

INDUCING KNOWLEDGE SHARING IN TEAMS THROUGH COST-EFFICIENT COMPENSATION SCHEMES

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Abstract

A natural challenge for firms seeking to implement knowledge-management systems is accounting for the interplay of incentives among workers and supervisors. This paper studies this interaction, focusing on the dynamics arising from joint projects, task evaluation, and knowledge sharing, in the framework of a game-theoretic model. We identify conditions under which a firm can minimize the costs of implementing an incentives-based system for knowledge sharing, taking into account the firm's ability to monitor individual performance. We show that an employer in our framework has a stronger incentive to monitor tasks when relative-performance pay is small and when higher-paid agents are more likely to generate new knowledge.

Keywords: Knowledge Sharing, Principal-Agent Models

Introduction

Production knowledge arrives at firms through a variety of channels. Firms can, for instance, research new technologies, perform competitive analyses, and, in many cases, rely on the problem-solving skills of workers (Davenport and Prusak, 1998). However, the discovery of knowledge does not guarantee its absorption into the best practices of an organization (Hansen, 1999). Knowledge is tacit (Sveiby, 1996) and is the output of a process in which raw data is converted into explicit information. This information can in turn be validated and authenticated for use in a given organizational context. Knowledge can be disseminated either through one-way sharing between individuals, multi-directional exchanges, or through knowledge-management systems (Bierly and Chakrabarti, 1996; Das, 2003; Wang, 2010). Alternatively, workers may choose to keep new knowledge private.

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Whether new knowledge ends up being disseminated by employees depends both on their abilities and motivations to disclose (Nonaka, 1991; Davenport and Prusak, 1998; Reagans and McEvily, 2003; Argote et al., 2003). Our focus in this paper is to examine how the mapping between a worker’s financial motivations and an organization’s policies (Alavi, 2001) affects a worker’s decision to share, transfer, or withhold knowledge from others. Specifically, we examine the case in which a firm employs a combination of group and individual incentives, can monitor individual and/or group performance outcomes, and can introduce a knowledge-management system to share information across the organization. While each of these elements has been examined individually in both empirical and theoretical settings, this work aims to study the combined effects of these dynamics in a unified framework.

Using a principal-agent framework (Laffont and Martimort, 2002), we incorporate the above dynamics into a theoretical model. We identify conditions under which a firm can minimize the costs of implementing incentives for knowledge sharing, allowing for a mix of relative- and group-performance incentives for completing joint projects. While a theoretical study requires naturally limiting assumptions, which we will discuss in detail, our model can help shed some light on the complex problem of inducing knowledge dissemination.

Our model consists of a manager (the employer) who assigns a project to her subordinate employees (the agents). Each agent is responsible for a task. If an agent exerts costly effort in performing his task, he increases the probability that his task will end successfully. The cost of effort to the agent represents his opportunity cost for time spent working on the task, as well as any disutility in monetary terms from his effort investment. The overall project succeeds only if all workers complete their tasks successfully. We assume that one agent may have knowledge that enhances his own productivity but other agents do not have this knowledge. If this knowledge is shared with another agent, the receiving agent’s productivity is increased as well.

A firm in our framework can engage in several policy decisions. The firm may choose to provide incentives based on: wages, overall team performance, relative individual performance, and transferring knowledge directly to the organization. The firm may also simply allow agents to compensate one another for sharing their self-acquired knowledge. Next, we vary a manager’s ability to observe individual task outcomes and group outcomes in the model. Given these options, we characterize optimal knowledge-sharing mechanisms that induce employees to exert effort and share knowledge in equilibrium, doing so at a minimum total reward for the agents. To keep our analysis simple, we assume that data and information have already been converted to knowledge, and that knowledge can be exchanged without friction (Alavi, 2001). Our framework can readily incorporate frictions in the transmission of knowledge and doing so does not alter the qualitative nature of our results.

We show that employers in our framework uniformly profit more from observing specific task outcomes rather than overall project outcomes. Further, our analysis calls into question the validity of a common practice amongst managers to encourage employees to collaborate directly with one another (Katz, 2000). We show that from a financial perspective, firms may be better off restricting such collaboration in order to facilitate the use of knowledge-management systems. This is because

in doing so, firms in our framework can then increase profits by lowering the real wages of employees (for instance, by allowing managers to assign more work).

We extend our base model in several ways. First, we endogenize task observability by enabling the employer to allocate resources for task-outcome monitoring. We find that employers have the greatest incentive to monitor tasks when agents derive small payoffs from relative performance. This is because the employer is able to implement larger cuts in operating expenses when agents' outside options (to organizational disclosure) are reduced. Second, we study situations where either higher-compensated or lower-compensated agents are more likely to generate new knowledge. We show that the employer has a greater incentive to monitor tasks if higher-paid agents are more likely to have new knowledge than lower-paid agents. Finally, we examine a case where, in addition to observing task outcomes, an employer has the ability to assess the activities of individuals to determine whether agents have new knowledge.

A Motivating Example

Take the case experienced by one of the authors while working with skilled analysts at a leading manufacturer of tungsten carbide woodworking tools. The company required quality analysts to evaluate each production step for subtle structural anomalies and defects. Analysts were required to cross-train at each step of the process (forging and assembly) and rotate roles. This created the opportunity to share best practices (Das, 2003). However, managers noticed that variations in analyst quality persisted despite a uniform and rigorous training regime.

To address the issue, managers proposed to develop a team-incentive structure and a knowledge-sharing system in the hopes of sharing best practices efficiently within and across teams. The analysts' response to the proposal was conflicted. On the one hand, the idea of knowledge sharing was professionally (Davenport and Prusak, 1998; Freidson, 2001; Auriol et al., 2006), morally, and altruistically appealing (Palfrey and Prisbrey, 1997). Disclosing new information to the firm may also result in benefits such as a promotion and an increased wage. On the other, doing so bears the risk of the entire team, including the disclosing agent, being assigned additional tasks or receiving lower compensation for their work. Alternatively, sharing new knowledge strictly within the team increases the productivity of the team at the cost of a potential personal edge in relative performance. Finally, failing to share information in a culture that explicitly sanctions knowledge sharing could be both socially costly within the team and damaging to one's status in the firm (Haas and Park, 2010; Duck et al., 1999).

The dynamics that emerge in this example extend to other standardized tasks beyond production tasks with low-skilled workers. For example, hospitals, schools, and social-service centers such as police departments have traditionally revolved their operations around team-based projects (e.g., surgeries, school projects, crime enforcement, etc). Major policy initiatives in large organizations such as the New York City Police Department and the Chicago Public School System focus on developing organizational processes that blend individual- and team-based professional development and know-how exchanges with group and individual-level performance (Sadoff et al., 2012).

Related Literature

Knowledge Sharing

Knowledge management has been generally divided into three fundamental activities: creation, transmission, and retention (see Argote et al., 2003, for a review). Our work is focused on the transmission-related aspects of knowledge-sharing. Previous empirical research largely supports the hypothesis that relative-performance wages promote desirable behavior in independent tasks, while group incentives create the collegial, collaborative environment necessary to complete interdependent tasks (Deutsch, 1949; Miller and Hamblin, 1963; Rosenbaum et al., 1980; Stanne et al., 1999; Wageman, 1995; Bushman et al., 1995; Beersma et al., 2003). It has also been suggested that these incentives can create reinforcing organizational cultures that explicitly sanction knowledge sharing at the threat of social punishment (Duck et al., 1999; Haas and Park, 2010). Social-giving motivations such as professionalism (Davenport and Prusak, 1998; Freidson, 2001; Auriol et al., 2006), morality, and altruism, have also been described as reasons for why workers disclose working knowledge (Palfrey and Prisbrey, 1997), and there are also status accounts of knowledge (particularly externally-derived knowledge) being disclosed if doing so enhances one's status in the organization (Menon, 2003). In contrast, asymmetries in worker know-how have been shown to reduce the effectiveness of group incentives (Latane et al., 1979; Milkovich and Newman, 1990).

A common prescription for aligning team incentives is to require managers to either observe individuals' task outcomes and processes, and reward or punish them directly for their work (Holmström, 1982; Miles and Greenberg, 1993; Beersma et al., 2003), or to create a hierarchy in the organization (Winter, 2004). The introduction of knowledge-management systems introduces an additional layer, since workers must now assess the strategic implications of sharing knowledge directly with the firm, directly with co-workers, or keeping it private. While some prior work has been empirically driven, it has focused on examining factors pertaining to knowledge sharing in isolation. This is not surprising given the difficulty in gaining cooperation from firms to manipulate their incentive and knowledge-sharing strategies (Milkovich and Wigdor, 1991; Katz, 2000).

Analytical Models

Models of organizations built on game-theoretic foundations developed in the economics literature can be used to understand the challenges that employers face in motivating agents to act on their behalf (Holmström, 1980). However, the underlying dynamics of these problems can be difficult to decompose without simplifying assumptions. Traditionally, these models assume that all actors are rational, exhibit consistent preferences, and maximize their expected payoffs (Hastie and Dawes, 2010). These assumptions help in identifying the behavior of individuals when the system is in equilibrium, in turn giving predictions about the nature of knowledge-sharing behavior under counterfactual institutional regimes (Itoh, 1992; Aoki, 1996).

The effectiveness of an incentive regime depends significantly on the relationship between workers and shared outcomes. Results from the economics literature on task allocation suggest that agent cooperation is favorable if there are complementarities between efforts (Drago and Turnbull, 1988,

1991; Itoh, 1991; Holmström and Milgrom, 1990; Ramakrishnan and Thakor, 1992; Macho-Stadler and Perez-Catrillo, 1993). Winter (2004) studies optimal compensation schemes when agents work on joint projects, have no new knowledge, and only overall project outcomes are observable. He shows that the optimal compensation scheme results in a wage hierarchy for the agents. Kvaløy and Olsen (2008) note that models such as the above describe situations with complete contracts and verifiable outputs. Their research shows that it can be suboptimal to implement cooperation when output is non-verifiable and the agents possess the *ex post* market power to hold up production processes.

Our study builds off the above works by adding the possibility that workers have new knowledge. Our findings show that even with verifiable outputs, it can be optimal to dissuade cooperation among agents in a team — doing so can reduce the principal’s cost of institutionalizing new knowledge. Moreover, our study shows that close team environments where agents can compensate each other for sharing new knowledge may actually be suboptimal — they tend to increase the principal’s cost of inducing agents to disclose new knowledge to the organization. Our work also complements the literature on knowledge dissemination, where it is argued that knowledge-intensive firms should design employment contracts to reward cooperation among agents (Balkin and Bannister, 1993; Kroumova and Lazarova, 2009). We examine the downstream effects of these dynamics on employers’ propensity to monitor employees under different incentive schemes.

Kvaløy and Olsen (2008) examines a joint task in which both agents are indispensable to the success of the project but individual task outputs are not verifiable. We extend this work by examining the complexity that arises when two types of cooperative action are possible: cooperating with another team member or cooperating with the employer. In our context, new knowledge disclosure to a team member is interpreted as team cooperation, while disclosure to the organization is interpreted as cooperation with the employer.

We note that rational-actor models are not without limitations (Mintzberg, 1992; Kahneman and Klein, 2009). Rational actors are assumed to have well-formed preferences and an ability to reason using fundamental rules of logic and probability. They make choices by finding the maximum expected utility of each option in a decision set contingent on the (strategic) behavior of others (Hastie and Dawes, 2010). Although some researchers have shown that people operating in real teams with repeated interactions make decisions consistent with rational actors (e.g., Che and Yoo, 2001), countless empirical studies also suggest otherwise (e.g., Kahneman and Tversky, 1986). Some non-financial aspects can be taken into account within an agent’s utility function (for instance, a social cost or benefit of impacting a co-worker’s status). However, theoretical models become increasingly complex once these simplifying assumptions are relaxed. Our model is therefore not prescriptive, but in the spirit of Mintzberg, meant to be used in conjunction with psychologically and sociologically-informed empirical research to understand the true inner workings of an organizational system.

The Model

An employer (the manager, she) hires two agents, 1 and 2 (the employees), to work on a project. All parties are risk neutral, except, as is common in the literature, the agents are subject to limited liability, that is, we assume that the employer cannot impose negative wages on the agents or extract payments from them. Limited liability of the agents may arise from workers' having the freedom to quit but it may also arise from institutional constraints such as laws banning firms' extracting payments from workers or workers' liquidity constraints. The project consists of two separate tasks, each to be performed by a different agent. Each agent makes a binary effort decision on whether to exert effort towards completing his task or not. The cost of effort is c . If an agent exerts effort, his task ends successfully with probability β . If he does not, the probability of his task ending successfully is γ , where $0 < \gamma < \beta < 1$.

