Optimal Incentives in Problem Solving Teams

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Abstract

Workers in problem solving teams- these are *short term* teams that are set up to generate ideas for improving a production process or a product- are often rewarded through group incentive pay. This is even though group incentives give workers an incentive to free ride. In our paper, we show how problem solving creates implicit incentives to reduce free riding, which in turn lowers the cost of using group incentive pay. In fact, when an employer has initial bargaining power and implicit incentives are strong, group incentive pay yields higher profits than monitoring workers, *even when monitoring is costless*.

1 Introduction

Over the past two decades, group incentive pay has become common in the workplace. In a survey of Fortune 1000 firms, Lawler and Mohrman (2003) find that the percentage of firms that use some form of team incentives increased from 21 per cent in 1990 to 50 per cent in 2002.[1] One setting where this form of incentive pay is regularly used is in problem solving teams: these are teams that are set up for *short periods* to generate ideas to improve a production process or a product. For example, steel minimills that use teams to improve the production process, almost always tie the pay of their workers to production, product quality or profit of a line (Boning, Ichniowski, and Shaw (2007)).[2] As another example, pay in product development teams typically depends on completion of the project on time and within budget (Zingheim and Schuster (2000)). This widespread use of group incentive pay is hard to reconcile with theories of free riding (Alchien and Demsetz (1972) and Holmstrom (1982b)). Indeed, when a worker is rewarded with a share of the output

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[1] According to their definition, at least 20 per cent of the employees in the firm are covered by some form of team incentives.

[2] As Boning, Ichniowski, and Shaw (2007) point out, problem solving teams without group incentive pay exist in only 1.5 percent of all monthly observations in their sample.

of a team, he gets only a fraction of his marginal product of effort whereas he bears the entire marginal cost. So he has little incentive to work hard.

The purpose of our paper is to explain why group incentive pay is frequently used in problem solving teams. Our key point is that idea generation in problem solving teams is a source of implicit incentives; when a worker can take an idea to a different firm in the future and when firms try to infer the value of these ideas, there is a link between wages tomorrow and productive actions today. Because workers in a team generate ideas *together*, these implicit incentives also reduce free riding and thus lower the cost of group incentive pay. In fact, we show that when employers have initial bargaining power and when implicit incentives are strong, group incentive pay yields higher profits for a firm when compared to monitoring workers, *even when monitoring is costless.* This last point, stands in sharp contrast to existing theories which emphasize the benefits of monitoring workers in teams (Alchien and Demsetz (1972)). The reason for this result, loosely, is that firms with initial bargaining power have an incentive to overwork their employees in earlier periods, to try to extract rents that workers earn from their ideas in the future. Group incentive pay, with a natural budget balance constraint on incentives, helps a firm to commit not to overwork its employees.

We build on a simple and well-known model of implicit incentives: the career concerns framework of Holmstrom (1982a). In our setting, a worker can influence output in two ways. First, he can generate ideas to solve problems. These ideas increase output today with the current employer. But they can also be used in the future at a different firm. So ideas play a similar role as ability in the traditional career concerns framework: an idea is a productive and time- invariant attribute of a worker, whose value all firms are trying to infer. Second, the worker can take costly actions (effort) to execute his ideas and increase output in the current period. These features give rise to implicit incentives in the form of career concerns: a worker has an incentive to work hard to make his ideas appear more valuable to a labor market.

Implicit incentives arise when a worker generates ideas to solve problems. But these implicit incentives alone are not enough to reduce free riding. In fact, when each worker on a team solves a different problem, free riding is once again an issue. This is because the value of an idea generated by a worker on one problem adds noise to the inference of the value of an idea on another. Instead, what does matter for reducing free riding is that workers on a team solve problems *together.* This reduces the noise in the inference process and because each worker in the team can take the same idea to a different firm in the future, workers can extract the full marginal benefit from an idea. We show that as problem solving becomes more important in production and as problems become more complex (i.e. as the proportion of problems solved together and the variance of the value of these problems increases), these implicit incentives become stronger, and in the limit free riding disappears so that effort is at its efficient level.

An alternative way to understand how implicit incentives reduce free riding in our framework is to consider a solution proposed by Holmstrom (1982b). His solution involves giving each worker in the team the entire share of the output produced by the team. As a result, the marginal benefit to a worker from an additional unit of effort equals the marginal product. This restores efficiency but violates a budget constraint: output is produced only once but it has to be paid to each worker. To make this scheme feasible, workers in the team have to post bonds up front. In our framework with career concerns, a worker's wage also depends on a share of output. But in contrast to Holmstrom (1982b), these *implicit shares* are determined by inferences made by a labor market. When all problems are solved together and when problem solving is very valuable in production in the limit, then these shares in our framework tend to a hundred per cent. So a worker's marginal benefit from altering inferences with an additional unit of effort equals the marginal product of effort, restoring efficiency. Our solution, however, does not require workers in a team to post bonds up front. Wages instead are financed by competing firms in a labor market that value a worker's ideas.

Given, implicit incentives, the role of an explicit scheme is to provide residual incentives so that effort reaches an efficient target level. The first type of explicit scheme that we consider is group incentive pay, where a team is rewarded based on its total output subject to a budget balance restriction where total payments to team members cannot exceed total output. We show that as implicit incentives become stronger (i.e. as problem solving becomes more important in production and as problems become more complex), the efficiency loss because of free riding gets smaller. Thus, we show that free riding costs associated with group incentive pay are lower in problem solving teams. This is our first main result and helps explain why group incentive pay is commonly used in problem solving teams.

We also compare group incentive pay with another explicit scheme where firms can monitor workers and observe their individual effort. In a static setting, without implicit incentives, monitoring workers clearly dominates group incentive pay in terms of generating a larger surplus. A firm that monitors effort can get workers to choose the efficient level of effort whereas free riding is a problem with group incentive pay. This role of monitoring in reducing free riding is the central point in Alchien and Demsetz (1972).

But in a dynamic setting with implicit incentives, things change. In particular, when an employer has initial bargaining power, his marginal benefit from inducing an additional unit of effort includes an increase in output today *and* higher wages paid by firms that use an employee's ideas in the future. So an employer will always have an incentive to induce too much effort initially to try to extract rents that its workers earn from their ideas in the future. Indeed, when firms monitor workers, effort always overshoots the efficient target level. Group incentive pay, on the other hand, because of a natural budget balance constraint, helps a firm to commit to not overworking its employees in earlier periods. When implicit incentives are strong (i.e when problem solving is valuable in production and when problems are complex), residual incentives are small, and group incentive pay yields higher profits for an employer relative to monitoring workers. Highlighting this endogenous cost of monitoring is the second main result of our paper. This result stands in sharp contrast to work that emphasizes the benefits of monitoring teams (Alchien and Demsetz (1972)).

While our focus is on teams that interact for *short periods*, there are complementary papers in the literature which explain the use of group incentive pay in teams that interact for *long periods*. In Kandel and Lazear (1992), profit sharing (a form of group incentive pay) creates externalities across team members and thus provides incentives for workers to monitor one another. To make this point, they modify an individual's effort cost function (as a proxy for repeated interaction possibly) to include peer punishments. Che and Yoo (2001) consider a repeated setting and show how joint performance evaluation, where workers are rewarded for good performance only when their co-workers also perform well, provides incentives for workers to punish their peers and thus lowers the cost of providing incentives. Finally, Rayo (2007) also considers a repeated framework with peer monitoring and endogenous partnership shares. Like in our paper, implicit incentives in all of these papers play an important role in lowering the cost of group incentive pay. But the way in which these implicit incentives arise, however, is different because of the duration of the team.

