown. In this section, we endogenize team size by letting the principal choose N, the number of agents to employ at the beginning of the game. The reason for this exercise is twofold. First, with this added dimension, one might arrive at a different conclusion regarding the ranking of team versus individual incentives. Second, this approach also generates testable predictions regarding the relationship between team size and the type of compensation scheme, which, so far, seems to have been neglected in the literature.

As in the previous section, we look at two situations: where information is verifiable so the principal can use formal contracts, and where it is non-verifiable so he must use relational contracts. In each situation, for given parameter values, we are interested in whether the principal prefers to use individual or team incentives.

The principal's problem is not to pick his preferred value of N, and choose the incentive regime under which it can be implemented. That is because, quite apart from credibility issues, the profit maximizing team size will depend on the incentive regime being used. Team incentives force the principal to share surplus, which affects his incentive to hire more agents. Beyond this issue, credibility will again play a key role. An important factor for the principal will be which incentive regime allows him to motivate a greater number of agents.

Suppose that information about output is verifiable so the principal can use formal contracts, and say the principal uses individual incentives. The principal will choose a value of N such that,

$$\pi_N^i - \pi_{N-1}^i \geq 0. \tag{12}$$

Substituting π_N^i from (5) into (12) and evaluating it at b_i^* yields,

$$p(1-p)^{N-1}K \geq c, \tag{13}$$

The marginal agent's contribution to project value is positive when he is the only agent to solve a problem, the probability of which is monotone decreasing in N. On the other hand, the expected bonus payment per agent is constant at c. Therefore, the principal maximizes expected profits by choosing the largest integer N such that (13) is satisfied.

To be more precise, define $N_1 \in \mathbb{R}$ as the largest value of N such that $\pi^i_N - \pi^i_{N-1} = 0$. Then, the optimal number of agents to employ, N_1^*, is the largest integer less than or equal to N_1, that is $N_1^* = \lfloor N_1 \rfloor$

Now suppose information about output is non-verifiable, so the principal must use relational contracts. We showed in the previous section that for any given N, the optimal individual bonus is the same as with formal contracts: $b_i^* = c/p$. Any lower bonus would fail to cover the cost of effort.

The problem is this bonus may not be credible for $N = N_1^*$. To motivate the agents, the principal must satisfy the credibility constraint (6). Substituting b_i^* and rearranging gives

$$(1 - (1-p)^N)\frac{K}{N} \geq \left(\frac{1 - \delta(1-p)}{\delta p}\right) c, \tag{14}$$

Each side of this inequality is strictly greater than the corresponding side in (13), because there are two competing forces at work. For a bonus to be credible, an agent's contribution to expected future profits has to be bounded away from zero. For hiring an additional agent to be profitable, that agent's contribution just has to be positive. This suggests the credibility constraint should be violated at N_1. On the other hand, for credibility, it is an agent's average contribution to expected profits which matters, while for hiring a new agent it is the marginal contribution. The average contribution is strictly higher than the marginal contribution, which suggests the credibility constraint should be satisfied at N_1. The net impact of these two effects determines whether a bonus is credible at the unconstrained optimum.

The left-hand side of (14) is decreasing in N and the right-hand side is constant, so the credibility constraint is violated when N exceeds a given threshold. Define $N_2 \in \mathbb{R}$ as the value of N such that (14) holds with equality, and let $\lfloor N_2 \rfloor$ be the largest integer less than or equal to N_2. Then the optimal number of agents to employ, N_2^*, is the minimum of N_1^* and $\lfloor N_2 \rfloor$. Team size is therefore weakly smaller than under formal contracts.

The analysis for team incentives proceeds in a similar fashion. However, it is not necessarily true that profits π^t_N are concave in N, or that credibility becomes a bigger problem for large values of N.