We consider the case where one of the agents has new knowledge that is not known to the other agent. This knowledge is useful in completing both agents' tasks. In particular, it increases the probability that a task will end successfully conditional on effort from β to α , such that $0 < \gamma < \beta < \alpha < 1$, where α , β , and γ are uniform across all agents and are common knowledge. Agents are not informed about each other's effort decisions when they make their own. Thus, these decisions will be modeled as if made simultaneously. Aside from the agent who has new knowledge, other agents are not necessarily informed of its existence (unless the agent chooses to share it); however, they can form arbitrary beliefs about an agent possessing it. We assume that the agent who has new knowledge is able to verifiably disclose it to another party at no direct cost; however, there may exist indirect costs due to a loss of a relative performance advantage or decreased real compensation. Our main conclusions extend to settings where disclosure is costly, provided that the cost of disclosure to an employee is no greater than the cost of disclosure to the employer.

To emphasize that this is a team environment, we assume that the project ends successfully provided that all of the individual tasks are successfully completed. Agents' opportunity costs from pursuing outside options are normalized to 0.

Let R denote the employer's revenue from a successful project. The revenue from an unsuccessful project is 0. A compensation scheme (w, B, P, D) is composed of wages, denoted by $w = (w_1, w_2)$, a relative performance bonus, denoted by B , a project completion bonus, denoted by P , and a knowledge-disclosure reward, denoted by D ; a formal description of each compensation component follows.

Let $w_i \geq 0$ denote the wage of agent i , $i \in \{1, 2\}$. Depending on the information regime, this wage may be conditioned either on an agent's effort or on a task or project outcome. Let $P \geq 0$ denote any additional reward given to each agent when the overall project succeeds. We assume that $\beta^2 R - 2c > \gamma^2 R$, i.e., both agents exerting effort is socially efficient.

In the case where task outcomes can be observed, we let $B \geq 0$ denote any additional pay that is assigned to an agent who outperforms his colleague (i.e., completes his task successfully while his colleague does not; if both agents complete their tasks successfully, they each already receive a bonus P , whereby B is only assigned when (i) task outcomes are observable, and (ii) the project fails but one task is completed successfully). Finally, we let $D \geq 0$ denote the disclosure reward

assigned to an agent who discloses new productive knowledge to the employer.

Following Winter (2004), we say that a mechanism M is incentive inducing (INI) if M induces all agents to exert effort in every Perfect-Bayesian Nash equilibrium (PBE). We say that a mechanism M is incentive-inducing knowledge sharing (INIKS) if M induces all agents to exert effort and share new knowledge in every PBE. In each setting, we will be interested in *optimal* INI and INIKS mechanisms.

M is an *optimal* INI mechanism if (1) there exists no INI mechanism with less total expected rewards for the agents, (2) for any $\epsilon > 0$, $\{\tilde{w}_i = w_i + \epsilon\}_{i \in \{1,2\}}$ is an INI mechanism, and (3) for any $\epsilon > 0$, an alternative mechanism \tilde{M} that sets $\tilde{P} = P - \epsilon$ but is otherwise identical to M is not INI (the second and third requirements for optimality of an INI mechanism are necessary because an agent's compensation is continuous). We say M is an *optimal* INIKS mechanism if (1) it is an optimal INI mechanism, and (2) agents weakly prefer to share knowledge prior to effort decisions. We note that while optimal INI and INIKS mechanisms are by definition unique in terms of total expected compensation assigned to agents, neither mechanism is necessarily unique with respect to a specific compensation scheme. This is because multiple compensation schemes can achieve the same total reward by redistributing pay across the different channels of wages and bonuses (and we place no restrictions on the employer's choice of relative-performance pay, B). When agents are indifferent between exerting and not exerting effort or between sharing and not sharing new knowledge, we break indifferences in favor of agents exerting effort and sharing new knowledge; this is assumed without loss of generality since agents' compensation is continuous.

We study optimal INIKS mechanisms in which an agent with new knowledge always chooses to either share his knowledge with a colleague or with the employer. The timeline of the game

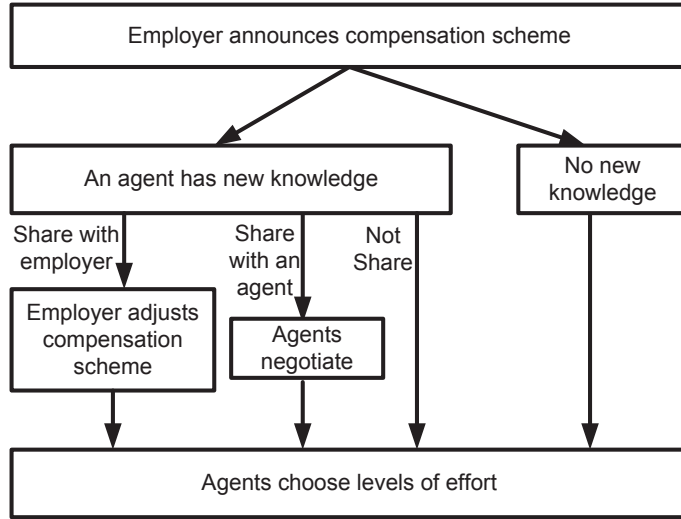


Figure 1: Timeline of the game.

is portrayed in Figure 1 and runs as follows. In the first stage, the employer announces the compensation scheme (w, B, P, D) . When there is no new knowledge, agents next make their effort decision and payoffs are realized in the second stage. If, on the other hand, one of the agents has

new knowledge, prior to effort decisions, he can choose to approach the other agent and negotiate terms for disclosing it, he can alternatively disclose the knowledge to the employer, or keep it private. When negotiating with the other agent, since the reward for disclosing to the employer is known at this point, we assume that the negotiation outcome over any additional surplus is the Nash bargaining outcome. (Our results hold independent of agents’ precise Nash bargaining powers, as they are predicated on whether or not an agreement between the agents can be reached, which depends on the existence of a bargaining surplus and not on its distribution.) If knowledge ends up being disclosed to the employer, then the employer announces new compensation packages (wages and bonuses) prior to agents exerting effort.

Observable Effort

As a benchmark, we examine the case where the employer can directly observe agents’ effort levels. In this case, when there is no new knowledge, the employer can incentivize effort by compensating agents based on their effort decisions. In an optimal INI mechanism, the employer pays each agent a wage w that is just sufficient to cover the agent’s cost of effort, $w = c$, and provides no further compensation ($B = P = 0$). The employer’s expected profit in such a mechanism is thus given by $\beta^2 R - 2c$. (The employer is also able to set $B > 0$ in an optimal INI mechanism and reduce the wage accordingly so that an agent’s expected payoff remains 0, although doing so comes at no gain in profit. We will address this possibility in the following sections, where it would be more relevant.)

Here, regardless of his team member’s performance, an agent’s expected payoff is 0, as agents are paid based on their effort decisions and not based on the success of their tasks or of the project. Hence, if one agent has new knowledge, he would be indifferent about sharing it with another agent (and, following our indifference assumptions, will share it). Furthermore, since new knowledge impacts the success probability of a task conditional on effort, and not the cost of effort itself, wages would be identical in an optimal INIKS mechanism. The employer’s expected profit when one of the agents has new knowledge is then given by $\alpha^2 R - 2c$.

Thus, when effort is observable, the employer is able to obtain the profit-maximizing (and socially-efficient) outcome, where both agents exert effort, receive no excess compensation beyond their effort costs, and share new knowledge if it is available.

The proceeding analysis is organized as follows. The next section on “Observable Task Outcomes” studies the case where the employer is able to observe individual task outcomes. We gradually work towards studying the model by first introducing a benchmark where agents do not generate new knowledge, and then building in relative-performance and disclosure bonuses. We then compare disclosure within teams to disclosure to the organization. We consider cases where agents can and cannot compensate each other directly for new knowledge, i.e., cases where *agent transfers* are and are not possible.

In a later section on “Unobservable Task Outcomes,” the employer is only able to observe the outcome of the overall project — here, too, we begin by introducing a benchmark where agents

do not generate new knowledge. The diagram in Figure 2 summarizes the proceeding steps for analyzing the two information regimes. We then proceed by comparing these two information regimes and performing two robustness checks: First, we relax the assumption that the chosen information regime is specified exogenously; second, we relax the assumption that the employer is unable to assess whether agents have new knowledge.

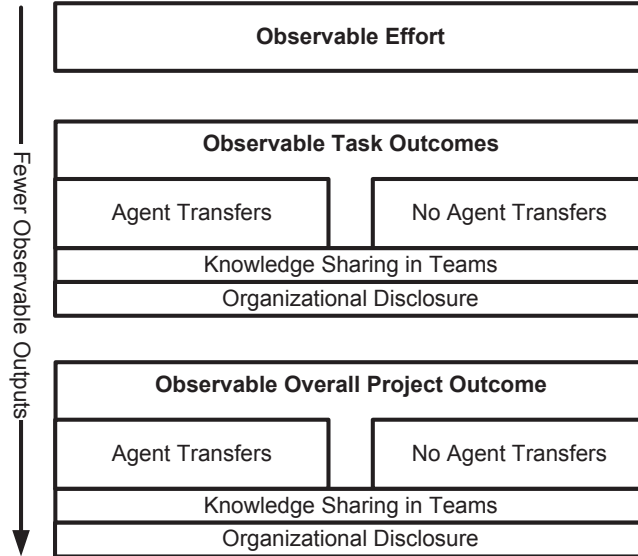


Figure 2: A depiction of the proceeding steps for analyzing the different information regimes.

Observable Task Outcomes

We now turn to the case where the employer cannot observe agents' effort choices but can observe the outcomes of individual tasks.

No New Knowledge Benchmark

We begin by solving for the optimal INI mechanism when neither agent can generate new knowledge. Since the employer no longer observes agents' effort choices, she can induce effort by conditioning an agent's wage on a successful outcome of his individual task and/or of the overall project — a fixed wage will not induce agents to exert effort. Following Holmström (1982), the employer can do no better than conditioning an agent's wage solely on the success of his individual task.

Let us assume initially that agents' compensation packages consist solely of wages, i.e. $B = P = 0$. Letting w_i , $i \in \{1, 2\}$, denote agent i 's wage conditional on a successfully completed task, agent i will exert effort if and only if his expected payoff with effort is greater than without, i.e., his incentive-compatibility constraint must satisfy

$$\beta w_i - c \geq \gamma w_i$$

It follows that in an optimal INI mechanism, the employer assigns each agent the wage of $w = \frac{c}{\beta - \gamma}$,

conditional on a successfully completed task. The employer's expected profit is then given by $\beta^2 R - \frac{2\beta c}{\beta - \gamma}$.

Relative Performance

Suppose now that the employer assigns a bonus to an agent who outperforms his colleague, denoted by B . (Alternatively, employees may perceive some form of relative-performance pay even if the employer does not directly assign it. For instance, if there are limited promotion opportunities, agents may perceive that the agent who outperforms the other is more likely to be promoted or to keep his job). Then, if an agent is successful at completing his individual task while his colleague is not, the agent is rewarded $B > 0$. We continue to assume that $P = 0$, i.e., there is no additional pay (beyond an agent's wage for a successful task) if the overall project succeeds. The following lemma characterizes the optimal wages in an INI mechanism.

Lemma 1. *In an optimal INI mechanism, wages are given by $w = \max\{\frac{c}{\beta - \gamma} - (1 - \beta)B, 0\}$.*

The proofs of Lemma 1 and all proceeding results are in the appendix.

For low amounts of such bonuses (i.e., $B \leq \frac{c}{(\beta - \gamma)(1 - \beta)}$), if the employer directly incurs the cost of rewarding the bonus, expected profit is given by $\beta^2 R - \frac{2\beta c}{\beta - \gamma}$; larger values of B decrease profit. It follows that when agents have no private knowledge, the employer's profit is highest at $B = 0$, and the cost of providing a relative-performance bonus washes out the benefit of reduced wages.

New Knowledge

Suppose now that agent i privately has new productive knowledge, which agent $j \neq i$ does not, $i, j \in \{1, 2\}$. Agent i has the option of keeping this knowledge private. Let us first consider a situation where, due to some constraints (e.g., due to physical barriers), it is infeasible for i to share this knowledge with j . We then have the following result.