Our paper is also related to a large literature on career concerns starting with Fama (1980) and Holmstrom (1982a). The two closest papers are Gibbons and Murphy (1992) and Meyer and Vickers (1997). Both consider explicit incentives in a career concerns setting. There are two key differences though. First, in their papers the output that an individual worker produces, is observable to firms. Second, there is no over-provision of effort in their setting. Our paper is also related to other work that considers career concerns in teams. There are three key features together that distinguish our analysis: i) only team output is observable to firms, ii) the productive attribute (ideas, in our setting) is similar across team members, and iii) we consider both implicit and explicit incentives. Meyer (1994), Jeon (1996) and Ortega (2003) have only the first feature where only team output can be observed by a firm. Auriol, Friebel, and Pechlivanos (2002) study explicit incentives but they do not have the first two features. Finally, Andersson (2002) considers a two-period setting with turnover and where contracts are unobservable and also shows that workers over-provide effort in equilibrium.

When employers have initial bargaining power, both current and future benefits accrue to the employer in the current period. This is why monitoring is inefficient in our setting; firms will induce inefficiently high levels of effort in earlier periods. There are other reasons in the literature that emphasize costs of monitoring. Bonatti and Horner (2011) consider a team setting where benefits are public but costs are private and where there is uncertainty about the feasibility of a project. They show that when efforts are observable, team members tend to (inefficiently) procrastinate more. The reason is that when low levels of effort by a member are detected, the team is less pessimistic about the feasibility of a project. This role of monitoring in influencing beliefs is also important in Bag and Pepito (2011).

While our focus is on incentives that arise from problem solving, there is a large team theoretic literature which looks at decision making when people have different information (VanZandt, Garicano (2000), Cremer (1993), Prat (2002)). These papers, however, do not focus on incentive issues. Our work is also related to other theories of knowledge transfer both within and across firms: theories of routines (Nelson and Winter (1982)), standard operational procedures (Cyert and March (1963)), and resources and organizational capabilities (Penrose (1959)). A similarity with this work is that knowledge of an idea is tacit and cannot be codified. Li (2012) considers incentives for workers to share knowledge in a team. Our paper is also related to work by Akerlof and Kranton (2008) on identity and its motivational effects. However, our paper provides a rationale for why individuals care about their group without having to change preferences of the agent.

2 Examples of Problem Solving Teams

In this section, we give a few examples of problem solving teams. These examples provide details in terms of the ideas teams generate and how they generate them. In particular, all of these examples emphasize the benefits from having a team generate ideas together.

1. New Product Development

   In 2004, Motorola put together a team to create the thinnest phone on the mobile phone market, the RAZR (Anthony (2005), Edmondson (2012)). The team consisted of 20 engineers in different fields such as electrical and mechanical engineering. The key tradeoff that the team faced was between appearance and functionality. For example, the team had to find ways in which to place the battery, antenna and camera without compromising the sleek design. These problems were solved together by the entire team. The team would meet at 4 pm every day to discuss solutions and these meetings usually ran for three hours or so. The following quote by the team leader, Roger Jellicoe, summarizes the role that discussions played in solving both design and functionality problems. "When the novel ideas were put together the risks seemed manageable. This illustrates....the fact that innovation can sometimes move forward only when ideas are evaluated in combination rather than isolation." Two aspects of this example are important. First, it highlights the benefit from having a team with different specialists generate ideas together. Second, it emphasizes the role of discussion in generating ideas so that each member of a team knows ideas.

2. Reducing Glitches

There are several examples of problem solving teams that are formed to reduce *glitches*: these are defects in a product which arise when a specialist in one functional area does not understand constraints faced by a specialist in another functional area. For example, Boeing formed *integrative* teams - these are teams that are set up to ensure better coordination across various functional areas- to reduce glitches on its 777 passenger jet by about fifty percent (Dumain 1994).[3] Hoopes and Postrel (1999) have several examples of costly glitches that arise when ideas are not coordinated across different functional areas. Here are some examples. The research department of an aircraft company can recommend that a fighter jet be built with a novel material, but when the prototype is being constructed, it is noticed that every known technique for mounting the engine causes the structure to crack. Similarly, a marketing department can propose a new lightweight vacuum cleaner but designers who are interested in more a more powerful cleaner design a product which is much heavier and more costly to produce.

3. Improving the Production Process

   Recent empirical work by Boning, Ichniowski, and Shaw (2007) focusses on problem solving in steel minimills. Minimills use electric arc furnaces to melt scrap steel to form raw steel bars which are then rolled into a final product. Boning, Ichniowski, and Shaw (2007) provide a variety of examples of problem solving: inserting a new gauge on the line to improve quality control, tackling defects by reconfiguring the layout of the line and learning to operate new capital better. Boning, Ichniowski, and Shaw (2007) also find that if a mill has formal procedures for teamwork then productivity increases. These productivity gains are larger in more "complex" production lines which produce more intricate shapes of steel and with tight tolerances for deviations from product specifications.

3 Model

There are two periods and no discounting. There are N different areas in production indexed by $i = 1, 2, 3, ..., N$. In terms of the new product development example, the different areas could be design, marketing and manufacturing. Associated with each area is a large pool of workers, each with a reservation utility normalized to 0. There is a firm who we also refer to as the principal, P. P can produce in both period 1 and in period 2. There are also competing firms that can only produce in period 2. All firms, P and competing firms, have a reservation profit level of 0 in each period. Everyone in the model is risk neutral.

To produce in period 1, P must hire a team of N workers, with each worker corresponding to a different area. At the start of period 1, P makes a take it or

[3] "The trouble with teams." by Brian Dumain, Fortune 1994.

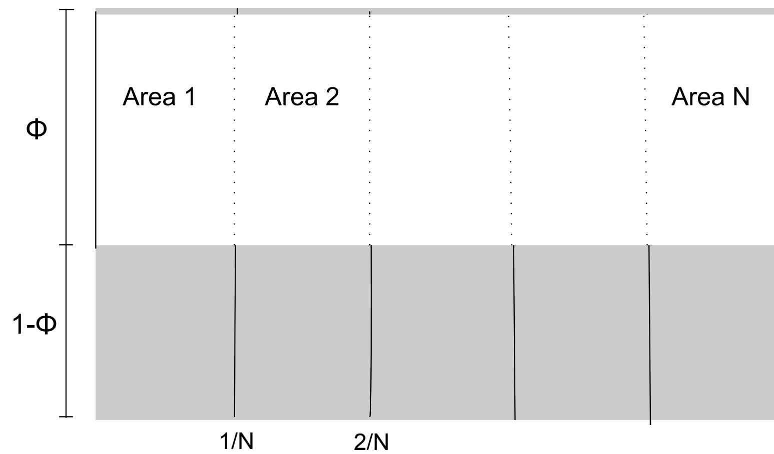

Figure 1: Set of Problems.

leave it wage contract to one worker from each area. Let w_{i1} be the wage of a worker in period 1 in area i. These contracts are enforceable for one period only.

If all the N wage offers are accepted, the team solves a set of problems represented by Figure 1. Problems are equally divided across each of the N different areas. A proportion of the problems $\phi > 0$ in each area are solved *together* by the team. In this case, each worker in the team knows the idea. The remaining proportion $(1 - \phi)$ of problems in an area are solved *individually* by a worker in that area. In this case, only the worker who solved the problem knows the idea. Ideas i) can be used for both current and future production, ii) have uncertain value (all economic agent's in the model do not know the value of an idea but they know the distribution of the value), iii) can only be transferred from one firm to another when a worker who knows an idea moves. For a problem solved by a team, the value of the idea is $\lambda\mathcal{V}$ where $\mathcal{V}$ is distributed normally with mean $E(\mathcal{V}) > 0$ and variance $\sigma^2_{\mathcal{V}} > 0$ and where $\lambda > 0$ is a parameter that measures the degree to which these ideas are valuable in production. For a problem that is solved individually, the value of the idea is λv_i, where v_i is normally distributed with a mean normalized to 0 and a variance $\sigma^2_v > 0$. Information about the distributions of these values is symmetric across all workers and firms in the model. We refer to a worker i who solves problems in area i as a *problem solver* i. In other words, each worker who is hired at the start of period 1 by firm P, becomes a problem solver at the end of this period.