Suppose team output is verifiable, so the principal can use formal contracts. Using (8) and (3), his optimal choice of N will maximize

$$\pi_N^t = \frac{1}{1-\delta}(1-(1-p)^N)(K - \frac{Nc}{\delta-(\delta-p)(1-p)^{N-1}}) \tag{15}$$

It will be an integer such that the following inequality holds for $N = N'$ but not for $N = N' + 1$,

$$\pi_N^t - \pi_{N-1}^t \geq 0. \tag{16}$$

Note that if π_N^t is quasi-concave in N, which we suspect is the case, it will be the largest value of N such that (16) holds. That is equivalent to

$$p(1-p)^{N-1}K \geq \left(\left[\frac{1-(1-p)^N}{\delta-(\delta-p)(1-p)^{N-1}}\right]N - \left[\frac{1-(1-p)^{N-1}}{\delta-(\delta-p)(1-p)^{N-2}}\right](N-1)\right)c. \tag{17}$$

The marginal benefit from hiring an additional agent is decreasing in N, just as it was under individual incentives. The marginal cost is the change in the expected total bonus payment, which is given by the right-hand side. The reason profits may not be concave is that this change is not always increasing in N. This is because moral hazard becomes a larger problem when N increases, but at a decreasing rate.

That being said, we show below that the change in the expected total bonus payment is strictly greater than c for all $N \geq 2$. Comparing (17) to (13), it therefore follows that with formal contracting, the optimal team size is weakly smaller under team incentives than under individual incentives.

Define $N_3 \in \mathbb{R}$ as the value of N that maximizes π_N^t, for which (17) holds with equality. Then, the optimal number of agents to employ is $N_3^* = \lfloor N_3 \rfloor$.

Finally, consider the case where information is non-verifiable, and the principal uses relational team incentives. For the promised bonus to be credible, it must satisfy the credibility constraint (9). Substituting b_t^* and rearranging gives

$$(1-(1-p)^N)\frac{K}{N} \geq \left[\frac{\frac{1}{\delta}-(1-p)^N}{\delta-(\delta-p)(1-p)^{N-1}}\right]c, \tag{18}$$

Just as with individual incentives, whether or not the constraint is violated at the unconstrained optimum, N_3^*, will depend on parameter values.

The left-hand side of (18) is decreasing in N, while the right-hand side can be either increasing or decreasing in N. Hence, in contrast to individual incentives, an increase in N does not necessarily make the credibility constraint harder to satisfy. One way to understand this is that the average contribution of each team member to expected profits is decreasing with N, but so is the size of the team bonus. The principal can promise each member of a large team a lower bonus, because team members expect to receive the bonus more often. The first effect hurts credibility, but the second effect helps. For some parameter values, a team bonus may not be credible for low or high values of N, but credible for values in between.

At first glance, this seems to suggest that, under team incentives, relational contracts can actually increase team size compared to formal contracts. That would be the case if all $N \leq N_3^*$ violate the credibility constraint, but some $N > N_3^*$ does not and gives strictly positive profits. However, we have looked extensively at numerical examples, and so far have no evidence that this actually occurs. At least in these examples, relational contracting decreases team size. Whether this is always the case remains to be seen.

Define N_4^* as the integer which maximizes π_N^t subject to (18). We then have the following result.

Proposition 3. Suppose $N \geq 2$ and $\delta > p$.

(i) Under individual incentives, the optimal team size is weakly smaller with relational contracting than with formal contracting: $N_2^* \leq N_1^*$

(ii) With formal contracting, the optimal team size is weakly smaller with team incentives than with individual incentives, $N_3^* \leq N_1^*$, and the principal uses individual incentives.

(iii) With relational contracting, the optimal team size can be either smaller or larger with team incentives than with individual incentives. The principal only uses team incentives if the optimal team size is strictly larger, $N_4^* > N_2^*$, but the converse is not true.

Proof.

(i) $N_2^* \leq N_1^*$ follows immediately from the fact that relational contracts just impose the constraint (14) on the principal's problem, which is satisfied if and only if N is below some threshold value.

(ii) To show $N_3^* \leq N_1^*$, it is sufficient to show that the right-hand side of (17) is greater than c. That will imply that (17) is violated for all $N \geq N_1$.

It is enough that the following expression be greater than 1 and increasing in N.

$$\frac{1-(1-p)^N}{\delta-(\delta-p)(1-p)^{N-1}} \tag{19}$$

It is greater than 1 because $\delta > p$. Taking the difference of (19) evaluated at $N = N'$ and at $N = N' - 1$, relabeling $N' = N$ and simplifying yields

$$\frac{(1-\delta)p^2(1-p)^{N-2}}{\left[\delta-(\delta-p)(1-p)^{N-1}\right]\left[\delta-(\delta-p)(1-p)^{N-2}\right]}$$

This is strictly positive for $N \geq 2$, so (19) is increasing in N.