Proposition 1. *If new knowledge cannot be shared, the employer's expected profit is highest with zero relative-performance pay, i.e., with $B = 0$.*

The intuition for this result is as follows. Since agents' beliefs can be arbitrary, if an agent suspects another to have private productive knowledge, his incentive to exert effort is diminished due to a lower likelihood of being awarded B . Subsequently, in an optimal INI mechanism, the employer must raise agents' wages to induce effort, which reduces expected profits. However, if a relative-performance bonus is not awarded, then no wage increase is required, resulting in a higher expected profit. Moreover, for $B = 0$, the employer's expected profit increases when one of the agents has private knowledge and is given by

$$\alpha\beta R - \frac{(\alpha + \beta)c}{\beta - \gamma} \tag{1}$$

Expected profit clearly rises because the probability of the project succeeding increases. However, profit can increase further if knowledge is shared among agents, which we consider next.

Knowledge Sharing in Teams

Suppose now that agents can only share new knowledge within a team, i.e., there are no means for disclosing new knowledge to the organization. Such an environment may exist in organizations where upward communication is infeasible due, for instance, to gaps in expertise (e.g., in academia, in terms of knowledge sharing related to research, there may exist a disconnect between the faculty and the administration). It is straightforward to see that when agents earn a bonus based on relative performance, there is a disincentive to share new knowledge — doing so reduces an agent’s chance of outperforming his colleague. This observation reinforces the result in Proposition 1: if relative-performance pay is high, knowledge will not be shared within the team; thus, relative-performance pay could again have a negative impact on the employer’s profit.

However, it may be infeasible for the employer to entirely eliminate the reward agents associate with outperforming colleagues, due, for instance, to potential promotions, matters related to job security, and other career-related concerns. Let us assume that because of such concerns, the reward agents associate with higher relative performance, B , can be positive. (Because of limited liability, the employer is unable to freely adjust wages to account for any $B > 0$. Without limited liability, the employer could assign negative wages to tax away any gain associated with relative performance.)

The following proposition formalizes our findings for cases where the employer can and cannot freely set B . We consider separately cases where agents can use transfers (i.e., compensate each other for sharing knowledge), and when they cannot.

Proposition 2. *If organizational disclosure is infeasible, then:*

(i) *An optimal INIKS mechanism sets $B = P = 0$ and $w = \frac{c}{\beta-\gamma}$, i.e., each agent is only paid upon successfully completing his task, regardless of the other agent’s effort decision.*

(ii) *If agents perceive a positive relative-performance reward and transfers among agents are infeasible, agents are rewarded both for relative performance and when the overall project succeeds. In particular, the optimal INIKS mechanism sets $P = B$ and $w = \max\{\frac{c}{\beta-\gamma} - B, 0\}$.*

(iii) *If agents perceive a positive relative-performance reward, and transfers among agents are feasible, agents are rewarded for relative performance and a significantly smaller amount when the overall project succeeds. In particular, the optimal INIKS mechanism sets $P = \max\{B - \frac{c}{(\beta-\gamma)(2\alpha-\beta)}, 0\}$ and $w = \max\{\frac{c}{\beta-\gamma} - B - \beta(P - B), 0\}$.*

Part (i) of Proposition 2 follows from the preceding observations; the proofs for parts (ii) and (iii) are in the appendix. An implication of parts (ii) and (iii) is that without organizational disclosure, facilitating agent transfers can result in a greater expected profit for the employer. The intuition is the following. Without agent transfers, when agents associate a high reward with relative performance, the employer would need to assign a large bonus P (conditional on a successful overall project outcome) in order to induce agents to share new knowledge. On the other hand, if agent transfers *are* possible, the employer can shrink the bonus P while still inducing knowledge dissemination. This is because agents can reach private agreements as long as sharing new knowledge increases the team’s overall expected payoff. Hence, agent transfers can enhance

knowledge dissemination within a team. We emphasize this observation in the following corollary.

Corollary 1. *When there are no means of organizational disclosure of new knowledge, facilitating agent transfers weakly increases the employer’s expected profit.*

While we have been interested in knowledge dissemination thus far, there can exist situations where knowledge sharing is discouraged. For instance, such situations may exist if free-riding is prevalent among agents who interact repeatedly. We can apply Proposition 2 to such settings. In particular, the result follows immediately: If agents associate a greater reward with relative performance than with the overall success of the project, then new knowledge will not be shared. We thus have the following corollary.

Corollary 2. *The employer is able to disincentivize knowledge sharing in teams by setting a sufficiently high relative-performance pay, B .*

The intuition for this finding is as follows. By sharing new knowledge, the receiving agent’s expected payoff increases; however, the disclosing agent has a lower probability of receiving the relative-performance bonus, which lowers his expected payoff. When this bonus is large, the receiving agent’s expected payoff increase is insufficient to make up for the disclosing agent’s loss. The reason for this gap is that both agents are now more likely to succeed in their individual tasks, in which case neither of them is rewarded for relative performance.

Organizational Disclosure of New Knowledge

In our framework, organizational disclosure of new knowledge benefits the employer: Once the employer disseminates new knowledge, she can guarantee an increase in productivity. In turn, the employer is able to reduce her operating expenses (specifically, agents’ compensation) while increasing the likelihood of a project succeeding.

In particular, in an optimal INI mechanism, if agent i were to share new productive knowledge with the employer, then the employer will (i) share this knowledge with agent j to increase the productivity of the team, and (ii) reduce the wages of both agents, since agents can be induced to exert effort at lower pay (i.e., since agents’ incentive compatibility constraints are satisfied at lower wages). A wage cut that results from increased productivity can be interpreted as a higher workload or a lower commission.

Thus, from the perspective of agent i , disclosing new knowledge to the employer would not only lead to lower wages, but would also eliminate i ’s advantage in outperforming j . It follows that in order for organizational disclosure of new productive knowledge to take place, agents must be compensated.

No Agent Transfers

Let us assume that agent i has new productive knowledge. When disclosing new knowledge to the employer, agent i would anticipate (1) a wage cut, (2) a loss of a relative performance advantage, and

(3) a reward D that is pre-determined and announced by the employer. Agent i must be sufficiently compensated to induce organizational disclosure, else he would choose to share within his team or to not share at all. The following proposition formally characterizes agents' compensation schemes in an optimal INIKS mechanism.

Proposition 3. *With no agent transfers, in an optimal INIKS mechanism for organizational disclosure, the employer sets $P = 0$, $B \in (0, \frac{c}{(1-\beta)(\beta-\gamma)}]$, $D = \frac{\alpha(\alpha-\beta)}{(\alpha-\gamma)(\beta-\gamma)}c$, and $w = \frac{c}{\beta-\gamma} - (1-\beta)B$ for each agent. If new knowledge is disclosed, the employer rewards the disclosing agent D and announces a new compensation package consisting of $P = 0$, $B \in [0, \frac{c}{(1-\alpha)(\alpha-\gamma)}]$, and $w = \frac{c}{\alpha-\gamma} - (1-\alpha)B$ to each agent.*

It follows from Proposition 3 that as a result of organizational disclosure, aside from the reward assigned for disclosing new knowledge, D , agents' effective wages are reduced. An easy way to see this is by setting $B = 0$. An agent's wage prior to the disclosure of new knowledge is $w = \frac{c}{\beta-\gamma}$, yet it is reduced to $\frac{c}{\alpha-\gamma}$ afterwards.

Interestingly, the employer also chooses to set a small bonus for relative performance, $B \in (0, \frac{c}{(1-\beta)(\beta-\gamma)}]$, and no project success pay, $P = 0$. The reason for doing so is to reduce a disclosing agent's outside option. In particular, an agent's best alternative to organizational disclosure is to not share at all (since the assigned relative-performance pay exceeds the reward from an overall project success, it follows from Proposition 2 that team sharing will not take place). By inducing agents not to share new knowledge within their team, the employer, in turn, is able to maintain a lower level of knowledge disclosure reward, D .

Agent Transfers

Let us maintain the assumption that agent i has new productive knowledge. If i discloses his knowledge to the employer, agent j experiences a wage cut. Hence, agent j has an incentive to dissuade i from doing so. It thus follows that when agent transfers are possible, the employer faces an additional constraint.

From his incentive-compatibility constraint, after knowledge is institutionalized, agent j 's expected payoff in a profit-maximizing mechanism is given by $\frac{\gamma c}{\alpha-\gamma}$. It is strictly lower than his expected payoff without any knowledge disclosure, as given by $\frac{\gamma c}{\beta-\gamma}$. It is also lower than j 's expected payoff when the knowledge is only shared within the team (which is bounded below by $\frac{\gamma c}{\beta-\gamma}$ and above by $\frac{\alpha-\beta+\gamma}{\beta-\gamma}c$, depending on the outcome of j 's negotiation with i). Hence, agent j indeed has an incentive to dissuade i from disclosing his knowledge to the employer. Accounting for this added consideration alters the compensation scheme required to sustain an optimal INIKS mechanism, as formally characterized by the following proposition.

Proposition 4. *With agent transfers, in an optimal INIKS mechanism for organizational disclosure, the employer sets $P = 0$, $B \in [0, \frac{c}{(\beta-\gamma)(\alpha-\gamma)}]$, $D = \frac{2\alpha(\alpha-\beta)}{(\alpha-\gamma)(\beta-\gamma)}c$, and $w = \max\{\frac{c}{\beta-\gamma} - (1-\alpha)B, 0\}$ for each agent. If knowledge is disclosed, the employer rewards the disclosing agent D and announces a new compensation package consisting of $P = 0$, $B \in [0, \frac{c}{(1-\alpha)(\alpha-\gamma)}]$, and $w = \frac{c}{\alpha-\gamma} - (1-\alpha)B$ for each agent.*

When agents can reach an agreement to share new knowledge within the team, the expected gain for the *receiving* agent exceeds the disclosing agent’s expected loss. To induce organizational disclosure in an INIKS mechanism, the employer must surpass the receiving agent’s best attempt to dissuade the other agent from sharing his knowledge with the employer. It is thus intuitive that the employer would benefit from disincentivizing team sharing, since doing so eliminates the constraint of having to match a receiving agent’s best offer. Indeed, the employer can readily achieve this by setting a large reward for relative performance. However, it turns out not to be in the employer’s best interest to do so. If relative-performance pay is high, the employer must assign additional compensation to the disclosing agent at a greater expected loss — a loss that is derived from losing his relative-performance advantage upon disclosure. Since the employer must pay more in this case, a high amount of relative-performance pay, B , actually results in lower expected profits. Hence, when agent transfers are possible, it is profit maximizing for the employer to set B low and face the externality imposed by a non-disclosing agent.

When organizational disclosure takes place in our framework, the employer’s benefit is twofold. First, the employer increases the likelihood of the project succeeding. Second, the employer is able to cut down on operating expenses. While the former can also be obtained when knowledge is shared within a team, the latter cannot. Interestingly, when agent transfers are possible, as a result of the employer facing an added constraint, the disclosing agent appropriates the rents, as they pertain to his team’s project, that are associated with organizational disclosure relative to team sharing. In other words, from the particular project pursued by the team, the employer does not gain from organizational disclosure relative to the knowledge being shared within the team.

Proposition 5. *With agent transfers, the agent who discloses new knowledge appropriates all of the rents associated with organizational disclosure that pertain to his team’s project.*

While there may exist external benefits to organizational disclosure, there may also exist external costs (e.g., the cost of acquiring a knowledge-management system and training employees to use it). Hence, the employer may or may not choose to pursue organizational disclosure, depending on the net external benefit of doing so.

Unobservable Task Outcomes

We now turn to the case where the employer is unable to observe the outcomes of individual tasks, but can observe the overall project outcome. Here, the mechanism must reward agents conditional on the outcome of the overall project, and no relative-performance rewards are possible as individual performance is not evaluated. Thus, we set $B = P = 0$ and only consider wages that are conditional on the overall project’s success (setting $P > 0$ in this case is redundant, as wages are already conditioned on the success of the overall project).