After problems are solved, production begins in period 1. Each problem solver i exerts privately observable effort e_{i1} to execute ideas. This effort is costly for the problem solver and his cost function is given by $\frac{1}{2}e^2_{i1}$. Problem solver $i's$ utility in period 1 from working for P is then $w_{i1} - \frac{1}{2}e_{i1}^2$. Output y_1 in firm P is given by

$$y_1 = f(e_{11}, e_{21}, .., e_{N1}) + \lambda(\phi\mathcal{V} + \frac{(1-\phi)}{N}(v_1 + v_2 .. + v_N)) + \epsilon_1 \tag{1}$$

Equation (1) has three parts. As in Holmstrom (1982b), output depends on effort of problem solvers and this part is given by $f(e_{11}, e_{21}, .., e_{N1})$ where f is strictly increasing, concave and differentiable with $f(0) = 0$. The second part in (1), shows how ideas contribute to output. The total value of ideas is the sum of the values of ideas generated individually, $\lambda\frac{(1-\phi)}{N}(v_1 + v_2 .. + v_N)$, and the values of the ideas generated together, $\lambda\phi\mathcal{V}$. Because the value of an idea is uncertain, it plays exactly the same role as a time invariant productive attribute (talent or ability) in the career concerns framework of Holmstrom (1982a). Finally there is a noise term in (1), given by ϵ_1 which is normally distributed with mean 0 and variance $\sigma_\epsilon^2 > 0$.

Next, consider period 2. As in period 1, a firm that wants to produce, must hire a team of N workers, with each worker corresponding to a different area. But it must also have at least one problem solver on the team. To keep the model tractable, we assume that a firm can make offers to at most one problem solver with firm P only making an offer to problem solver 1. We relax this assumption later in our robustness section. So for example, consider a firm that successfully hires problem solver 2. To produce, this firm also has to hire a worker in area 1, a worker in area 2, a worker in area 4, and so on all the way up to area N. From this point on we use the superscript i to denote the area of a problem solver and the subscript j to denote the area of a worker. When $i = j$, the worker is a problem solver. Let w_{j2}^i denote wages in period 2.

If a firm hires a team with a problem solver i, each worker on the team, exerts privately observable effort given by e_{j2}^i to execute problem solver $i's$ ideas. To simplify notation, we sometimes drop the superscript when we refer to a problem solver's effort in period 2 and denote $e_{i2}^i = e_{i2}$. A problem solver's utility in period 2 is thus given by $w_{i2}^i - \frac{1}{2}e_{i2}^2$ and for workers who are not problem solvers their utility is given by $w_{j2}^i - \frac{1}{2}e_{j2}^{i2}$ where $j \neq i$.

Output in period 2, for a firm that hires problem solver i is then given by

$$y_2 = f(e_{12}^i, e_{22}^i, .., e_{N2}^i) + \lambda(\phi\mathcal{V} + \frac{(1-\phi)}{N}v_i) + \epsilon_2 \tag{2}$$

The noise term, ϵ_2, is normally distributed with mean 0 and variance $\sigma_\epsilon^2 > 0$ and is independent of ϵ_1.

Given that problem solvers can take their ideas to a competing firm, it is useful to define a new variable $\mathcal{V}_i = \lambda\phi\mathcal{V} + \frac{\lambda(1-\phi)}{N}v_i$. $\mathcal{V}_i$ is the value of ideas that problem solver i can transfer to a competing firm.

We can then rewrite output in period 2, for a firm that hires problem solver i as

$$y_2 = f(e^i_{12}, e^i_{22}, .., e^i_{N2}) + \mathcal{V}_i + \epsilon_2 \tag{3}$$

The timing and information of the game is as follows. At the start of period 1, P offers a take it or leave it contract with a wage w_{i1} to one worker from each area. Initially, in our model with implicit incentives, we assume that these wages are fixed. Later on when we consider explicit incentives, we allow for contingent wages. We also assume that firms can only commit to short term contracts for one period. Each worker decides whether to participate or not. If P cannot successfully hire a team, no production takes place and all agents in the model get their reservation utility for both periods. If P does successfully hire a team, problems are solved and ideas generated. Problem solver i then chooses his effort level e_{i1}, which he alone observes. Output y_1 is then produced and everyone including competing firms observe it. In period 2, firms compete for problem solvers by offering wages w^i_{i2}. We also assume that each firm can make offers to at most one problem solver, with P making an offer only to problem solver 1. A firm that makes an offer to problem solver i also makes take it or leave it offers to other workers in areas besides the area of problem solver i (there is no competition amongst firms for workers who are not problem solvers). Each problem solver i then chooses which firm to work for, and workers who are not problem solvers also decide whether to accept offers. A firm that cannot successfully hire a team gets its reservation profit of 0. On the other hand, if a firm successfully hires a team with a problem solver, all workers (including the problem solver) exert privately observable effort. Output for period 2, y_2 is then realized and then the game ends.

Given the production functions in both periods, there are three important parameters to keep track of when performing comparative statics. The first parameter, λ is the degree to which problem solving is important in production. The other two parameters measure the degree of complexity in problem solving. When ϕ is larger, problem solving is more complex because a larger proportion of problems have to be solved by workers in different areas. When $\sigma^2_{\mathcal{V}} > 0$ is larger, the values of ideas solved together vary a lot, once again indicating that problems are more complex.

4 Efficiency

We start our analysis by characterizing efficient levels of effort. A useful benchmark is to think of a social planner who maximizes total expected surplus at the start of period 1. The planner then chooses effort in both periods to maximize

$$W = W^P_1 + \sum_i E(W^i_2(y_1))$$

where

$$W_1^P = f(e_{11}, e_{21}, .., e_{N1}) - \sum_i \frac{1}{2} e_{i1}^2 + \lambda \phi E(\mathcal{V})$$

and

$$W_2^i(y_1) = f(e_{11}^i, e_{22}^i, .., e_{N2}^i) - \sum_j \frac{1}{2} e_{j2}^{i2} + E(\mathcal{V}_i | y_1)$$

The first order necessary conditions to this problem are

$$f_{e_{i1}}(e_{11}, e_{21}, .., e_{N1}) = e_{i1} \text{ for all } i = 1, 2, 3, ..., N \tag{4}$$

and

$$f_{e_{j2}^i}(e_{12}^i, e_{22}^i, .., e_{N2}^i) = e_{j2}^i \text{ for all } i, j = 1, 2, 3, ..., N \tag{5}$$

These conditions equate the marginal product of effort with the marginal cost.

5 Equilibrium- Implicit Incentives

The objective in this section is to compare equilibrium effort levels with the efficient effort levels above. The equilibrium concept we use is a Perfect Bayesian Equilibrium and we restrict our attention to pure strategies. To solve for the equilibrium, let us start at the last stage of period 2 where workers make effort choices. Because wages in period 2 are paid before effort is chosen, no effort is exerted in period 2.

Next, consider wage offers made to problem solver i at the start of period 2. Because no effort is exerted in period 2 and because $E(\epsilon_2 | y_1) = 0$, perfect competition ensures that in equilibrium

$$w_{i2}^i = E(\mathcal{V}_i | y_1) \quad \text{for all } i = 1, 2, 3, ..., N \tag{6}$$

All other workers in period 2 who are not problem solvers get a wage of 0 so that their utility equals the reservation level of 0. Next, consider the updating rule for the posterior mean of $\mathcal{V}_i$. Let $(\bar{e_{11}}, \bar{e_{21}}, .., \bar{e_{N1}})$ be the levels of period 1 effort that firms conjecture. Given these conjectures of firms, a firm then uses the signal z to update its beliefs about $\mathcal{V}_i$ where

$$z = y_1 - f(\bar{e_{11}}, \bar{e_{21}}, .., \bar{e_{N1}}) = \mathcal{V}_i + \frac{\lambda(1-\phi)}{N} \sum_{-i} v_{-i} + \epsilon_1 \tag{7}$$

The signal z has two parts. The first part is the value of problem solver $i's$ ideas given by, $\mathcal{V}_i$ which other firms are trying to infer before making wage offers in (6). The second term given by $\frac{\lambda(1-\phi)}{N} \sum_{-i} v_{-i} + \epsilon_1$ is the noise component of the signal. Given all the random variables are normally distributed, the updating rule then is simply a weighted average of the signal z and the prior mean of $\mathcal{V}_i$, where the weight depends on how much of the variation in z is driven by $\mathcal{V}_i$ as opposed to the noise term.