To show that the principal uses individual incentives, note that the principal's expected profits with individual incentives for given N is (5) evaluated at (2):

$$\pi^i(N) = \frac{1}{1-\delta}\left[(1-(1-p)^N)K - Nc\right].$$

The principal's expected profits with team incentives is given by (15):

$$\pi^t(N) = \frac{1}{1-\delta}\left\{(1-(1-p)^N)K - \left[\frac{1-(1-p)^N}{\delta-(\delta-p)(1-p)^{N-1}}\right]Nc\right\}.$$

The term in square brackets is strictly greater than 1 for $N \geq 2$, so $\pi^i(N) > \pi^t(N)$. That implies profits are higher under individual incentives if $N_1^* = N_3^*$. Now say instead $N_3^* < N_1^*$. The optimal choice of N under individual incentives was N_1^*, so we have $\pi^i(N_1^*) > \pi^i(N_3^*)$. Combined with $\pi^i(N_3^*) > \pi^t(N_3^*)$, this implies $\pi^i(N_1^*) > \pi^t(N_3^*)$.

(iii) We illustrate that N_4^* can be either smaller or larger than N_2^* by example. Let $c/K = 1/30$, $\delta = 0.9$ and $p = 0.2$. The largest integer satisfying (13) and (14) is $N_2^* = 9$, while maximizing (15) subject to (18) yields $N_4^* = 8$. In this case, neither credibility constraint binds. Carrying out the same exercise for $\delta = 0.6$ gives $N_2^* = 4$ and $N_4^* = 6$, where the credibility constraint only binds under individual incentives. Moreover, in this last case, plugging into expected profits gives $\pi^i = 1.143$ and $\pi^t = 1.058$. So there are parameters for which $N_4^* > N_2^*$ but $\pi^i > \pi^t$.

To show that the principal uses individual incentives for all $N_4^* \leq N_2^*$, the proof follows similar lines to that in (ii). Profits are clearly higher under

individual incentives if $N_2^* = N_4^*$. If $N_4^* < N_2^*$, then $\pi^i(N_2^*) > \pi^i(N_4^*)$ because N_2^* was the optimal choice under individual incentives. That means N_2^* must have been credible. A choice of N is credible under individual incentives if and only if it is below a threshold value, so $N_4^* < N_2^*$ must be credible as well. That implies $\pi^i(N_4^*) > \pi^t(N_4^*)$, which yields $\pi^i(N_2^*) > \pi^t(N_4^*)$. $\square$

The intuition behind the proposition is as follows. That relational contracting (weakly) decreases the optimal team size under individual incentives is not so surprising. Relational contracting only adds an additional constraint to a well-defined problem, and each agent's contribution to team output is decreasing in team size. For instance, if $N_2^* = N_1^*$, then the credibility constraint does not bind, and profits are the same as under verifiable information. If $N_2^* < N_1^*$, then hiring an extra agent would increase expected profits, but by too little to make the principal's promise of a bonus credible. Because of this, profits under relational contracts are lower.

The second result is that with formal contracts, team incentives call for a (weakly) smaller team size than individual incentives do. When the principal hires a new agent, he has to give the new agent strictly positive surplus, and he also has to increase the surplus given to all other agents. This makes hiring extra agents unattractive, and in fact causes the principal to prefer individual incentives. For certain projects, however, individual incentives may be infeasible because the principal cannot observe individual output, in which case he would be constrained to offer team incentives. The result says that in such a case, the optimal team size with team incentives will be lower than it would be under individual incentives.

The last result tells us that with relational contracts, the principal may be better off choosing team incentives rather than individual incentives. In the previous section, this was because individual bonuses were not credible, and team incentives were required for agents to work at all. Here team incentives can allow the principal to motivate a larger number of agents. This can increase the principal's expected profits, particularly when the problems are difficult to solve. So if the principal chooses to use team incentives, the optimal team size will be higher than it would be under individual incentives.

To summarize, under formal contracting, team incentives will be used in small teams, and only because information on individual output is not observable. Under relational contracting, team incentives will be used in large teams, and it will be because they soften the principal's credibility constraint.