Winter (2004) shows that in an optimal INI mechanism, there exists an organizational hierarchy in terms of compensation. Specifically, one of the agents is induced to exert effort independent of the other agent’s effort decision (we recall that once announced, wages and/or titles become

common knowledge). Given this part of the compensation scheme, the other agent, conditional on the project's success, is then compensated less than the first agent, because he already recognizes that it is in the best interest of the higher-paid agent to exert effort. In other words, the second agent's incentive-compatibility constraint requires a lower wage to be satisfied. Hence, a hierarchy is established in terms of compensation.

Without loss of generality, let us assume that agent i is the higher paid agent, and let us first consider, as a benchmark, the case where neither agent can generate new knowledge. Then agent i is induced to exert effort independent of j 's effort decision. Agent i 's wage is set to satisfy the following incentive compatibility constraint:

$$\beta\gamma w_i - c \geq \gamma^2 w_i$$

Hence, in an optimal INI mechanism, the employer sets $w_i = \frac{c}{\gamma(\beta-\gamma)}$. Given agent i 's wage, agent j 's incentive compatibility constraint is given by

$$\beta^2 w_j - c \geq \gamma\beta w_j$$

which gives $w_j = \frac{c}{\beta(\beta-\gamma)}$. It follows that in an optimal INI mechanism (without new knowledge), expected payoffs are given by $\frac{\beta^2 c - \beta\gamma c + \gamma^2 c}{\gamma(\beta-\gamma)}$ for agent i and by $\frac{\gamma}{\beta-\gamma}c$ for agent j .

Knowledge Sharing in Teams

We first observe that since wages are conditioned solely on the success of the project, agents always have an incentive to share new knowledge within the team. By sharing knowledge, agents increase the success likelihood of the project, which increases their respective expected payoffs. We thus have the following result.

Proposition 6. *In an optimal INIKS mechanism for team sharing, when only the project outcome can be observed, the employer creates a wage hierarchy, with $w_i = \frac{c}{\gamma(\beta-\gamma)}$ and $w_j = \frac{c}{\beta(\beta-\gamma)} < w_i$, paid conditional on the project's success. With new knowledge, the employer's expected profit is given by*

$$\alpha^2 \left(R - \frac{c}{\gamma(\beta-\gamma)} - \frac{c}{\beta(\beta-\gamma)} \right) \quad (2)$$

Organizational Disclosure

Under the above compensation scheme, agents do not have an incentive to disclose new knowledge to the employer, as doing so would result in wage cuts.

We present the case where agent i has private knowledge; the analysis is similar for agent j . Once new knowledge is disclosed to the employer, wages will be cut to $w_i = \frac{c}{\gamma(\alpha-\gamma)}$ and $w_j = \frac{c}{\alpha(\alpha-\gamma)}$. (Technically, the employer can switch the ordering of the wage hierarchy between the agents once new knowledge is disclosed, which we do not consider. In the case where i is the disclosing agent,

doing so would result in an even further wage cut for i , which seems implausible given the fact that he is the disclosing agent.)

No Agent Transfers

When agent transfers are impossible, the employer would need to at least compensate agent i for his expected wage loss, given by $D_i = \alpha^2(\frac{1}{\gamma(\beta-\gamma)} - \frac{1}{\gamma(\alpha-\gamma)})c = \frac{\alpha^2(\alpha-\beta)c}{\gamma(\alpha-\gamma)(\beta-\gamma)}$. We note that due to the wage hierarchy, the employer can specify different organizational-disclosure rewards, D_i and D_j , for the two agents. This is because the required disclosure reward is smaller if agent j has the new knowledge, as his expected wage loss is lower.

Agent Transfers

With agent transfers, the employer is again faced with an added constraint. In particular, agent j would be willing to pay i an amount no larger than his expected loss, given by $\alpha^2(\frac{1}{\beta(\beta-\gamma)} - \frac{1}{\alpha(\alpha-\gamma)})c$. Hence, for organizational disclosure of new knowledge to take place, the employer would need to compensate agent i for his own as well as for agent j 's expected reduction in payoff. Thus, it follows that relative to team sharing, as in the case with observable task outcomes, agent i appropriates the rents associated with organizational disclosure as they pertain to the project. We summarize these observations in the following proposition.

Proposition 7. *In an optimal INIKS mechanism for organizational disclosure, when tasks are unobservable, with no agent transfers, the employer's expected profit has a least upper bound of*

$$\alpha^2(R - \frac{c}{\gamma(\alpha - \gamma)} - \frac{c}{\beta(\beta - \gamma)})$$

With agent transfers, relative to team sharing, the disclosing agent appropriates all of the rents associated with the project.

Intuitively, when there are no agent transfers, the employer is able to save more on operating expenses when the lower-paid employee discloses new knowledge, due to a larger wage cut for the higher-paid employee. With agent transfers, the employer's decision of whether or not to induce organizational disclosure of new knowledge once more depends on the net external benefit, as the rents from doing so for the specific project in question are dissipated from compensating the disclosing agent.

Comparison

In this section, we compare the two informational settings presented in the two previous sections and offer additional observations.

Performance Observability

If the employer is able to observe effort, then she is able to obtain the first-best level of expected profits. In our framework, we considered two extreme alternatives. Under the first information regime, the outcomes of individual tasks are observable (and thus also the overall project outcome), and under the second, only the overall project outcome can be observed.

From the perspective of the employer, whether tasks should be observed depends in part on whether agents are able to compensate each other for sharing knowledge. It is intuitive that in many cases where teams work together, some types of agent transfers are feasible. For instance, in academia, John can assist Jane on a team project in sociology in return for assistance from Jane in statistics. We have shown that in such cases, agent transfers dissipate the employer's rents from organizational disclosure of new knowledge as they pertain to the individual project (i.e., not accounting for external benefits or costs). The following result addresses the case where agent transfers are infeasible.

Proposition 8. *With no agent transfers, the employer has a stronger incentive to induce organizational disclosure when only the project outcome is observable relative to when individual task outcomes can be observed; however, overall expected profit is always higher when task outcomes can be observed.*

It follows from Proposition 8 that the employer sees greater returns to inducing organizational disclosure when only the overall outcome of the project can be observed. The reason for these greater returns are larger cuts in operating expenses once new knowledge is disclosed. However, given a choice, the employer would prefer to observe the outcomes of individual tasks, as the moral hazard problem that arises in inducing effort is greatly diminished. At the same time, there are cases where observing the outcomes of individual tasks is infeasible, due, for instance, to the employer lacking the required expertise to assess such outcomes. Thus, the result in Proposition 8 gives rise to the empirical prediction that the adoption of knowledge-management systems is more likely in organizations where the outcomes of individual tasks are not observed.

In the case where agent transfers are possible, given organizational disclosure, both information regimes generate the same expected profits for the employer. This is because the disclosing agent appropriates any additional rents relative to team sharing (to be precise, this statement is true when the relative-performance pay, B , is small, which would indeed be the case when the employer can freely set it to maximize expected returns). It follows that the availability of agent transfers reduces the employer's incentive to implement organizational protocols for sharing new knowledge.

However, when the employer is unable to induce organizational disclosure, it follows from Corollary 1 that facilitating agent transfers can only work to increase expected profits. Moreover, if agent transfers are possible, the result from Proposition 8 does not always extend. In particular, if agents associate a large reward with relative performance (i.e., the employer is constrained by $B \gg 0$), team sharing of new knowledge will not always occur. In the context of a factory, if agents are primarily motivated by the prospect of a considerable promotion, job security, or other career-related concerns, then even with agent transfers, team sharing may be too costly for the employer to induce

(by Proposition 2, it would require setting a high reward, P , for the success of the overall project). In that case, as the following result indicates, the employer would prefer to *only* observe the outcome of the overall project; i.e., the employer would prefer to ignore any information associated with task outcomes.

Proposition 9. *With agent transfers, if agents derive a large reward from relative performance, the employer’s profit under an optimal INIKS mechanism is higher when only outcome of the overall project can be observed.*

By only observing the outcome of the overall project, the employer commits not to reward agents based on relative performance. In doing so, the employer is able to induce team sharing and increase expected profits. In other words, committing to having less information can actually lead to greater expected returns. In the factory context, the employer, for instance, could spend most of her time off the floor. Doing so could help assuage employees’ concerns about relative-performance evaluations and increase their incentive to share knowledge with fellow workers.

Relative Performance

Should the employer compensate in part based on relative performance? In our framework, when individual task outcomes are observable, we find that large amounts of compensation based on relative performance can only hinder knowledge sharing within teams, and can only increase the employer’s cost of inducing organizational disclosure. Granted, it is likely that employees would always associate some reward with higher relative performance, due, for instance, to potential promotions, portfolio building, and other career-related motives. Our findings indicate that when task outcomes are observable, as long as employees’ expectations of this form of compensation are not high, it will not affect the employer’s cost of implementing protocols for knowledge dissemination. At the same time, relative performance contracts may be desirable in settings where the employer wishes to discourage agents from sharing knowledge.

Organizational Disclosure

Should an employer implement organizational protocols for sharing new knowledge? We showed that the employer indeed benefits from organizational disclosure when agent transfers are infeasible. In practice, there are costs associated with institutionalizing knowledge that are not directly considered in our model (e.g., the costs of acquiring, setting up, and training employees to use a knowledge-management system). Moreover, such costs may exceed any potential benefits.

When agent transfers are possible, we find that organizational disclosure of new knowledge does not result in additional profits from the individual project. This is because the agent who discloses the knowledge to the employer is able to extract any rents relative to team sharing. Our findings here are reinforced when there are some exogenous costs associated with institutionalizing knowledge.

Going beyond our framework, there may exist benefits to organizational disclosure outside of the team-employer environment. Such benefits may include bolstering a patent portfolio to deter

competitors, and sharing new knowledge with other teams in the organization. However, while such benefits may exist, it is unlikely that the employer would be able to properly assess their value.

In contrast, the employer can readily induce team sharing of new knowledge by simply limiting the amount of relative-performance pay and facilitating agent transfers. Thus, our findings suggest that a better approach for the dissemination of new knowledge within an organization would (1) foster relationships among the organization’s knowledge-intensive teams, and (2) limit the use of relative-performance pay within such teams.

In the following two sections, we study extensions of the base model which address some of the tradeoffs between the two information regimes. In the first extension, the employer can work to monitor task outcomes. In the second, the employer can assess whether a team is making use of new knowledge.

Endogenous Information Monitoring

In this section, we extend the base model by considering a setting where the amount of information the employer observes is determined endogenously. Suppose that at the beginning of the game, the employer chooses a monitoring intensity λ at a cost $C(\lambda) = \frac{R}{2}\lambda^2$. The monitoring technology works in the following simple way. With probability λ , the employer is able to observe the outcomes of agents’ individual tasks, and with probability $1 - \lambda$, the employer is only able to observe the overall project outcome. The realization of the monitoring outcome is determined after agents make their effort decisions. (Without this assumption, the continuation game following the monitoring outcome is either the game with observable task outcomes or the game where only the project outcome can be observed.)

Let us suppose that with probability λ , the employer is able to observe the outcomes of agents’ individual tasks and make profit π_{obs} , and with probability $1 - \lambda$, the employer is only able to observe the overall project outcome and make profit π_{unobs} . Here, π_{obs} and π_{unobs} each pertain to an optimal INIKS mechanism in their respective continuation game. The employer’s expected profit is then given by $\lambda\pi_{obs} + (1 - \lambda)\pi_{unobs} - \frac{R}{2}\lambda^2$.

Knowledge Sharing in Teams

Given that organizational disclosure of new knowledge is infeasible, depending on the employer’s chosen compensation scheme, new knowledge may be shared within teams. The following proposition compares the employer’s chosen monitoring intensities depending on whether or not agent transfers are feasible and whether or not agents derive a reward from relative performance.

Proposition 10. *The employer has a greater incentive to monitor tasks when agents derive smaller rewards from relative performance and/or when agent transfers are feasible.*

The intuition for Proposition 10 is clear. The employer chooses her monitoring intensity depending on the difference in her expected profits when she can and cannot monitor tasks. This

difference is greater when agents derive small rewards from relative performance and when agent transfers are feasible, thus increasing the employer's incentive to monitor.

Organizational Disclosure of New Knowledge

No Agent Transfers

As shown in the previous section, given sufficient compensation, agents willingly disclose new knowledge to the employer. Due to the wage hierarchy in an optimal INIKS mechanism with unobservable task outcomes, the employer rewards agents differently for such knowledge disclosure.