Thus

$$w_{i2}^i = E(\mathcal{V}_i|y_1) = Sz + (1 - S)E(\mathcal{V}_i) \tag{8}$$

where

$$S = \frac{\sigma_{\mathcal{V}_i}^2}{\sigma_{\mathcal{V}_i}^2 + \sigma_{noise}^2}$$

where

$$\sigma_{\mathcal{V}_i}^2 = \frac{N^2\lambda^2\phi^2\sigma_{\mathcal{V}}^2 + \lambda^2(1-\phi)^2\sigma_v^2}{N^2}$$

and where

$$\sigma_{noise}^2 = \frac{\lambda^2(1-\phi)^2(N-1)\sigma_v^2 + N^2\sigma_\epsilon^2}{N^2}$$

.

There are two aspects to the equilibrium wage in (8). First, wages reflect the (updated) value of ideas that problem solver i can transfer to a competing firm. Second, this inference about the value of ideas made by firms along with perfect competition creates implicit incentives for problem solver i to exert effort in period 1. To see this, substitute $z = y_1 - f(\bar{e_{11}}, \bar{e_{21}}, .., \bar{e_{N1}})$ in (8). Problem solver $i's$ wage then, as in the teams framework of Holmstrom (1982b), depends on a share of output, S. But in contrast to Holmstrom's analysis, this *implicit share*, S, is determined endogenously by inferences about problem solver $i's$ ideas made by firms.

In the proposition below, we state conditions under which this implicit share gets arbitrarily close to 1, which in turn leads to efficient effort levels in period 1. The proofs of all of the lemmas and propositions are in the appendix.

Proposition 1 *Suppose any of the following conditions hold.*

1. $\phi = 1$ *and* λ *tends to infinity.*
2. σ_v^2 *and* σ_ϵ^2 *tend to zero.*
3. $\sigma_{\mathcal{V}}^2$ *tends to infinity.*

Then in the limit S tends to 1 and effort levels in equilibrium in period 1 are efficient.

The first condition in Proposition 1 clearly illustrates the channel through which problem solving teams reduce free riding. Because $\phi = 1$, all problems are solved *together*. This clearly reduces σ^2_{noise}, which now consists only of the variance of the noise of the error term ϵ_1: this is because inferences about the value of ideas are not being divided across different problem solvers. Also, because λ gets arbitrarily large, the signal z becomes very informative about the value of ideas. Finally, because each problem solver i can take his ideas (including those generated together) to a different firm, he can earn the wage in (6). Taken together, these features completely eliminate the free riding problem in the limit. The first condition in Proposition 1 also bears a close resemblance to the bond-posting scheme in Holmstrom (1982b). In his scheme each member gets the entire team output ex-post, and because this breaks the budget (output is produced once but has to be paid N times), team members have to post bonds ex-ante to finance it. In our framework, each team member gets the updated value of his ideas in equilibrium. But in contrast to Holmstrom (1982b), the budget is financed not by members posting bonds but instead by competing firms in the labor market.

In the next proposition we look at how the implicit share S varies as we change the parameters, λ, $\sigma^2_{\mathcal{V}}$, and ϕ.

Proposition 2 *The implicit share S is*

1. *strictly increasing in λ.*
2. *strictly increasing in $\sigma^2_{\mathcal{V}}$.*
3. *strictly increasing in ϕ if and only if $\phi > \bar{\phi}$ where $\bar{\phi}$ is implicitly determined by $\dfrac{1}{\bar{\phi}\sigma^2_{\mathcal{V}}} = \dfrac{\lambda^2(N-1)}{\sigma^2_\epsilon} + \dfrac{N^2}{(1-\bar{\phi})\sigma^2_v}$.*

Proposition 2 looks at how the implicit share varies as problem solving becomes more important in production (as λ increases) and as problems become more complex (as ϕ increases or as $\sigma^2_{\mathcal{V}}$ increases). For the parameters λ and $\sigma^2_{\mathcal{V}}$, the relationship is increasing. But for the third parameter ϕ, the relationship is non-monotone. The implicit share S initially decreases and then starts to increase as beyond a certain level of ϕ. The reason for this non-monotonicity, is that though σ^2_{noise} decreases with ϕ, the variance of $\mathcal{V}_i$ also falls for low levels of ϕ. It is worth noting that as λ gets arbitrarily large or as σ^2_ϵ gets sufficiently close to 0, then $\bar{\phi}$ tends to 0.

Propositions 1 and 2, highlight how implicit incentives reduce free riding in teams. In the next section, we build on these results, to study the effects of explicit incentive schemes.

6 Explicit Incentives

In the previous section, we restricted our attention to implicit incentives to show how the free riding problem in teams can be resolved when problems are solved together. In reality, firms rely both on implicit incentives *and* explicit incentive contracts to motivate workers. In this section, we add explicit incentive contracts to our analysis. Given implicit incentives, the role of an explicit scheme is to provide residual incentives. Our objective is to compare two explicit incentive schemes, group incentive pay and monitoring, to see how effectively they perform this residual incentive role.

We also make an additional simplification in this section and assume that the function f, which maps effort to output, is linear in effort. So from this point on, we assume that

$$f(e_{11}, e_{21}, .., e_{N1}) = e_{11} + e_{21} + ... + e_{N1} \quad (9)$$

$$f(e^i_{12}, e^i_{22}, .., e^i_{N2}) = e^i_{12} + e^i_{22} + ... + e^i_{N2} \quad (10)$$

Note that with this specification, the efficient level of effort for a worker in either period is 1. Thus the maximum value of W^P_1 is $\frac{N}{2} + \lambda\phi E(\mathcal{V})$ and the maximum value of $E(W^i_2(y_1))$ is $\frac{N}{2} + \lambda\phi E(\mathcal{V})$. Also, effort in period 1 in equilibrium in section 5 equals the implicit share S.

6.1 Group Incentive Contracts

In this subsection, we allow firms to offer group incentive contracts which are contingent on the output of the team. We make three assumptions about these contracts. First, we assume that contracts are linear. That is in period 1, contracts take the form $w_{i1} = \alpha_{i1} + \beta_{i1} y_1$, where α_{i1} is a fixed transfer and where β_{i1} is an output share in period 1. In period 2, contracts are given by $w^i_{j2} = \alpha^i_{j2} + \beta^i_{j2} y_2$, where the superscript i denotes the problem solver that a firm intends to produce with. Second, because we want to explicitly model free riding costs associated with group incentive pay, we impose a budget balance condition, where the sum of output shares to all workers in a team must not exceed 1. Third, we assume that contracts are enforceable for a single period only.

To solve the equilibrium when group incentive schemes are offered, let us start with period 2 and consider a problem solver i. In equilibrium, all firms in period 2, taking period 1 effort levels as given, update using Baye's rule. Thus

$$E(\mathcal{V}_i|y_1) = Sz + (1 - S)E(\mathcal{V}_i) \quad (11)$$

Given these beliefs, firms compete for problem solver i in period 2, by making the surplus from hiring i, $W_2^i(y_1)$, as large as possible (subject to incentive compatibility conditions for all workers on the team and subject to the budget balance condition) and by transferring the entire surplus to problem solver i, subject to all other workers participating. The following Lemma characterizes the optimal output shares, effort, and transfers in period 2 in equilibrium.

Lemma 1 *In equilibrium, the following conditions must hold for all* $i, j = 1, 2, 3, ..., N$.

i $\beta_{j2}^i = \frac{1}{N}$.

ii $e_{j2}^i = \frac{1}{N}$.

iii $\alpha_{i2}^i = \frac{2N-1}{2N} + \frac{1}{2N^2} - \frac{1}{N} + (1 - \frac{1}{N})(Sz + (1-S)E(\mathcal{V}_i))$.

iv $\alpha_{j2}^i = \frac{1}{2N^2} - \frac{1}{N} - \frac{1}{N}(Sz + (1-S)E(\mathcal{V}_i))$ *for* $j \neq i$.