Letting team size be endogenous also allows us to say something about efficiency. The principal captures all surplus under individual incentives, but under team incentives he must give agents strictly positive rents. Agents need these rents to be willing to work despite the free-riding problem. That implies whenever the principal uses team incentives, they must be more efficient than individual incentives. Team incentives can be more efficient if they soften the principal's credibility problem and allow him to motivate more agents.

In contrast, the simulations below show many parameter values where team incentives are more efficient but the principal still uses individual incentives. The principal chooses team incentives over individual incentives less often than what would be optimal from a social perspective, because they do not allow him to appropriate all surplus.[5] We therefore have the following result.

Proposition 4. For any parameter values such that the principal uses team incentives, total surplus is higher than it would be under individual incentives. However, there exist parameter values such that the principal uses individual incentives, but total surplus would be higher under team incentives.

Proof. If the principal uses team incentives, then by Proposition 3 he must be using relational contracts. Total surplus under individual incentives is $\pi_i(N_2^*)$, plus the expected payment to agents, minus Nc. By (2), each agent's expected payment under individual incentives is just c, so total surplus equals $\pi_i(N_2^*)$.

Similarly, total surplus under team incentives is $\pi_t(N_4^*)$, plus the expected payment to agents, minus Nc. By (3), each agent's expected payment is

$$\left[\frac{1-(1-p)^N}{\delta-(\delta-p)(1-p)^{N-1}}\right]c$$

which, by $\delta > p$, is strictly greater than c for all $N \geq 2$. Total surplus is therefore strictly greater than $\pi_t(N_4^*)$. The fact that the principal uses team

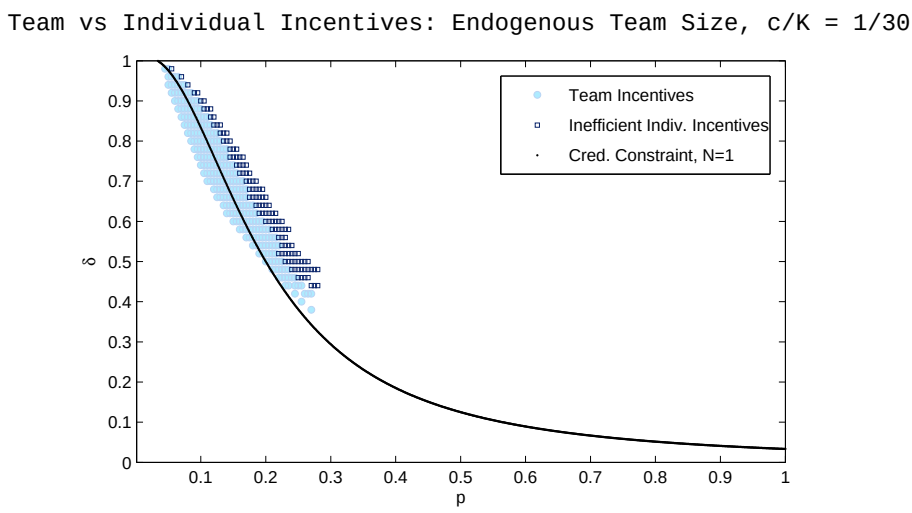
[5] In the simulations, the team incentives are more efficient than individual incentives if and only if they allow the principal to motivate more agents. To establish this as a general result, it would be sufficient that $N_4^* < N_3^*$, so that credibility problems cannot cause teams to be inefficiently large under team incentives. This appears to be the case, but it is not immediately clear since (18) can be non-monotonic in N.

incentives implies $\pi_t(N_4^*) \geq \pi_i(N_2^*)$, so team incentives must give strictly higher total surplus.