Let us suppose that agent i is the higher-paid agent. Then the employer's chosen disclosure payments are given by $D_i = \frac{\alpha^2(\alpha-\beta)c}{\gamma(\alpha-\gamma)(\beta-\gamma)}$ and $D_j = \alpha^2(\frac{c}{\beta(\beta-\gamma)} - \frac{c}{\alpha(\alpha-\gamma)})$, where simple algebra shows that $D_i > D_j$. Once knowledge is disclosed by i , his wage and agent j 's wage are reduced to $w_i = \frac{c}{\gamma(\alpha-\gamma)}$ and $w_j = \frac{c}{\alpha(\alpha-\gamma)}$, respectively. Let us assume for a moment that only higher-paid agents generate new knowledge. It then follows that the employer's profit-maximizing level of monitoring intensity is given by $\lambda_i^* = \frac{\alpha c(\alpha-\gamma)}{R\gamma(\beta-\gamma)}$.

Let us now consider the opposite case where only lower-paid agents generate new knowledge. If knowledge is disclosed by j , his wage and agent i 's wage are reduced to $w_j = \frac{c}{\alpha(\alpha-\gamma)}$ and $w_i = \frac{c}{\gamma(\alpha-\gamma)}$, respectively. The employer's profit-maximizing level of monitoring intensity in this case is given by $\lambda_j^* = \frac{\alpha c(\beta^2 - 2\beta\gamma + \gamma\alpha)}{R\gamma\beta(\beta-\gamma)}$.

It can be readily shown that $\lambda_i^* > \lambda_j^*$, indicating that the employer is more inclined to monitor task outcomes when higher-paid agents are more likely to generate new knowledge. That is, the employer has a greater incentive to monitor task-pertinent information when higher-paid employees are more likely to have new productive knowledge. This arises from the fact that the employer rewards lower-paid agents less for organizational disclosure, which reduces the incentive to monitor tasks. Said another way, when only the project outcome can be observed, the disclosure payment awarded to higher-paid agents significantly reduces the employer's bottom line, thus increasing her incentive to monitor. The following Proposition summarizes our finding in this case.

Proposition 11. *When agent transfers are infeasible, the employer sets a higher level of monitoring intensity if higher-paid agents are more likely to have new knowledge than lower-paid agents.*

In the following, to focus on a worst-case scenario from the employer's perspective, we consider cases where agent i has new knowledge.

Agent Transfers

When agent transfers are feasible, agents may work towards reaching an agreement for sharing new knowledge and not disclosing it to the employer. Such an agreement is possible when the expected gain for the receiving agent exceeds the disclosing agent's expected loss from not pursuing other knowledge-sharing alternatives. As shown in the previous section, in an optimal INIKS mechanism, this results in the agent with the knowledge appropriating the rents associated with organizational disclosure as they pertain to the project. It thus follows that the employer has a greater incentive

to monitor agent tasks relative to the case where agent transfers are infeasible. In particular, the employer chooses to set $\lambda^* = \frac{\alpha c(\alpha\beta + \gamma\alpha - 2\beta\gamma)}{R\gamma\beta(\beta - \gamma)}$ independent of which agent has new knowledge. The following proposition summarizes our finding in this case.

Proposition 12. *The employer chooses to set a higher level of monitoring intensity when agent transfers are feasible than when transfers are infeasible.*

The next section studies a related extension of the base model where the employer can attempt to determine whether agents have new knowledge by assessing their productivity.

Endogenous Knowledge Monitoring

In the prior section, we have determined the employer’s chosen information monitoring intensity given two possible information regimes: i) individual task outcomes are observable, and ii) only project outcome is observable. In this section, we consider a related setting where the employer is unable to reward organizational disclosure (i.e., $D = 0$ is a constraint), but can attempt to detect whether agents have new knowledge in a given information regime and adjust wages accordingly. That is, the employer can assess a team’s productivity to determine whether it is using new knowledge. Such settings are motivated by situations where a team’s supervisor is not assigned a budget for rewarding organizational disclosure, yet monitors agents’ output progress and can impact agents’ real wages by setting an appropriate task allocation.

We study two possible cases, depending on whether task outcomes are observable or not. In either case, the employer, at some cost, has a chance to determine whether agents are utilizing new knowledge, and if so, adjust wages accordingly. (Since agents are rewarded based on success, a “strategic failure” to mask the existence of new knowledge is not payoff maximizing for the agents.)

Assume that at the beginning of the game, the employer chooses a knowledge monitoring intensity θ at a cost $C(\theta) = \frac{R}{2}\theta^2$. Let us also assume a prior probability ρ that there exists new knowledge. The knowledge monitoring technology works in the following simple way. If individual task outcomes are observable, with probability θ , the employer is able to determine whether there is new knowledge and which agent has the new knowledge, and with probability $1 - \theta$ the employer is unable to determine the existence of new knowledge. Likewise, if only project outcome is observable, with probability θ , the employer is able to determine whether there is new knowledge but is unable to determine which agent has it, and with probability $1 - \theta$ the employer is unable to determine the existence of new knowledge. For technical simplicity, we consider cases where $B = P = 0$, which, by Proposition 3 and 4, is without loss of generality when small rewards are associated with relative performance.

From the employer’s perspective, there are 3 possible outcomes. In particular, let π_1 denote the employer’s expected profit in the case where new knowledge is detected and a new compensation scheme is subsequently implemented; let π_2 denote the employer’s expected profit when there is no new knowledge; and let π_3 denote the employer’s expected profit when new knowledge exists but detection fails.

Observable Task Outcomes

If task outcomes are observable, the employer's expected profit is given by

$$\theta(\rho\pi_1 + (1 - \rho)\pi_2) + (1 - \theta)(\rho\pi_3 + (1 - \rho)\pi_2) - \frac{R}{2}\theta^2$$

Here, π_1 , π_2 , and π_3 are $\alpha^2 R - \frac{2\alpha c}{\alpha - \gamma}$, $\beta^2 R - \frac{2\beta c}{\beta - \gamma}$, and $\alpha^2 R - \frac{2\alpha c}{\beta - \gamma}$, respectively, where the derivation of π_3 is based on the assumption that new knowledge is shared within team. The first-order condition shows that the employer's expected profit is maximized at $\theta^* = \frac{2\alpha\rho c(\alpha - \beta)}{R(\beta - \gamma)(\alpha - \gamma)}$.

It is instructive to compare the employer's expected profit given θ^* and $D = 0$ to the employer's profit from the base model where the disclosure award D can be set to induce organizational disclosure. For comparison purposes, we use the same prior ρ and focus on the case where agent transfers are infeasible. (When agent transfers are feasible, since the disclosing agent appropriates all of the rents relative to team sharing, the employer would always prefer to assess whether new knowledge is being used versus inducing disclosure — provided that there are no external net benefits to institutionalizing.) We find that when agents are likely to have new knowledge, the employer may prefer to check for new knowledge rather than induce its disclosure. Proposition 13 below details our finding for this case.

Unobservable Task Outcomes

As before, if new knowledge is detected, agents' real wages are adjusted downward, accounting for their productivity increase. The employer's expected profit in this case is given by

$$\pi = \theta(\rho\pi_1 + (1 - \rho)\pi_2) + (1 - \theta)(\rho\pi_3 + (1 - \rho)\pi_2) - \frac{R}{2}\theta^2$$

Here, π_1 , π_2 , and π_3 are $\alpha^2(R - \frac{c(\gamma + \alpha)}{\gamma\alpha(\alpha - \gamma)})$, $\beta^2(R - \frac{c(\gamma + \beta)}{\gamma\beta(\beta - \gamma)})$, and $\alpha^2(R - \frac{c(\gamma + \beta)}{\gamma\beta(\beta - \gamma)})$, respectively. The employer's expected profit is maximized at $\theta^* = \frac{\rho\alpha^2 c}{R\gamma}(\frac{\gamma + \beta}{\beta(\beta - \gamma)} - \frac{\gamma + \alpha}{\alpha(\alpha - \gamma)})$.

We compare the employer's expected profit given the above θ^* and $D = 0$ to the employer's profit from the base model where the disclosure award D can be set to induce organizational disclosure. For comparison purposes, we use the same prior ρ , assume that agent transfers are infeasible, and focus on the case where only higher-paid agents generate new knowledge. As Proposition 13 indicates, when agents are likely to have new knowledge, the employer prefers to check for new knowledge rather than induce its disclosure.

Proposition 13. *The employer chooses to check for new knowledge in lieu of setting a disclosure reward when organizational disclosure results in significant cuts in operating expenses and the probability of agents' possessing new knowledge is sufficiently high.*

The condition in Proposition 13 is easily explained: The employer prefers to check for new knowledge when (i) agents are likely to generate new knowledge and (ii) institutionalizing such knowledge results in significant reductions in operating expenses (i.e., in agents' wages). The intuition is as follows. In inducing disclosure by setting an appropriate reward $D > 0$, the employer gives up a portion of the gains from institutionalizing new knowledge, since some of the rents from

diminished operating expenses are shifted to the disclosing agent. In expectation, some of these losses can be recapped if the employer checks for new knowledge in lieu of inducing disclosure.

Conclusions and Future Work

The empirical literature on productivity of teams suggests a tension between group-based incentives and relative-performance incentives. Relative-performance measures can undermine team performance in joint tasks while group incentives are subject to moral-hazard and free-riding problems. Ironically, a common remedy for moral hazard in groups has been to increase the level of task outcome and process monitoring. Recent efforts by industry leaders to introduce knowledge-management systems into organizations only further complicates these dynamics. Knowledgeable workers can now share directly with their firms, directly with co-workers, or simply withhold new information. Given the complexity of these dynamics, it is unclear how a firm should seek to implement an incentive structure for sharing knowledge in a cost-effective manner.

To address this question, we developed a theoretical model of knowledge sharing built upon a principal-agent framework. Taking into account a mix of relative- and group-based incentives, and a firm's ability to monitor individual task outcomes, we characterized knowledge-sharing mechanisms that induce agents to exert effort and share new knowledge in return for minimum compensation. We find that in our model, close team environments where agents can compensate each other for sharing new knowledge may actually be suboptimal — they tend to increase the principal's cost of inducing agents to disclose new productive knowledge to the organization.

We extended our base model in several ways: First, we endogenized task observability by enabling the employer to allocate resources for task monitoring. Here we found that employers in our framework have the greatest incentive to monitor tasks when agents derive small payoffs from relative performance. Second, we studied situations where either higher-compensated or lower-compensated agents were more likely to generate new knowledge. We showed that the employer had a greater incentive to monitor tasks if higher-paid agents were more likely to have new knowledge than lower-paid agents. Finally, to address a commonly-examined question in the empirical literature, we examined a case where the employer has the ability to probe productivity to determine whether agents have new knowledge. Here we found that the employer chooses to do so when institutionalizing knowledge results in significant reductions in operating expenses.

Few empirical studies have examined the combined dynamics that arise when introducing a knowledge-management system into an existing incentive structure. Our theoretical framework can help guide future experimental and empirical research, both from economic and sociological perspectives. Although our model focused on the financial benefits to workers, non-financial considerations such as altruism, professionalism, status, and social conformity can be readily addressed within the existing framework through a modification of the utility function. Our model can also readily accommodate several other extensions: It can extend beyond two agents in a team, as well as allow for situations where the value of new knowledge or the cost of transmitting it is asymmetrically-distributed across agents. Our model can also be extended to study knowledge-

sharing mechanisms that are optimal in expectation rather than in dominant strategies, as well as cases where disclosing knowledge may stochastically improve an agent's productivity.

Several limitations of our model provide additional directions for future research. These include accounting for risk-averse agents, studying repeated interactions, and considering other aspects of organizations, such as the characteristics of multi-team settings, subgroups, and broad social networks within firms (Fang et al., 2010).

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Appendix

The appendix contains all proofs omitted from the text.