Because there are no implicit incentives in period 2, firms would like to ideally offer contracts with $\beta_{j2}^i = 1$ to make the surplus as large as possible. But they run into the budget balance constraint and thus are forced to set $\beta_{j2}^i = \frac{1}{N}$. Also, because, workers only get a fraction $\frac{1}{N}$ of the marginal product, they choose inefficiently low levels of effort. This is what the first two conditions in Lemma 1 say. The third part of Lemma 1, says that problem solver i, because of competition in the labor market, gets all of the surplus in period 2 and the last part of Lemma 1, gives conditions under which workers who are not problem solvers get their reservation utility of 0 so that they are willing to participate.

Now consider period 1. $P's$ problem is to maximize his expected profit in period 1, given by

$$\sum_i e_{i1} + \lambda\phi E(\mathcal{V}) - \sum_i (\alpha_{i1} + \beta_{i1} E(y_1)) + \sum_j e_{j2}^1 + E(\mathcal{V}_1) - E(\alpha_{12}^1) - \beta_{12}^1 E(y_2) - \sum_{j\neq 1} E(\alpha_{j2}^1) - \sum_{j\neq 1} \beta_{j2}^1 E(y_2)$$

subject to the following individual rationality constraints

$$\alpha_{i1} + \beta_{i1} E(y_1) - \frac{1}{2} e_{i1}^2 + E(\alpha_{i2}^i) + \beta_{i2}^i E(y_2) - \frac{1}{2} e_{i2}^2 \geq 0 \quad \text{for all } i = 1, 2, 3, ..., N \quad (12)$$

subject to incentive compatibility conditions, which from condition (iii) of Lemma 1, are given by

$$e_{i1} = \beta_{i1} + (1 - \frac{1}{N})S \quad \text{for all } i = 1, 2, 3, ..., N \tag{13}$$

subject to the budget balance condition

$$\sum_i \beta_{i1} \leq 1 \tag{14}$$

and subject to conditions (i)-(iv) in Lemma 1. Substituting (12) (which must bind at the optimum,[4]) and conditions (i) and (ii) from Lemma 1, we can rewrite expected profit as

$$W_1^P + \frac{(2N-1)}{2N} + E(\mathcal{V}_1) + \sum_{i \neq 1} E(\alpha_{i2}^i) - \sum_{j \neq 1} E(\alpha_{j2}^1)$$

The expression above has a simple interpretation. The principal's expected profit consists of the expected surplus in the first period W_1^P, the second period surplus that he can extract from problem solver 1, given by $\frac{(2N-1)}{2N} + E(\mathcal{V}_1)$, and finally the expected fixed transfers that he can extract from problem solvers that move to different firms in period 2 and the fixed transfers that he has to pay to all other workers who work along with problem solver 1 in period 2.

Next, substituting, conditions (iii) and (iv) from Lemma 1, and using the fact that $E(v_i) = 0$, we can rewrite the expected profit as

$$W_1^P + \frac{N(2N-1)}{2N} + \lambda\phi E(\mathcal{V}) + (N-1)E(Sz + (1-S)\lambda\phi E(\mathcal{V})) \tag{15}$$

Substituting (13) into (15) and taking first order conditions with respect to β_{i1} gives us

$$1 + (N-1)S - \beta_{i1} = \mu \quad \text{for all } i = 1, 2, 3, ..., N \tag{16}$$

where μ is the non-negative multiplier associated with the budget balance constraint. Equation (16) clearly highlights the marginal benefit to P from inducing more effort. First, inducing an additional unit of effort increases the current surplus W_1^P by one unit. But given that competing firms offer wages that are contingent on y_1, P also benefits from trying to alter inferences of competing firms that hire problem solvers in the future, which is given by $(N-1)S$. Thus firms have a tendency to induce too much effort relative to the efficient level. However, at the optimum, the budget balance constraint always binds and so we have

$$\beta_{i1} = \frac{1}{N} \quad \text{for all } i = 1, 2, 3, ..., N \tag{17}$$

[4]Otherwise the transfer to problem solver i in period 1 can always be reduced by a small amount without altering any of the constraints of the problem.

and

$$e_{i1} = \frac{1}{N} + (1 - \frac{1}{N})S \quad \text{for all } i = 1, 2, 3, ..., N \tag{18}$$

Thus group incentive pay, with its natural constraint on incentives, turns out to be beneficial to P. In particular, it allows P to commit not to try and extract future rents from ideas that his employees earn in the future.

Finally, because conjectures about effort in period 1 are correct, we can write $P's$ expected profit in equilibrium as

$$\underbrace{N(\frac{1}{N} + (1 - \frac{1}{N})S - \frac{1}{2}(\frac{1}{N} + (1 - \frac{1}{N})S)^2) + \lambda\phi E(\mathcal{V})}_{\text{Expected Surplus from period 1}} + \underbrace{N(\frac{2N-1}{2N} + \lambda\phi E(\mathcal{V}))}_{\text{Expected Surplus from period 2}} \tag{19}$$

Notice there are two parts to (19). The first part is the expected surplus in period 1. And the second part is the expected surplus from period 2. Because P has all of the bargaining power in period 1, an alternative way to think about profits of P is to compute losses in expected surplus that arise in equilibrium relative to the efficient benchmark in Section 4.

Define a new variable L_t^g which is the efficiency loss per team in period t when firms use group incentive pay. Thus

$$L_1^g = \frac{N}{2} - N(\frac{1}{N} + (1 - \frac{1}{N})S - \frac{1}{2}(\frac{1}{N} + (1 - \frac{1}{N})S)^2) \tag{20}$$

and

$$L_2^g = \frac{N}{2} - \frac{(2N-1)}{2N} \tag{21}$$

and let the total efficiency loss associated with group incentive pay be given by $L^g = L_1^g + NL_2^g$. The following proposition compares these efficiency losses and examines how they vary with implicit incentives.

Proposition 3 *Consider a setting where firms can offer group incentive contracts. Then L_1^g is strictly decreasing in S. In the limit as S tends to 1, L_1^g tends to 0.*

Proposition 3 is the main result of our paper. It says that as implicit incentives get stronger (these incentives only arise in period 1 in our two period model), efficiency losses associated with group incentive pay reduce (equivalently, profits of P increase). And in fact, in the limit as implicit incentives get very strong (i.e. any of the conditions in Proposition 1 hold), the free riding problem associated with group incentive pay completely disappears. Proposition 3 thus provides an explanation for why group incentive pay is frequently used in problem solving teams. When worker in a team generate ideas together, free riding is far less of an issue and this lowers the cost of using group incentive pay.

There are two parts to Proposition 3. The first part is straightforward. As implicit incentives become stronger, residual incentives fall. Thus the "distance" required to get to the efficient target level falls and group incentive pay, in spite of its low powered incentives, gets sufficiently close to this efficient target. The second part, which Proposition 3 does not highlight as clearly, is that group incentive pay prevents P from inducing inefficiently high levels of effort. This is because group incentive pay has a natural budget balance condition which places an upper bound on the level of effort that P can induce. To make this second part clearer, we compare group incentive pay to a setting where firms can monitor workers.

6.2 Comparing Monitoring with Group Incentive Pay

In the previous subsection, we showed how implicit incentives reduce the free riding cost associated with group incentive pay. In this subsection, we allow firms to monitor workers. In a static setting, as Alchien and Demsetz (1972) point out, monitoring has a clear advantage over group incentive pay. Indeed, with monitoring firms can induce the efficient level of effort and maximize surplus. However, we show that in dynamic settings where implicit incentives are important this advantage can disappear.