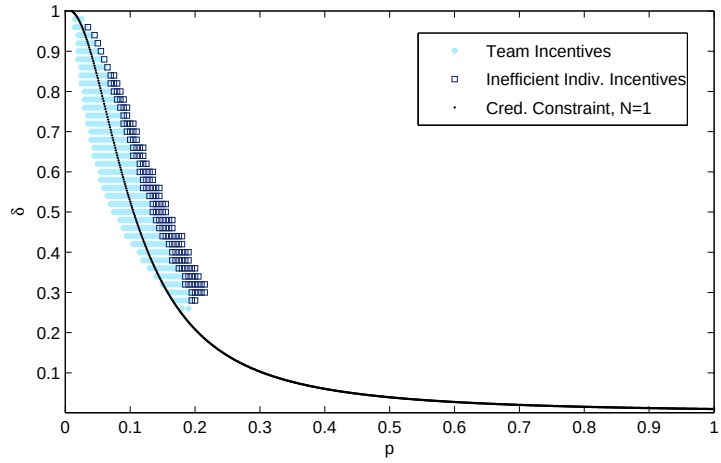
The second part of the proposition follows from the numerical simulations below. □

We now use simulations to gain more insight into when the principal uses team incentives, and when he uses individual incentives even though they are inefficient. The parameters p and δ both lie between 0 and 1, while N is endogenous, and c and K only matter through the ratio c/K. We fix the value of c/K, and divide (p, δ)-space into a grid of 200 by 50. For each vertex of the grid, we determine how many agents the principal would hire under individual and team incentives, and which regime gives the highest profits.

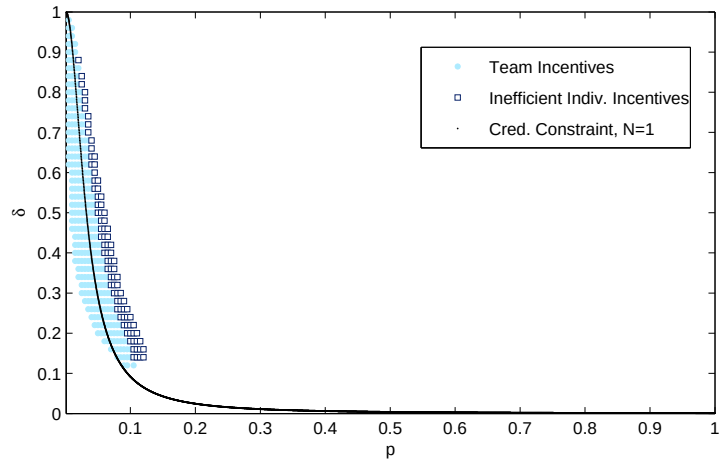
We represent the results graphically, and vary c/K to show how they change. The lighter circles show where the principal uses team incentives, while the darker squares show where he uses individual incentives even though they are inefficient. By the first part of Proposition 4, these two regions give the parameter values for which team incentives are efficient. The solid curve gives the principal's credibility constraint when $N = 1$.



Team vs Individual Incentives: Endogenous Team Size, c/K = 1/100



Team vs Individual Incentives: Endogenous Team Size, c/K = 1/1000



The results show that the principal uses team incentives in a region around the solid curve. This is not surprising, since this is the region where credibility is a problem.

The principal tends to use team incentives when p is relatively low, and then for intermediate values of δ. If p is high, then an individual bonus will likely be paid in most periods, and team incentives do little to smooth payments over time. In particular, we know from Proposition 2 that the

principal will never use team incentives for $p \geq \delta/(1+\delta)$, because then they cannot help with credibility for any N.

If both p and δ are low, the principal cannot motivate any agents because a bonus is not credible under either incentive regime. As δ increases, team incentives become credible and the principal can motivate agents to work. This is the case both for some parameter values below the solid curve, where individual incentives are not credible, and for some parameter values above the solid curve, where individual incentives are credible but team incentives allow the principal to motivate more agents.

As δ increases still more, credibility becomes less of a problem and the principal switches to individual incentives, because they allow him to capture all surplus. The graphs suggest he switches at a value of δ where team incentives are still efficient.

The graphs illustrate how, in contrast to individual incentives, the credibility constraint under team incentives can actually become easier to satisfy as N increases. When $N = 1$, an individual bonus is equivalent to a team bonus. The principal cannot motivate a single agent to work in the region below the solid curve, because the promised bonus is not credible. However, the principal is able to motivate at least $N \geq 2$ agents with team incentives at each point where there is a light blue circle, some of which lie below the solid curve. By helping with credibility, team incentives expand the parameter space for which the principal can profitably motivate agents.

As c/K decreases, credibility is less of a concern and the region where team incentives are efficient shifts towards the south-west corner of (p, δ)-space. Team incentives can now motivate agents at points where they previously were not credible. At the same time, there are other points where the principal now uses individual rather than team incentives because credibility is no longer an issue.