Lemma 1

Proof. First, consider the case where agent $j \neq i$ exerts effort. Agent i then exerts effort if

$$\beta w_i + \beta(1 - \beta)B - c \geq \gamma w_i + \gamma(1 - \beta)B$$

which reduces to

$$w_i \geq \frac{c}{\beta - \gamma} - (1 - \beta)B \quad (\text{A1})$$

If, on the other hand, agent j does not exert effort, then agent i exerts effort if

$$w_i \geq \frac{c}{\beta - \gamma} - (1 - \gamma)B \quad (\text{A2})$$

The RHS in (A1) is greater than that in (A2), since agent i is less likely to receive a bonus when j exerts effort; thus, the compensation required to incentivize effort is greater. ■

Proposition 1

Proof. Consider first the same compensation scheme as in Lemma 1. Conditional on a successful outcome, wage is given by $w = \frac{c}{\beta - \gamma} - (1 - \beta)B$. With his private knowledge, agent i 's probability of a successful task given effort is $\alpha > \beta$. Hence, given w , agent i will exert effort and obtain a higher expected payoff. However, if $B > 0$, agent j 's expected payoff is lower since he is less likely to outperform i . Both INI and INIKS mechanisms require agents to exert effort in equilibrium. Since j 's beliefs about i possessing new knowledge can be arbitrary, j 's wage must be set to ensure that he exerts effort independent of such beliefs. Given this observation, we have

$$w_j \geq \frac{c}{\beta - \gamma} - (1 - \alpha)B$$

It follows that an optimal INI mechanism requires both agents' wages to be set at $\frac{c}{\beta - \gamma} - (1 - \alpha)B$, which, given $B > 0$, results in lower expected profits for the employer. ■

Proposition 2

Proof. Part (i) is explained in the text. For Part (ii), suppose $B > 0$ and $P \geq 0$. Given that agents exert effort, an agent will share new knowledge if and only if

$$\alpha w + \alpha^2 P + \alpha(1 - \alpha)B - c \geq \alpha w + \alpha\beta P + \alpha(1 - \beta)B - c$$

Simplifying, it follows that $P \geq B$ must hold. In other words, $P \geq B$ is a requirement for an optimal INIKS mechanism. Given $B > 0$, the smallest reward P the employer can assign is thus $P = B$.

Recall that an INIKS mechanism is also an INI mechanism, i.e., effort must be induced independent of whether agents have new knowledge. Hence, to obtain the minimum wage that would achieve that, let us suppose that there is no new knowledge. Given that agent j exerts effort, agent i exerts effort when

$$\beta^2 P + \beta w_i + \beta(1 - \beta)B - c \geq \gamma\beta P + \gamma w_i + \gamma(1 - \beta)B$$

or if

$$w_i \geq \frac{c}{\beta - \gamma} - B - \beta(P - B)$$

Given that agents j does not exert effort, agent i exerts effort when

$$\beta\gamma P + \beta w_i + \beta(1 - \gamma)B - c \geq \gamma^2 P + \gamma w_i + \gamma(1 - \gamma)B$$

or if

$$w_i \geq \frac{c}{\beta - \gamma} - B - \gamma(P - B)$$

Combining the above observations, it follows that an agent's wage is given by $w = \max\{\frac{c}{\beta - \gamma} - B, 0\}$.

For Part (iii), suppose agent transfers are possible, and agent i has new knowledge. Assume j believes with certainty i has private knowledge (since beliefs can be arbitrary, this assumption is without loss of generality). Agent j 's expected payoff without the knowledge is given by $\beta\alpha P + \beta w_j + \beta(1 - \alpha)B - c$. With the knowledge, it is $\alpha^2 P + \alpha w_j + \alpha(1 - \alpha)B - c$. Hence, the expected value of the knowledge to j is given by

$$(\alpha - \beta)w_j + (\alpha - \beta)B - \alpha(\alpha - \beta)(B - P)$$

Analogously, the expected loss to agent i from sharing the knowledge is given by $\alpha(\alpha - \beta)(B - P)$. Thus, there exists a surplus from an agreement if

$$w_j + B \geq 2\alpha(B - P) \tag{A3}$$

To induce effort, $w_j \geq \frac{c}{\beta - \gamma} - B - \beta(P - B)$ must also hold, whereby in an optimal mechanism,

$$w = \max\{\frac{c}{\beta - \gamma} - B - \beta(P - B), 0\} \tag{A4}$$

Combining (A3) and (A4), then, if $w > 0$, the employer can facilitate knowledge sharing if $P \geq \max\{B - \frac{c}{(\beta - \gamma)(2\alpha - \beta)}, 0\}$; if $w = 0$, the employer can do so by setting $P = 0$. ■

Proposition 3

Proof. Once new knowledge is disclosed to the employer, to induce agent i to exert effort, if agent j exerts effort, his incentive constraint must satisfy

$$\alpha^2 P + \alpha w_i + \alpha(1 - \alpha)B - c \geq \alpha\gamma P + \gamma w_i + \gamma(1 - \alpha)B. \tag{A5}$$

If agent j does not exert effort, it must satisfy

$$\alpha\gamma P + \alpha w_i + \alpha(1 - \gamma)B - c \geq \gamma^2 P + \gamma w_i + \gamma(1 - \gamma)B. \tag{A6}$$

For (A5), it follows that agent i exerts effort when

$$w_i \geq \frac{c}{\alpha - \gamma} - B + \alpha(B - P).$$

For (A6), i exerts effort when

$$w_i \geq \frac{c}{\alpha - \gamma} - B + \gamma(B - P).$$

Hence, given that new knowledge had been shared, we have $w = \max\{\frac{c}{\alpha - \gamma} - B + \alpha(B - P), 0\}$ in an optimal INI mechanism, and i 's subsequent expected payoff is given by

$$\alpha^2 P + \alpha \max\{\frac{c}{\alpha - \gamma} - B + \alpha(B - P), 0\} + \alpha(1 - \alpha)B - c$$

Since performance at an individual task constitutes a sufficient statistic (Holmström, 1982), it is sufficient to consider the case where $B = P = 0$ holds after the knowledge had been disclosed to the

employer. In this case, agent i 's expected payoff is given by $\frac{\gamma c}{\alpha - \gamma}$. However, prior to organizational disclosure, the employer may have an incentive to affect the outcome of team sharing as it affects i 's outside option. In particular, if $B > P$, team sharing will not take place, whereas it will when $P \geq B$.

Let us first consider the case where $P \geq B$, where without organizational disclosure, team sharing will always take place. Then to induce organizational disclosure, the employer must reward i an amount D such that

$$D + \frac{\alpha c}{\alpha - \gamma} - c \geq \alpha^2 P + \alpha w_i^{ND} + \alpha(1 - \alpha)B - c$$

where $w_i^{ND} = \max\{\frac{c}{\beta - \gamma} - B - \beta(P - B), 0\}$ denotes agent i 's wage prior to disclosure. Hence, D must satisfy

$$D \geq \alpha^2(P - B) + \alpha B + \alpha(\max\{\frac{c}{\beta - \gamma} - B - \beta(P - B), 0\} - \frac{c}{\alpha - \gamma})$$

There are then two subcases to consider:

- If $\frac{c}{\beta - \gamma} - B - \beta(P - B) \geq 0$, then $D = \alpha(\alpha - \beta)(P - B) + \frac{\alpha(\alpha - \beta)}{(\beta - \gamma)(\alpha - \gamma)}c$
- If $\frac{c}{\beta - \gamma} - B - \beta(P - B) < 0$, then simple algebra shows $D > \frac{\alpha(\alpha - \beta)}{(\beta - \gamma)(\alpha - \gamma)}c$.

It follows that if $P \geq B$, setting $P = B = 0$ maximizes the employer's expected revenue. If, on the other hand, $P < B$, then team sharing will never take place. Then to induce organizational disclosure, the employer must reward i an amount D such that

$$D + \frac{\alpha c}{\alpha - \gamma} - c \geq \alpha\beta P + \alpha w_i^{ND} + \alpha(1 - \beta)B - c$$

Hence, D must satisfy

$$D \geq -\alpha\beta(B - P) + \alpha B + \alpha(\max\{\frac{c}{\beta - \gamma} - B + \beta(B - P), 0\} - \frac{c}{\alpha - \gamma})$$

There are again two subcases to consider:

- If $\frac{c}{\beta - \gamma} - B + \beta(B - P) \geq 0$, then $D = \frac{\alpha(\alpha - \beta)}{(\beta - \gamma)(\alpha - \gamma)}c$
- If $\frac{c}{\beta - \gamma} - B + \beta(B - P) < 0$, then simple algebra shows $D > \frac{\alpha(\alpha - \beta)}{(\beta - \gamma)(\alpha - \gamma)}c$.

Thus, if $B > P$ and $B - \beta(B - P) \leq \frac{c}{\beta - \gamma}$, the employer is able to reach the highest expected revenue level. The result follows from the above and the fact that $P = 0$ in an optimal INIKS mechanism. ■

Proposition 4

Proof. As in Proposition 3, given that new knowledge had been shared with the employer, both agents' expected payoffs are given by $\frac{\gamma c}{\alpha - \gamma}$. Prior to organizational disclosure taking place, the employer may have an incentive to affect the outcome of a possible team sharing of new knowledge, as that would determine i 's expected payoff when not sharing with the employer (i.e., i 's outside option). In particular, if $B \geq P + \frac{c}{(\beta - \gamma)(2\alpha + \beta)}$, team sharing will not take place, whereas otherwise it will.

When knowledge is shared with the employer, j 's expected payoff after an incentive compatible wage cut is $\frac{\gamma c}{\alpha - \gamma}$. When knowledge is *not* institutionalized, j 's payoff depends on the outcome of his negotiation with i . Without organizational disclosure, agents i and j are able to strike an

agreement if j 's loss from i 's disclosure to the employer exceeds i 's loss from sharing it privately with j , i.e., if $\alpha(\alpha - \beta)(B - P) < \frac{\alpha - \beta + \gamma}{\beta - \gamma}c - \frac{\gamma c}{\alpha - \gamma}$, or if $B - P < \frac{c}{(\beta - \gamma)(\alpha - \gamma)}$.

We consider two possible cases:

(1) Team sharing, i.e., $B - P < \frac{c}{(\beta - \gamma)(\alpha - \gamma)}$: When knowledge is not shared with the employer, agent j 's expected payoff is given by $\frac{\alpha - \beta + \gamma}{\beta - \gamma}c$. Hence, j is willing to pay agent i at most $(\frac{\alpha - \beta + \gamma}{\beta - \gamma} - \frac{\gamma}{\alpha - \gamma})c$ to dissuade i from sharing with the employer.

(2) No team sharing, i.e., $B - P \geq \frac{c}{(\beta - \gamma)(\alpha - \gamma)}$: When knowledge is not shared with the employer, agent j 's expected payoff is given by $\frac{\gamma c}{\beta - \gamma}$. Hence, j 's is willing to pay agent i at most $(\frac{\gamma}{\beta - \gamma} - \frac{\gamma}{\alpha - \gamma})c$ to dissuade i from sharing with the employer.

There are thus two cases for determining a ceiling on agent i 's expected payoff:

(1) Team sharing: the least upper bound on i 's expected payoff is given by

$$\frac{\alpha - \beta + \gamma}{\beta - \gamma}c + \left(\frac{\alpha - \beta + \gamma}{\beta - \gamma} - \frac{\gamma}{\alpha - \gamma}\right)c. \quad (\text{A7})$$

(2) No team sharing: i 's expected payoff has a least upper bound given by $\frac{\alpha - \beta + \gamma}{\beta - \gamma}c + \alpha(\alpha - \beta)(B - P) + (\frac{\gamma}{\beta - \gamma} - \frac{\gamma}{\alpha - \gamma})c$. When $B - P = \frac{c}{(\beta - \gamma)(\alpha - \gamma)}$ (the minimum amount for no team sharing to take place), this least upper bound is given by

$$\left(\frac{\alpha - \beta + \gamma}{\beta - \gamma} + \frac{(\alpha + \gamma)(\alpha - \beta)}{(\beta - \gamma)(\alpha - \gamma)}\right)c \quad (\text{A8})$$

Simple algebra shows that the least upper bound in (A8) is greater than that in (A7). Hence, the minimum reward that the employer would give i for disclosure is smaller when team sharing is feasible, i.e., when $B - P < \frac{c}{(\beta - \gamma)(\alpha - \gamma)}$. Then the reward D that the employer sets in an optimal INIKS mechanism is given by $\frac{2\alpha(\alpha - \beta)}{(\alpha - \gamma)(\beta - \gamma)}c$. ■

Proposition 5

Proof. In the optimal INIKS mechanism specified by Proposition 4, the employer's expected profit when there is new knowledge is given by

$$\alpha^2 R - 2\alpha\left(\frac{c}{\alpha - \gamma} - (1 - \alpha)B\right) - 2\alpha(1 - \alpha)B - \frac{2\alpha(\alpha - \beta)}{(\alpha - \gamma)(\beta - \gamma)}c$$

which can be simplified as

$$\alpha^2 R - \frac{2\alpha c}{\beta - \gamma}$$

This is the same profit as when knowledge is only shared within the team. The disclosing agent's expected payoff increases by the receiving agent's wage cut relative to the latter's expected payoff under team sharing. Thus, the disclosing agent appropriates all of the rents. ■