As in the previous subsection, we start solving for the equilibrium in period 2. Consider a problem solver i where $i \neq 1$. In this case, given beliefs in (11), firms compete with each other for problem solver i in period 2, by making the surplus from hiring problem solver i, $W_2^i(y_1)$, as large as possible and by transferring the entire surplus to problem solver i (subject to other workers participating). The key difference from the previous subsection, however, is that in the case of problem solver 1, information about the value of an idea is asymmetric. In particular, because P observes effort in the first period, he has better information about the value of an idea in period 2.

Lemma 2 *Given conjectures $(\bar{e_{11}}, \bar{e_{21}}, .., \bar{e_{N1}})$, the following conditions must hold for all $i, j = 1, 2, 3, ..., N$ in equilibrium.*

i $e_{j2}^i = 1$.

ii $w_{i2}^{im} = \frac{1}{2} + \frac{N}{2} + Sz + (1 - S)E(\mathcal{V}_i)$.

iii $w_{j2}^{im} = \frac{1}{2}$ *for* $j \neq i$.

Lemma 2 says that effort is always at its efficient level in period 2, when firms can monitor workers. Condition (ii) in the Lemma says that problem solver i gets all of the surplus, and condition (iii) ensures that workers who are not problem solvers are held to their reservation utility of 0.

Now consider period 1. $P's$ problem, taking period 2 conjectures as given, is to maximize his expected profit in period 1, given by

$$\sum_i e_{i1} + \lambda\phi E(\mathcal{V}) - \sum_i w_{i1}^m + \sum_j e_{j2}^1 + E(\mathcal{V}_1) - E(w_{12}^{1m}) - \sum_{j\neq 1} w_{j2}^{1m}$$

subject to individual rationality constraints for each problem solver i given by

$$w_{i1}^m - \frac{1}{2}e_{i1}^2 + E(w_{i2}^{im}) - \frac{1}{2}e_{i2}^2 \geq 0 \tag{22}$$

and subject to conditions (i)-(iii) in Lemma 2.

Substituting the participation constraint (which always binds at the optimum) and condition (i) from Lemma 2, we can rewrite the expected profit as

$$W_1^P + \frac{N}{2} + E(\mathcal{V}_1) + \sum_{i\neq 1} E(w_{i2}^{im}) - \sum_{j\neq 1} w_{j2}^{1m}$$

Once again, the expression above has a simple interpretation. The principal's expected profit consists of the expected surplus in the first period W_1^P, the second period surplus that he can extract from problem solver 1, given by $\frac{N}{2} + E(\mathcal{V}_1)$, the expected wage that he can extract from problem solvers that move to different firms in period 2 given by $E(w_{i2}^{im})$, and finally the wages that he has to pay to all other workers who work along with problem solver 1 in period 2.

Substituting conditions (ii) and (iii) from Lemma 2, and using the fact that $E(v_i) = 0$, we can rewrite the expected profit as

$$W_1^P + \frac{N}{2} + \lambda\phi E(\mathcal{V}) + (N-1)(\frac{N}{2} + Sz + (1-S)\lambda\phi E(\mathcal{V})) \tag{23}$$

The expected profit in (23) clearly captures $P's$ incentives from inducing an additional unit of effort. With an additional unit of effort, expected surplus in the first period also increases by a unit. But because, he can extract all of the rents that problem solvers $2, 3, 4, ...N$ earn in the future, and because their wage depends on the performance in the first period, he has an incentive to induce more effort than the efficient level.

The first order conditions with respect to e_{i1} give us

$$e_{i1} = 1 + (N-1)S$$

In equilibrium, where conjectures about effort are correct, the expected profit of the principal is

$$\underbrace{N(1+(N-1)S)(1-\frac{1}{2}(1+(N-1)S))+\lambda\phi E(\mathcal{V})}_{\text{Expected Surplus from period 1}}+\underbrace{N(\frac{N}{2}+\lambda\phi E(\mathcal{V}))}_{\text{Expected Surplus from period 2}} \tag{24}$$

Finally, we need to check that P has no incentive to deviate and choose a different effort level given conjectured effort levels of $1+(N-1)S$. Suppose P chooses a strictly higher effort level, then he always makes lower wage offers than competing firms in period 2 and loses the surplus from problem solver 1 in period 2. Suppose P chooses an effort level that is strictly lower than $1+(N-1)S$, then he increases his surplus at the expense of problem solver 1 in period 2, but then in that case he has to pay exactly the same amount to get the worker to participate in period 1.

Once again, it is convenient to work with efficiency losses in the monitoring case and compare them with the efficiency losses in the group incentive case. Define a new variable L_t^m which is the efficiency loss per team in period t when firms monitor workers. Thus

$$L_1^m = \frac{N}{2} - N(1+(N-1)S)(1-\frac{1}{2}(1+(N-1)S)) \tag{25}$$

and

$$L_2^m = 0 \tag{26}$$

Also define $L^m = L_1^m + NL_2^m$. Notice that with monitoring, there are no efficiency losses in period 2, instead all of the losses are in period 1. The following Proposition compares profits in equilibrium across the group incentive case and the monitoring case.

Proposition 4 *There exists a critical level of the implicit share given by $S^g \in (0,1)$, above which $L^m > L^g$.*

Proposition 4 says that when firms have initial bargaining power and when implicit incentives are strong, group incentive pay dominates monitoring in terms of efficiency (and equivalently in terms of profits for P). This result, which seems odd at first, has a simple intuition. Because P has all of the initial bargaining power, he has an incentive to induce too much effort because he can extract rents that problem solvers earn from their ideas in the future. Whereas group incentive pay has a natural constraint on the degree of incentives, monitoring does not. Thus P in equilibrium will overwork each of the problem solvers inefficiently which in turn reduces his profits. This is our second main result in the paper.

7 Discussion of Assumptions

7.1 P can make offers to all problem solvers in period 2

So far, we have assumed that each firm can make wage offers to only one problem solver. Here we discuss what happens when P can make offers to all problem solvers. We still assume that competing firms can make offers to one problem solver only. Consider the setting with implicit incentives first and consider any problem solver i at the start of period 2. Because no effort is exerted in equilibrium in period 2, the value of any problem solver i to a competing firm is $E(\mathcal{V}_i|y_1) > 0$. For P, however, the value of one problem solver (say problem solver 1) in the team is $E(\mathcal{V}_i|y_1) > 0$ and his value of all of the other problem solvers is $E(v_i|y_1)0$. This is because an idea can only be used once, regardless of how many workers know it.

Now consider two possible cases. First, suppose $E(\mathcal{V}|y_1) > 0$. For this case, there is an equilibrium where each firm offers a wage which equals its value of the problem solver. In fact, if we assume that firms do not make offers with some small probability then, this is the only possible equilibrium. In this equilibrium, problem solver 1 works for P and all other problem solvers work for competing firms, in period 2. To check that this is an equilibrium, notice that P has no incentive to deviate and offer a different wage for problem solver 1. A higher wage would increase his wage bill whereas with a lower wage he still makes an expected profit of 0. P also dos not have an incentive to increase his wage offer by $E(\mathcal{V}|y_1)$ for problem solvers $2, 3, ..., N$. This is because he can only use ideas once even though other problem solvers on the team may know an idea. Similarly, competing firms have no incentive to deviate and offer a different wage for the problem solver that they are competing for.

Next, consider the second case where $E(\mathcal{V}|y_1) \leq 0$. For this case there is an equilibrium where all firms offer a wage of $E(\mathcal{V}_i|y_1)$ to each problem solver. In this case there is no turnover and P earns rents on problem solvers $2, 3, ..., N$ when the inequality is strict. Once again P does not have an incentive to deviate for any problem solver. If he offers a lower wage to one or more, but not all, problem solvers he loses him (them) but it does not change his expected profit. And he does strictly worse when hoe offers lower wages to all problem solvers. He also has no incentive to offer a higher wage for any problem solver because it increases his wage bill. Competing firms, once again which bid their value have no incentive to change their wage offers.