6 Hybrid Incentives

The assumption that the principal can choose either individual or team incentives may appear restrictive, because in the real world, organizations sometimes reward employees both for individual and team performance. There may exist a pay differential between performers and non-performers within teams, but the firm also rewards all team members if the group achieves a certain goal.

In this section, we consider a hybrid incentive scheme, in which the principal can use both an individual and team bonus. In line with the previous sections, we do not consider the optimal contract, but rather all combinations of individual and team-based incentives.

To further simplify the analysis, we treat N here as exogenous. Our purpose is to investigate whether simultaneous use of individual and team incentives would eliminate the need for team incentives, and whether efficiency can be further increased by combining the two incentive schemes. The answer to the second question is a fairly straightforward yes because this is merely a relaxed program for the principal. The answer to the first question is no, which means that our results on team incentives are in fact robust to this extension.

Suppose that the principal promises to pay an individual bonus b_i to any agent who solves a problem, and at the same time he promises to pay each team member a bonus b_t whenever any one of the agents solves a problem. Then, the principal's problem is to choose b_i and b_t, which minimize the total costs necessary to induce the agents to work,

$$\min_{b_i, b_t} (1 - (1-p)^N) N b_t + N p b_i,$$

subject to the agents' incentive constraints:

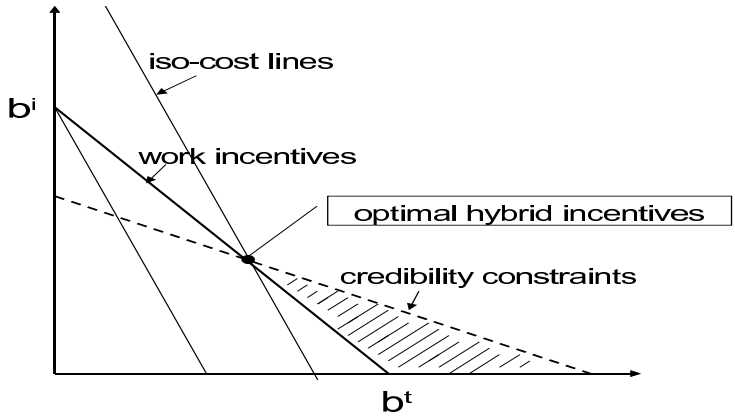
$$\frac{1}{1-\delta} \left[p b_i + (1 - (1-p)^N) b_t - c \right] \geq (1 - (1-p)^{N-1}) b_t.$$

This incentive constraint reduces to

$$p b_i \geq \left[(1-p)^{N-1} (\delta - p) - \delta \right] b_t + c, \tag{20}$$

These work incentives are illustrated below in Figure 1 as a solid line.

Figure 1



The slope of this constraint is

$$-\frac{\delta - (1-p)^{N-1}(\delta - p)}{p},$$

whereas the slope of any iso-cost line is

$$-\frac{1-(1-p)^N}{p}.$$

Thus, the iso-cost lines are steeper than the agents' work incentive constraint as long as $N \geq 2$. It then follows that the optimal formal contract is to use only individual incentives, which is in line with the previous findings.

On the other hand, relational contracts impose the following credibility constraint:

$$N(b_t + b_i) \leq \frac{\delta}{1-\delta}[(1-(1-p)^N)(K - Nb_t) - Npb_i] \tag{21}$$

The principal's maximum gain from reneging is $N(b_t + b_i)$, which is the total bonus payment if all agents solve the problem in a period. This must be less than or equal to the lost value from discontinuing the productive relationship.

This constraint is illustrated in Figure 1 as a dotted line. In fact, Figure 1 illustrates a case where the principal chooses an incentive scheme involving a team-based bonus, and the shaded area represents the set of bonus pairs that satisfy both the agents' work incentive and the principal's credibility constraint. Since the iso-cost lines are steeper than these lines, the principal's optimal choice is at the intersection of the two constraints. In general, what matters is the relative position of the two constraints, which determines which incentive scheme the principal will choose under relational contracting.