Proposition 7

Proof. When the higher paid agent discloses the knowledge, expected profit is given by

$$\alpha^2\left(R - \frac{c}{\gamma(\beta - \gamma)} - \frac{c}{\alpha(\alpha - \gamma)}\right)$$

if the lower paid agent discloses new knowledge, expected profit is given by

$$\alpha^2\left(R - \frac{c}{\gamma(\alpha - \gamma)} - \frac{c}{\beta(\beta - \gamma)}\right)$$

It is straightforward to check that the latter is larger. ■

Proposition 8

Proof. When there are no agent transfers and only the project outcome is observable, the employer is able to cut $\frac{1}{\gamma}(\frac{1}{\beta-\gamma} - \frac{1}{\alpha-\beta})c$ in operating expenses when the lower paid agent discloses knowledge; when the higher paid agent discloses, the employer cuts $(\frac{1}{\beta(\beta-\gamma)} - \frac{1}{\alpha(\alpha-\gamma)})c$. When task outcomes are observable, the employer is only able to cut $(\frac{1}{\beta-\gamma} - \frac{1}{\alpha-\gamma})c$, strictly lower than the former two. The employer's expected profit when task outcomes are observable is given by

$$\alpha^2 R - \alpha \left(\frac{2}{\alpha - \gamma} + \frac{\alpha - \beta}{(\alpha - \gamma)(\beta - \gamma)} \right) c$$

When only the overall outcome is observable, the least upper bound on expected profit is given by

$$\alpha^2 R - \alpha^2 \left(\frac{1}{\gamma(\alpha - \gamma)} + \frac{1}{\beta(\beta - \gamma)} \right) c$$

The difference between the two gives $-(\frac{\alpha-\beta}{\beta(\beta-\gamma)} + \frac{1}{\gamma})$. ■

Proposition 9

Proof. From Proposition 2, for $B > \frac{c}{\alpha(\beta-\gamma)}$, the employer sets $P = B - \frac{c}{\alpha(\beta-\gamma)}$ and $w_i = w_j = 0$ in an optimal INIKS mechanism that induces team sharing. Expected profit is thus given by

$$\alpha^2 \left(R - \left(B - \frac{c}{\alpha(\beta - \gamma)} \right) \right) - 2\alpha B \leq \alpha^2 R - \frac{2\alpha c}{\alpha(\beta - \gamma)}$$

In contrast, the employer's expected profit when she only observes the overall project outcome is strictly greater and is given by

$$\alpha^2 R - \frac{2\alpha c}{\beta - \gamma}$$

Hence, the employer obtains a higher expected profit under the latter information regime. ■

Proposition 10

The following technical Lemma applies Propositions 2 and 6 to determine the employer's chosen monitoring intensity given that compensation is assigned to implement optimal INIKS mechanisms. We let λ_1 , λ_2 , and λ_3 respectively denote the employer's chosen monitoring intensities when (1) there is no relative-performance pay; (2) there exists relative-performance pay but agent transfers are infeasible; and (3) there exists relative-performance pay and agent transfers are feasible.

Lemma 2. *If organizational disclosure is infeasible, then:*

1. Given $B = 0$, the employer sets $\lambda_1 = -\frac{2\alpha c}{R(\beta-\gamma)} + \frac{\alpha^2 c}{R(\beta-\gamma)} \left(\frac{1}{\beta} + \frac{1}{\gamma} \right)$.
2. Given $B > 0$, if agent transfers are infeasible, the employer sets $\lambda_2 = -\frac{2\alpha c}{R(\beta-\gamma)} + \frac{\alpha^2 c}{R(\beta-\gamma)} \left(\frac{1}{\beta} + \frac{1}{\gamma} \right)$ if $B \leq \frac{c}{\beta-\gamma}$ and $\lambda_2 = -\frac{2\alpha B}{R} + \frac{\alpha^2 c}{R(\beta-\gamma)} \left(\frac{1}{\gamma} + \frac{1}{\beta} \right)$ otherwise.
3. Given $B \in (0, \frac{c}{(\beta-\gamma)(2\alpha-\beta)})$, if agent transfers are feasible, the employer sets $\lambda_3 = \frac{2\alpha B(\alpha-\beta)}{R} + \frac{\alpha c}{R(\beta-\gamma)} \left(\frac{\alpha}{\gamma} + \frac{\alpha}{\beta} - 2 \right)$ if $\alpha \leq \frac{1}{2}$ and $\lambda_3 = \frac{2\alpha^2 B}{R} + \frac{\alpha^2 c}{R(\beta-\gamma)} \left(\frac{1}{\gamma} + \frac{1}{\beta} - \frac{4}{2\alpha-\beta} \right)$ otherwise. Given

$B \geq \frac{c}{(\beta-\gamma)(2\alpha-\beta)}$, the employer sets $\lambda_3 = -\frac{2\alpha B}{R} + \frac{\alpha^2 c}{R(\beta-\gamma)}(\frac{2}{2\alpha-\beta} + \frac{1}{\gamma} + \frac{1}{\beta})$ if $\alpha \leq \frac{1}{2}$; she sets $\lambda_3 = \frac{\alpha^2 c}{R(\beta-\gamma)}(\frac{1}{\gamma} + \frac{1}{\beta} - \frac{2}{2\alpha-\beta})$ if $\alpha > \frac{1}{2}$ and $B \in [\frac{c}{(\beta-\gamma)(2\alpha-\beta)}, \frac{2\alpha c}{(\beta-\gamma)(2\alpha-\beta)}]$; and she sets $\lambda_3 = -\frac{2\alpha B}{R} + \frac{\alpha^2 c}{R(\beta-\gamma)}(\frac{2}{2\alpha-\beta} + \frac{1}{\gamma} + \frac{1}{\beta})$ if $\alpha > \frac{1}{2}$ and $B > \frac{2\alpha c}{(\beta-\gamma)(2\alpha-\beta)}$.

Proof. (i) An optimal INIKS mechanism sets $B = P = 0$ and $w = \frac{c}{\beta-\gamma}$. The employer's expected profit is $\alpha^2 R - \frac{2\alpha c}{\beta-\gamma}$. Expected profit given λ_1 is given by

$$\pi = (\alpha^2 R - \frac{2\alpha c}{\beta-\gamma})\lambda_1 + \alpha^2(R - \frac{c}{\gamma(\beta-\gamma)} - \frac{c}{\beta(\beta-\gamma)})(1 - \lambda_1) - \frac{R}{2}\lambda_1^2$$

Hence, the employer maximizes profit by setting $\lambda_1 = -\frac{2\alpha c}{R(\beta-\gamma)} + \frac{\alpha^2 c}{R(\beta-\gamma)}(\frac{1}{\beta} + \frac{1}{\gamma})$.

(ii) The optimal INIKS mechanism sets $P = B$ and $w = \max\{\frac{c}{\beta-\gamma} - B, 0\}$. The employer's expected profit is $\alpha^2 R - 2\alpha(w + B)$. Expected profit given λ_2 is given by

$$\pi = (\alpha^2 R - 2\alpha(w + B))\lambda_2 + \alpha^2(R - \frac{c}{\gamma(\beta-\gamma)} - \frac{c}{\beta(\beta-\gamma)})(1 - \lambda_2) - \frac{R}{2}\lambda_2^2$$

There are two cases to consider:

- If $B \leq \frac{c}{\beta-\gamma}$, the employer maximizes expected profit by setting $\lambda_2 = -\frac{2\alpha c}{R(\beta-\gamma)} + \frac{\alpha^2 c}{R(\beta-\gamma)}(\frac{1}{\beta} + \frac{1}{\gamma})$. Obviously $\lambda_2 = \lambda_1$.
- If $B > \frac{c}{\beta-\gamma}$, the employer maximizes expected profit by setting $\lambda_2 = -2\frac{\alpha B}{R} + \frac{\alpha^2 c}{R(\beta-\gamma)}(\frac{1}{\gamma} + \frac{1}{\beta})$. It is straightforward that $\lambda_2 < \lambda_1$.

(iii) The optimal INIKS mechanism sets $P = \max\{B - \frac{c}{(\beta-\gamma)(2\alpha-\beta)}, 0\}$ and $w = \max\{\frac{c}{\beta-\gamma} - B - \beta(P - B), 0\}$. The employer's expected profit is $\alpha^2 R - 2\alpha(w + B) + 2\alpha^2(B - P)$. Given λ_3 , expected profit is given by

$$\pi = (\alpha^2 R - 2\alpha w - 2\alpha(1 - \alpha)B - 2\alpha^2 P)\lambda_3 + \alpha^2(R - \frac{c}{\gamma(\beta-\gamma)} - \frac{c}{\beta(\beta-\gamma)})(1 - \lambda_3) - \frac{R}{2}\lambda_3^2$$

There are several subcases to consider:

- If $\alpha \leq \frac{1}{2}$ and $B \geq \frac{c}{(\beta-\gamma)(2\alpha-\beta)}$, then $P = B - \frac{c}{(\beta-\gamma)(2\alpha-\beta)}$, and $w = 0$. The employer's expected profit is maximized at $\lambda_3 = -\frac{2\alpha B}{R} + \frac{\alpha^2 c}{R(\beta-\gamma)}(\frac{2}{2\alpha-\beta} + \frac{1}{\gamma} + \frac{1}{\beta})$. Since $2\alpha - \beta < 1$, we have $B > \frac{c}{\beta-\gamma}$; thus, $\lambda_3 > \lambda_2$. Simple algebra shows that if $\frac{c}{(\beta-\gamma)(2\alpha-\beta)} \leq B \leq \frac{c(3\alpha-\beta)}{(\beta-\gamma)(2\alpha-\beta)}$, $\lambda_3 \geq \lambda_1$, and if $B > \frac{c(3\alpha-\beta)}{(\beta-\gamma)(2\alpha-\beta)}$, $\lambda_3 < \lambda_1$.
- If $\alpha \leq \frac{1}{2}$ and $B < \frac{c}{(\beta-\gamma)(2\alpha-\beta)}$, then $P = 0$, and $w = \frac{c}{\beta-\gamma} - (1 - \beta)B$. The employer's expected profit is maximized at $\lambda_3 = \frac{2\alpha B(\alpha-\beta)}{R} + \frac{\alpha c}{R(\beta-\gamma)}(\frac{\alpha}{\gamma} + \frac{\alpha}{\beta} - 2)$. It follows that $\lambda_3 = \lambda_1 + \frac{2\alpha B(\alpha-\beta)}{R}$; thus, $\lambda_3 > \lambda_1 \geq \lambda_2$.
- If $\alpha > \frac{1}{2}$ and $\frac{2\alpha c}{(\beta-\gamma)(2\alpha-\beta)} \geq B \geq \frac{c}{(\beta-\gamma)(2\alpha-\beta)}$, then $P = B - \frac{c}{(\beta-\gamma)(2\alpha-\beta)}$ and $w = \frac{2\alpha c}{(\beta-\gamma)(2\alpha-\beta)} - B$. The employer's expected profit is maximized at $\lambda_3 = \frac{\alpha^2 c}{R(\beta-\gamma)}(\frac{1}{\gamma} + \frac{1}{\beta} - \frac{2}{2\alpha-\beta})$. It can then be readily shown that $\lambda_3 > \lambda_1$ and $\lambda_3 > \lambda_2$.
- If $\alpha > \frac{1}{2}$ and $B > \frac{2\alpha c}{(\beta-\gamma)(2\alpha-\beta)}$, then $P = B - \frac{2\alpha c}{(\beta-\gamma)(2\alpha-\beta)}$ and $w = 0$. The employer's expected profit is maximized at $\lambda_3 = -\frac{2\alpha B}{R} + \frac{\alpha^2 c}{R(\beta-\gamma)}(\frac{2}{2\alpha-\beta} + \frac{1}{\gamma} + \frac{1}{\beta})$. In the case where $\frac{2\alpha c}{(\beta-\gamma)(2\alpha-\beta)} <$

$B \leq \frac{c(3\alpha-\beta)}{(\beta-\gamma)(2\alpha-\beta)}$, simple algebra shows that $\lambda_3 \geq \lambda_1$, whereas when $B > \frac{c(3\alpha-\beta)}{(\beta-\gamma)(2\alpha-\beta)}$, we have $\lambda_3 < \lambda_1$. Since $B > \frac{c}{\beta-\gamma}$ holds due to $B > \frac{2\alpha c}{(\beta-\gamma)(2\alpha-\beta)}$, we also have, $\lambda_3 > \lambda_2$.