Regardless of which case occurs, the wage in equilibrium in period 2 for a problem solver is always $E(\mathcal{V}_i|y_1)$. So all of our results in Section 5 go through. However, because with some probability (when $E(\mathcal{V}|y_1) \leq 0$) there is no turnover in equilibrium, the inefficiencies associated with monitoring are smaller. However, as the prior mean of $\mathcal{V}$ gets arbitrarily high, in the limit the probability of having no turnover goes to 0 and all of our results in Section 6 go through.

7.2 Bargaining Power in Period 1

In our model, we assume that P has all of the bargaining power in period 1, so that he can extract the total expected surplus both in period 1 and in period 2 from all problem solvers. We could alter this assumption and assume instead, that wages are set so that P shares some of this total expected surplus with all of the problem solvers. This once again does not qualitatively change any of the results in Section 5. All it changes is how the surplus gets divided in period 1 across problem solvers and P. In the case of Section 6, altering bargaining power once again reduces the inefficiencies associated with monitoring. However, we can show that when P gets to keep a sufficiently large share of the total expected surplus in period 1, our results in Proposition 4 still hold.

7.3 Monitoring and Group Incentive Pay

In our section on explicit contracts, we considered group incentive pay and monitoring in isolation. That is we considered a case where all firms can only offer group incentive contracts and another case where all firms can only monitor workers. We could relax this assumption by allowing firms to commit to a type of contract at the start of each period. It turns out in this setting that only monitoring contracts are accepted by workers in period 2. This is because without implicit incentives, monitoring generates a larger surplus than group incentive pay. In period 1, the choice between monitoring and group incentive pay depends once again on the strength of implicit incentives. When implicit incentives are sufficiently strong, P will prefer to commit to a group incentive contract at the start of period 1.

8 Conclusion

We provide an explanation for why group incentive pay is common in problem solving teams. Using a simple and well-known career concerns model, we show how implicit incentives arise when workers in a team generate ideas to solve problems. Furthermore, when workers generate ideas together in a team, free riding is less of an issue. So these implicit incentives from problem solving reduce the cost of using group incentive pay. We also show that when employers have initial bargaining power and implicit incentives are strong, group incentive pay yields higher profits than monitoring workers. The interesting feature of this result is that it holds even when monitoring is costless and thus offers a new perspective to the literature on monitoring workers in teams (e.g. Alchien and Demsetz (1972)).

Our work on short term teams complements the literature on incentives for long term teams. Though there is a large business literature on teams that interact for short periods, there is little theoretical work on how free riding problems can be overcome in this setting (Edmondson (2012)).

A central feature in our framework is that competition for ideas in the future creates incentives for effort today. One particularly interesting extension would be to look at how returns from ideas decrease in the number of firms that use a particular idea. Introducing this feature creates a tradeoff: having more firms use ideas in period 2 creates implicit incentives whereas the value of an idea declines.

Appendix A

Proofs

Proof of Proposition 1: The first order conditions for problem solver i are given by

$$Sf_{e_{i1}}(e_{11}, e_{21}, .., e_{N1}) = e_{i1}$$

When S tends to 1 in the limit, the first order conditions are the same as those required for efficiency in (4).■

Proof of Proposition 2: Notice that we can rewrite S as

$$S = \frac{N^2\phi^2\sigma_{\mathcal{V}}^2 + (1-\phi)^2\sigma_v^2}{N^2\phi^2\sigma_{\mathcal{V}}^2 + (1-\phi)^2\sigma_v^2 + (1-\phi)^2(N-1)\sigma_v^2 + \dfrac{N^2\sigma_\epsilon^2}{\lambda^2}}$$

which is strictly increasing in λ. Also because S is strictly increasing in $\sigma_{\mathcal{V}_i}^2$ and $\sigma_{\mathcal{V}_i}^2$ is strictly decreasing in $\sigma_{\mathcal{V}}^2$, it follows that S is strictly decreasing in $\sigma_{\mathcal{V}}^2$. For the third part of Proposition 2, notice that the partial derivative of S with respect to ϕ has the same sign as

$$(\lambda^2(1-\phi)^2(N-1)\sigma_v^2 + N^2\sigma_\epsilon^2)(2N^2\lambda^2\phi\sigma_{\mathcal{V}}^2 - 2\lambda^2(1-\phi)\sigma_v^2)$$

$$+(N^2\lambda^2\phi^2\sigma_{\mathcal{V}}^2 + \lambda^2(1-\phi)\sigma_v^2)(2\lambda^2(1-\phi)\sigma_v^2)$$

This can be rewritten as

$$2N^2\lambda^4\phi(1-\phi)(N-1)\sigma_v^2\sigma_{\mathcal{V}}^2 + 2N^4\lambda^2\phi\sigma_{\mathcal{V}}^2\sigma_\epsilon^2 - 2N^2\lambda^2(1-\phi)\sigma_v^2\sigma_\epsilon^2 \qquad (A1)$$

The expression in (A1) is equal to 0 if and only if

$$\phi(\lambda^2(N-1)\sigma_v^2\sigma_{\mathcal{V}}^2 + \frac{N^2\sigma_\epsilon^2\sigma_{\mathcal{V}}^2}{(1-\phi)}) = \sigma_v^2\sigma_\epsilon^2$$

Thus the sign of the derivative of S with respect to ϕ is non-negative if and only if

$$\frac{1}{\phi\sigma_{\mathcal{V}}^2} \leq \frac{\lambda^2(N-1)}{\sigma_\epsilon^2} + \frac{N^2}{(1-\phi)\sigma_v^2} \qquad (A2)$$

Similarly the sign of the derivative of S is strictly positive (negative) if

Notice that the left hand side of (A2) is strictly decreasing in ϕ and tends to infinity as ϕ tends to 0. The right hand side on the other hand is strictly increasing in

ϕ for $\phi < 1$ and tends to infinity as ϕ approaches 1. Thus there is a unique $\bar{\phi} \in (0,1)$ for which (A2) holds with equality. Furthermore when $\phi > \bar{\phi}$, the inequality in (A2) is strict and thus S is strictly increasing in in ϕ. And when $\phi > \bar{\phi}$, the inequality in (A2) does not hold and S is strictly decreasing in ϕ.■

Proof of Lemma 1: Consider an problem solver i. Firms choose β^i_{jt} for all $j = 1, 2, 3, ...N$ to maximize $W^i_2(y_1)$, subject to incentive compatibility conditions given by

$$e^i_{j2} = \beta^i_{j2} \quad \text{for all } j = 1, 2, 3, ..., N \tag{A3}$$

and subject to the budget balance condition

$$\sum_j \beta^i_{j2} \leq 1 \tag{A4}$$

After substituting the incentive compatibility condition into $W^i_2(y_1)$, the first order necessary conditions with respect to β^i_{j2} for all $j = 1, 2, 3...N$ give us

$$1 - \beta^i_{j2} = \mu \quad \text{for all } j = 1, 2, 3, ..., N \tag{A5}$$

where μ is the non-negative multiplier associated with the budget balance constraint. Notice that the budget balance constraint must bind at the optimum.If the constraint does not bind, then from the complementary slackness condition it follows that $\mu = 0$. Since $\sum_j \beta^i_{j2} \leq 1$, (13) cannot be satisfied for all $j = 1, 2, ...N$, leading to a contradiction. Thus from (13), we have

$$\beta^i_{j2} = \frac{1}{N} \quad \text{for all } j = 1, 2, 3, ..., N \tag{A6}$$

and

$$e^i_{j2} = \frac{1}{N} \quad \text{for all } j = 1, 2, 3, ..., N \tag{A7}$$

Thus a firm that hires problem solver i in period 2, can generate a surplus of

$$\frac{2N-1}{2N} + E(\mathcal{V}_i|y_1)$$

Competition also ensures that all of this surplus, goes to problem solver i. Thus

$$\alpha^i_{i2} = \frac{2N-1}{2N} + (1 - \beta^i_{i2})(Sz + (1-S)\bar{\mathcal{V}}_i) + \frac{1}{2}e^2_{i2} - \beta^i_{i2}\sum_j e^i_{j2} \tag{A8}$$

Using (A6) and (A7), we can rewrite (A8) as

$$\alpha^i_{i2} = \frac{2N-1}{2N} + \frac{1}{2N^2} - \frac{1}{N} + (1 - \frac{1}{N})(Sz + (1-S)\bar{\mathcal{V}}_i)$$

Finally, the transfer α^i_{j2} is set so that workers $j \neq i$ earn a reservation utility of 0. Thus

$$\alpha^i_{j2} = \frac{1}{2N^2} - \beta^i_{j2}(\sum_j e^i_{j2} + Sz + (1-S)\bar{\mathcal{V}}_i) \tag{A9}$$

Using (A6) and (A7), we can rewrite (A9) as

$$\alpha^i_{j2} = \frac{1}{2N^2} - \frac{1}{N} - \frac{1}{N}(Sz + (1-S)\bar{\mathcal{V}}_i)$$

.