Proposition 5. Suppose $N \geq 2$ and $\delta > p$, and the principal can use hybrid incentives. (i) Under formal contracting, the principal uses individual incentives. (ii) Under relational contracting, the principal uses hybrid incentives that involve a team bonus if and only if he would have chosen pure team incentives had there been no possibility of a mixture. Both individual and team bonuses are smaller under optimal hybrid incentives than when they are used separately, and the principal earns higher profits.

Proof. (i) The proof follows directly from the text. (ii) It suffices to show that the condition under which the principal chooses hybrid incentives involving a team bonus is the same as when he would choose team incentives from Proposition 2. It can be verified that the x- and y-intercepts of the agents' work incentive constraint (20) are just b_t^* and b_i^* from (2) and (3).

Say (6) holds so the principal would choose individual incentives over team incentives. He will also choose only individual incentives now if the y-intercept of the credibility constraint (21) is higher than b_i^*. That is just

$$b_i^* \leq \frac{\delta(1-(1-p)^N)}{1-\delta(1-p)}\frac{K}{N}, \tag{22}$$

which is the same condition as (6).

Now say (6) is violated but (9) is satisfied, so the principal would choose team incentives over individual incentives. The x-intercept of the credibility constraint (21) is higher than b_t^* if

$$b_t^* \leq \frac{\delta(1-(1-p^N))}{1-\delta(1-p)^N}\frac{K}{N}, \tag{23}$$

which is the same condition as (9). Given (i) and the fact that the slopes are all negative, it follows that the principal will use a team bonus as part of a hybrid incentive scheme as in Figure 1. The optimum lies at the

intersection of the two constraints, and the bonuses are smaller than the x- and y-intercepts. The boundary case occurs when condition (22) is violated but (23) is satisfied with equality, so the principal uses only the optimal team bonus, b_t^*. □

The proposition says that under exactly the same conditions as when the principal chose team incentives in Section 3.4, team incentives are now used as part of a hybrid incentive scheme. They are used alongside individual incentives, except for the boundary case. This means that our previous findings do not change substantially when we allow the principal to combine both incentive schemes. The only difference is that now the principal's expected cost is lower than before.

As mentioned above, a hybrid incentive scheme seems more consistent with the observation that incentive pay may depend on more than one performance measure, so on both individual and team performance. That is, all workers receive a bonus when the team's project succeeds, but those who have made a large contribution receive more than others. The key is again that the group bonus is used to reduce the principal's commitment problem.

7 Conclusion

This paper provides a rationale for using group incentive schemes, such as a divisional bonus, even if individual output is observable. When individual incentives are not credible, the principal may still be able to motivate employees by rewarding them based on group outcomes.

We set our argument in the context of problem-solving organizations, providing a particularly tractable model where we can endogenize team size. We show that team-based incentives are sometimes used under relational contracting, even when the production technologies are independent and agents are risk neutral.

The key point is that agents may be willing to work for a lower bonus when they are rewarded each time a team member solves a problem, rather than only when they solve a problem themselves. Agents then expect to receive a bonus more often, so the principal can smooth payments out over time. Team incentives also create a free-riding problem, but it can be mitigated by implicit contracting if agents are sufficiently patient.

If information about output is non-verifiable, then smoothing bonus pay-

ments via team incentives is good for credibility. The principal is less tempted to renege on smaller, more frequent, bonuses, and this effect becomes stronger when problems are difficult to solve.

Under formal contracting, in our set-up, the principal always prefers to use individual incentives. The principal would only use team incentives if he did not observe individual output, in which case team incentives would lead him to reduce team size. Under relational contracting, however, the principal will use team incentives when problems are difficult to solve, and the effort cost is moderate relative to the project value. In this case, team incentives allow the principal to motivate more agents and increase team size.

We also show that, from a social point of view, the principal chooses team incentives over individual incentives less often than would be efficient. Team incentives can be more efficient if they allow the principal to motivate a greater number of agents. In some such situations, however, the principal still prefers individual incentives because they allow him to capture all surplus.

As more and more people solve problems rather than manufacture goods, we believe team-based incentive schemes may be increasingly important for knowledge workers and organizations that employ them. We already observe that in many cases, team members share both monetary and reputation rewards based on the outcome of the whole project. Our results suggest that when credibility is an issue and problems are difficult to solve, team incentives can play a particularly important role.

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