- If $\alpha > \frac{1}{2}$ and $B < \frac{c}{(\beta-\gamma)(2\alpha-\beta)}$, then $P = 0$, and $w = \frac{2\alpha c}{\beta-\gamma(2\alpha-\beta)} - B$. The employer's expected profit is maximized at $\lambda_3 = \frac{2\alpha^2 B}{R} + \frac{\alpha^2 c}{R(\beta-\gamma)}(\frac{1}{\gamma} + \frac{1}{\beta} - \frac{4}{2\alpha-\beta})$. In the case where $\frac{c\beta}{\alpha(\beta-\gamma)(2\alpha-\beta)} \leq B < \frac{c}{(\beta-\gamma)(2\alpha-\beta)}$, we have $\lambda_3 \geq \lambda_1$, whereas if $B < \frac{c\beta}{\alpha(\beta-\gamma)(2\alpha-\beta)}$, then $\lambda_3 < \lambda_1$. In the case where $B < \frac{2\alpha c}{(\alpha+1)(\beta-\gamma)(2\alpha-\beta)}$ and $\frac{c}{\beta-\gamma} \leq B \leq \frac{c\beta}{\alpha(\beta-\gamma)(2\alpha-\beta)}$ hold, we have $\lambda_3 < \lambda_2$. It follows that if $\frac{c}{\beta-\gamma} \leq B \leq \min\{\frac{c\beta}{\alpha(\beta-\gamma)(2\alpha-\beta)}, \frac{2\alpha c}{(\alpha+1)(\beta-\gamma)(2\alpha-\beta)}\}$, then $\lambda_3 < \lambda_2$; otherwise, $\lambda_3 > \lambda_2$.

■

Proposition 11

Proof. Suppose agent i is the higher-paid agent. The employer's expected profit given observable task outcomes is given by

$$\pi_{\text{obs}} = \alpha^2 R - 2\alpha\left(\frac{c}{\alpha-\gamma} - (1-\alpha)B\right) - 2\alpha(1-\alpha)B - \frac{\alpha(\alpha-\beta)}{(\alpha-\gamma)(\beta-\gamma)}c$$

The employer's expected profit if only the project outcome is observable and agent i has new knowledge is given by

$$\pi_{\text{unobs}}^i = \alpha^2 R - \frac{\alpha^2 c}{\gamma(\alpha-\gamma)} - \frac{\alpha^2 c}{\alpha(\alpha-\gamma)} - \alpha^2\left(\frac{1}{\gamma(\beta-\gamma)} - \frac{1}{\gamma(\alpha-\gamma)}\right)c$$

The employer's expected profit if only the project outcome is observable and agent j has new knowledge is given by

$$\pi_{\text{unobs}}^j = \alpha^2 R - \frac{\alpha^2 c}{\gamma(\alpha-\gamma)} - \frac{\alpha^2 c}{\alpha(\alpha-\gamma)} - \alpha^2\left(\frac{1}{\beta(\beta-\gamma)} - \frac{1}{\alpha(\alpha-\gamma)}\right)c$$

The employer's expected profit if agent i has new knowledge is given by $\pi_{\text{exp}} = \pi_{\text{obs}}\lambda + \pi_{\text{unobs}}^i(1-\lambda) - \frac{R}{2}\lambda^2$. The first-order condition gives $\lambda_i^* = \frac{\alpha c(\alpha-\gamma)}{R\gamma(\beta-\gamma)}$. The employer's expected profit if agent j has new knowledge is given by $\pi_{\text{exp}} = \pi_{\text{obs}}\lambda + \pi_{\text{unobs}}^j(1-\lambda) - \frac{R}{2}\lambda^2$. The first-order condition gives $\lambda_j^* = \frac{\alpha c(\beta^2 - 2\beta\gamma + \gamma\alpha)}{R\gamma\beta(\beta-\gamma)}$. Then:

$$\frac{\lambda_i^*}{\lambda_j^*} = \frac{\alpha c(\alpha-\gamma)}{R\gamma(\beta-\gamma)} \times \frac{R\gamma\beta(\beta-\gamma)}{\alpha c(\beta^2 - 2\beta\gamma + \gamma\alpha)}$$

$$\frac{\lambda_i^*}{\lambda_j^*} = \frac{(\alpha-\gamma)\beta}{\beta^2 - 2\beta\gamma + \gamma\alpha}$$

It follows that the RHS > 1 when

$$\frac{(\alpha-\gamma)\beta}{\beta^2 - 2\beta\gamma + \gamma\alpha} > 1 \tag{A9}$$

Since $\beta^2 - 2\beta\gamma + \gamma\alpha > (\beta-\gamma)^2 \geq 0$, Inequality (A9) holds if

$$(\alpha-\gamma)\beta > \beta^2 - 2\beta\gamma + \gamma\alpha$$

or when

$$\alpha(\beta-\gamma) > \beta(\beta-\gamma)$$

Since $\beta - \gamma > 0$ and $\alpha > \beta$, it follows that Inequality (A9) is always satisfied. Thus, $\lambda_i^* > \lambda_j^*$ ■

Proposition 12

Proof. Assume agent transfers are infeasible. The employer's expected profit when task outcomes are observable is given by

$$\pi_{\text{obs}} = \alpha^2 R - 2\alpha \left(\frac{c}{\alpha - \gamma} - (1 - \alpha)B \right) - 2\alpha(1 - \alpha)B - \frac{\alpha(\alpha - \beta)}{(\alpha - \gamma)(\beta - \gamma)}c$$

The employer's expected profit when task outcomes are unobservable is given by

$$\pi_{\text{unobs}} = \alpha^2 R - \frac{\alpha^2 c}{\gamma(\alpha - \gamma)} - \frac{\alpha^2 c}{\alpha(\alpha - \gamma)} - \alpha^2 \left(\frac{1}{\gamma(\beta - \gamma)} - \frac{1}{\gamma(\alpha - \gamma)} \right) c$$

Hence, given λ , the employer's expected profit is given by

$$\pi_{\text{exp}} = \lambda\pi_{\text{obs}} + (1 - \lambda)\pi_{\text{unobs}} - \frac{R}{2}\lambda^2$$

which is maximized at $\lambda_1^* = \frac{\alpha c(\alpha - \gamma)}{R\gamma(\beta - \gamma)}$.

Suppose now that agent transfers are feasible. The employer's expected profit if the outcomes of agents' individual tasks are observable is given by

$$\pi_{\text{obs}} = \alpha^2 R - 2\alpha(1 - \alpha)B - 2\alpha \left(\frac{c}{\alpha - \gamma} - (1 - \alpha)B \right) - \frac{2\alpha(\alpha - \beta)}{(\alpha - \gamma)(\beta - \gamma)}c$$

Expected profit when only the project's outcome is observable is given by

$$\pi_{\text{unobs}} = \alpha^2 R - \frac{\alpha^2 c}{\gamma(\alpha - \gamma)} - \frac{\alpha^2 c}{\alpha(\alpha - \gamma)} - \alpha^2 \left(\frac{1}{\beta(\beta - \gamma)} - \frac{1}{\alpha(\alpha - \gamma)} \right) c$$

Hence, given λ , the employer's expected profit is

$$\pi_{\text{exp}} = \lambda\pi_{\text{obs}} + (1 - \lambda)\pi_{\text{unobs}} - \frac{R}{2}\lambda^2$$

which is maximized at $\lambda_2^* = \frac{\alpha c(\alpha\beta + \gamma\alpha - 2\beta\gamma)}{R\gamma\beta(\beta - \gamma)}$. It follows that

$$\frac{\lambda_1^*}{\lambda_2^*} = \frac{\alpha\beta - \gamma\beta}{\alpha\beta + \gamma\alpha - 2\beta\gamma} \tag{A10}$$

Since the RHS of Inequality (A10) is strictly smaller than 1, we have $\lambda_1^* < \lambda_2^*$. ■

Proposition 13

Proof. If task outcomes are observable and agent transfers are infeasible, expected profit when the employer sets $D = 0$ and probes for new knowledge is given by

$$\pi_{\text{detect}} = \theta(\rho\pi_1 + (1 - \rho)\pi_2) + (1 - \theta)(\rho\pi_3 + (1 - \rho)\pi_2) - \frac{R}{2}\theta^2$$

Here, π_1 , π_2 , and π_3 are $\alpha^2 R - \frac{2\alpha c}{\alpha - \gamma}$, $\beta^2 R - \frac{2\beta c}{\beta - \gamma}$, and $\alpha^2 R - \frac{2\alpha c}{\beta - \gamma}$, respectively, and $\theta^* = \frac{2\alpha\rho c(\alpha - \beta)}{R(\beta - \gamma)(\alpha - \gamma)}$. The employer's expected profit if she sets $D > 0$ to induce organizational disclosure instead is given

by

$$\pi_{\text{induce}} = \rho\pi_Y + (1 - \rho)\pi_N$$

Here, π_Y (π_N) denotes the case where (no) new knowledge exists, such that $\pi_Y = \alpha^2 R - \frac{2\alpha c}{\alpha - \gamma} - \frac{\alpha(\alpha - \beta)}{(\alpha - \gamma)(\beta - \gamma)}c$ and $\pi_N = \beta^2 R - \frac{2\beta c}{\beta - \gamma}$. It follows that

$$\pi_{\text{detect}} - \pi_{\text{induce}} = \frac{2\alpha^2 \rho^2 c^2 (\alpha - \beta)^2 - \rho \alpha (\alpha - \beta) c R (\beta - \gamma) (\alpha - \gamma)}{R (\beta - \gamma)^2 (\alpha - \gamma)^2} \quad (\text{A11})$$

For the RHS of Inequality (A11) to be nonnegative, the prior probability ρ need satisfy

$$\rho \geq \frac{R(\beta - \gamma)(\alpha - \gamma)}{2\alpha c(\alpha - \beta)}$$

Suppose now that only the project outcome is observable and agent transfers are infeasible. Expected profit when the employer probes for new knowledge is given by

$$\pi_{\text{detect}} = \theta(\rho\pi_1 + (1 - \rho)\pi_2) + (1 - \theta)(\rho\pi_3 + (1 - \rho)\pi_2) - \frac{R}{2}\theta^2$$

where π_1 , π_2 , and π_3 are $\alpha^2(R - \frac{c(\gamma + \alpha)}{\gamma\alpha(\alpha - \gamma)})$, $\beta^2(R - \frac{c(\gamma + \beta)}{\gamma\beta(\beta - \gamma)})$, and $\alpha^2(R - \frac{c(\gamma + \beta)}{\gamma\beta(\beta - \gamma)})$, respectively, and $\theta^* = \frac{\rho\alpha^2 c}{R\gamma}(\frac{\gamma + \beta}{\beta(\beta - \gamma)} - \frac{\gamma + \alpha}{\alpha(\alpha - \gamma)})$. The employer's expected profit when she induces knowledge disclosure is given by

$$\pi_{\text{induce}} = \rho\pi_Y + (1 - \rho)\pi_N$$

where π_Y denotes the case where the higher-paid agent has new knowledge and π_N refers to the case where there is no new knowledge, such that $\pi_Y = \alpha^2 R - \frac{\alpha^2 c}{\gamma(\alpha - \gamma)} - \frac{\alpha^2 c}{\alpha(\alpha - \gamma)} - \alpha^2(\frac{1}{\gamma(\beta - \gamma)} - \frac{1}{\gamma(\alpha - \gamma)})c$ and $\pi_N = \beta^2 R - \frac{\beta^2 c}{\gamma(\beta - \gamma)} - \frac{\beta^2 c}{\beta(\beta - \gamma)}$. It follows that for $\pi_{\text{detect}} \geq \pi_{\text{induce}}$ to hold, the prior probability ρ need satisfy

$$\rho \geq \frac{2R\gamma^2\beta(\alpha - \gamma)(\beta - \gamma)(\alpha(\alpha - \gamma) - \beta(\beta - \gamma))}{\alpha c(\alpha(\alpha - \gamma)(\beta + \gamma) - \beta(\beta - \gamma)(\alpha + \gamma))^2}$$

■