Proof of Lemma 2: Consider an problem solver i. Firms choose $e^i_{j2} = 1$ for all $j = 1, 2, 3, ...N$ to maximize $W^i_2(y_1)$. The firs order conditions are given by

$$e^i_{j2} = 1 \quad \text{for all } j = 1, 2, 3, ..., N \tag{A10}$$

Thus a firm that hires problem solver i in period 2, can generate a surplus of

$$\frac{N}{2} + E(\mathcal{V}_i|y_1)$$

Competition also ensures that all of this surplus, goes to problem solver i. Thus, using (A10) we have

$$w^{im}_{i2} = \frac{1}{2} + \frac{N}{2} + Sz + (1-S)E(\mathcal{V}_i)$$

Finally the following condition must be satisfied so that workers who are not problem solvers participate. Using (A10) again, we have $w^{im}_{j2} = \frac{1}{2}$.■

Proof of Proposition 3: The expected surplus in either period is strictly concave in effort with a unique maximum when each worker exerts one unit of effort. Thus since $e^i_{j2} < e_{i1} < 1$, the expected surplus in the first period is strictly larger than the expected surplus in the first period. Also, because e_{i1} is strictly increasing in S, and because the expected surplus function is strictly increasing in e_{i1} when $e_{i1} < 1$, it follows that L^g_1 is strictly increasing in S.

Proof of Proposition 4: Notice that effort in the monitoring case is strictly above 1 and is strictly increasing in S. Because the expected surplus function in either period is strictly concave in effort with a unique maximum when effort equals 1, it follows that L^m is strictly decreasing in S. Similarly, it can be shown that L^g is strictly increasing in S. Now take limits as S tends to 0. It follows that

$$\lim_{S\to 0} L^g = (N+1)(\frac{N}{2} - \frac{2N-1}{2N}) > 0 = \lim_{S\to 0} L^g$$

Thus when S tends to 0 in the limit, we have $L^g - L^m > 0$. On the other hand taking limits as S tends to 1, we have

$$\lim_{S\to 1} L^g = N(\frac{N}{2} - \frac{2N-1}{2N}) \quad (A11)$$

and

$$\lim_{S\to 1} L^m = \frac{N}{2} - N^2(1 - \frac{N}{2}) \quad (A12)$$

The expression in (A11) is strictly less than the expression in (A12) if and only if

$$\frac{1}{N} < 3(1-N) + N^2 \quad (A13)$$

Notice that for $N = 2$, the inequality in (A13) holds. Furthermore because the left hand side is strictly decreasing in N and the right hand side is strictly increasing in N when $N \geq 2$ it follows that the inequality in (A13) always holds for $N \geq 2$. Thus when S tends to 1 in the limit, we have $L^g - L^m < 0$.

Because $L^g - L^m$ is continuous and strictly decreasing in S, it follows that there is a unique S^g for which $L^g - L^m = 0$. ■

References

Akerlof, G., and R. Kranton (2008): "Identity, Supervision, and Work Groups," *American Economic Review, Papers and Proceedings*, 95(3), 212–217.

Alchien, A., and H. Demsetz (1972): "Production, Information Costs, and Economic Organization.," *American Economic Review*, 62, 775–795.

Andersson, F. (2002): "Career Concerns, Contracts, and Effort Distortions," *Journal of Labor Economics*, 20(1), 42–58.

Anthony, S. D. (2005): "Making the Best of a Slim Chance.," *Harvard Business Case Study*, pp. 1–5.

Auriol, E., G. Friebel, and L. Pechlivanos (2002): "Career Concerns in Teams," *Journal of Labor Economics*, 20(2), 289–307.

Bag, P., and N. Pepito (2011): "Double-edged transparency in teams.," *Journal of Public Economics*, 95, 531–542.

Bonatti, A., and J. Horner (2011): "Collaborating.," *American Economic Review*, 101, 632–663.

Boning, B., C. Ichniowski, and K. Shaw (2007): "Opportunity Counts: Teams and the Effectiveness of Production Incentives.," *Journal of Labor Economics*, 25(4), 613–650.

Che, Y.-K., and S.-W. Yoo (2001): "Optimal Incentives for Teams.," *American Economic Review*, 91(3), 525–541.

Cremer, J. (1993): "Corporate Culture and Shared Knowledge," *Industrial and Corporate Change*, 2(3), 351–386.

Cyert, R., and J. March (1963): *A Behavioral Theory of the Firm.* Prentice-Hall, Englewood Cliffs, NJ.

Edmondson, A. C. (2012): *Teaming.* Jossey Bass, San Francisco, U.S.A.

Fama, E. (1980): "Agency Problems and the Theory of the Firm," *Journal of Political Economy*, 88, 288–307.

Garicano, L. (2000): "Hierarchies and the Organization of Knowledge in Production," *Journal of Political Economy*, 108(5), 874–904.

Gibbons, R., and K. Murphy (1992): "Optimal Incentive Contracts in the Presence of Career Concerns: Theory and Evidence," *Journal of Political Economy*, 100(3), 468–505.

Holmstrom, B. (1982a): *Essays in Economics and Management in Honor of Lars Wahlbeck*chap. Managerial Incentive Problems- A Dynamic Perspective. Sweedish School of Economics, Helsinki.

——— (1982b): "Moral Hazard in Teams," *Bell Journal of Economics*, 13(2), 324–340.

Hoopes, D., and S. Postrel (1999): "Shared knowledge, glitches, and product development performance.," *Strategic Management Journal*, 20(9), 837–865.

Jeon, S. (1996): "Moral Hazard and Reputational Concerns in Teams: Implications for Organizational Choice," *International Journal of Industrial Organization*, 14, 297–315.

Kandel, E., and E. Lazear (1992): "Peer Pressure and Partnerships.," *Journal of Political Economy*, 100(4), 801–817.

Lawler, E., and S. Mohrman (2003): "Pay Practices in Fortune 1000 Companies.," *Center for Effective Organizations*, pp. 1–16.

Li, H. (2012): "Developing Shared Knowledge.," *Working Paper*, (4).

Meyer, M. (1994): "The Dynamics of Learning with Team Production: Implications for Task Assignment," *The Quarterly Journal of Economics*, 109(4), 1157–1184.

Meyer, M., and J. Vickers (1997): "Performance Comparisons and Dynamic Incentives.," *Journal of Political Economy*, 105(3), 547–581.

Nelson, R., and S. Winter (1982): *An Evolutionary Theory of Economic Change.* Belknap, Cambridge.

Ortega, J. (2003): "Power in the Firm and Managerial Career Concerns," *Journal of Economics and Management Strategy*, 12(1), 1–29.

Penrose, E. (1959): *The Theory of the Growth of the Firm.* Oxford University Press, Oxford, U.K.

Prat, A. (2002): "Should a team be homogeneous?," *European Economic Review*, 46(7), 1187–1207.

Rayo, L. (2007): "Relational Incentives and Moral Hazard in Teams," *Review of Economic Studies*, 74(3), 937–963.

Zingheim, P., and J. Schuster (2000): *Pay People Right! Breakthrough Reward Strategies to Create Great Companies.* Jossey Bass, San Francisco.