Incentives That Induce Task-Related Effort, Helping, and Knowledge Sharing in Workgroups

Enno Siemsen
Department of Business Administration, University of Illinois at Urbana-Champaign, Champaign, Illinois 61820, siemsen@uiuc.edu

Sridhar Balasubramanian
Department of Marketing, Kenan-Flagler Business School, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina 27599, sridhar_balasubramanian@unc.edu

Aleda V. Roth
Department of Management, College of Business and Behavioral Science, Clemson University, Clemson, South Carolina 29634, aroth@clemson.edu

Cooperation and coordination among employees can yield significant productivity gains. In this study, we explore the design of optimal incentive systems that induce task-related effort, helping, and knowledge sharing within workgroups. We identify three distinct types of employee linkages that must be accommodated in the design of effective incentive systems: (1) outcome linkages, whereby the outcome of one employee's task is influenced by that of another; (2) help linkages, whereby each employee can directly expend effort on helping another; and (3) knowledge linkages, whereby each employee can share job-related knowledge with another. We analytically investigate the effect of each type of employee linkage, and some combinations of these linkages, on the optimal design of incentive systems. Our analytical results demonstrate how, by optimally weighting individual-level and workgroup-level incentives, managers can balance the need to induce cooperation and coordination among employees with the need to manage employees' incentive-related risk. Counter to conventional wisdom, we also demonstrate that both group and individual incentives are necessary to facilitate cooperative behaviors such as knowledge sharing in workgroups. Further, we empirically test some of the insights developed from the analytical models; our empirical findings support these analytical results.

Key words: incentive theory; compensation theory; task linkages; cooperation; knowledge sharing; moral hazard; job design; teams

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1. Introduction

From early hunter-gatherers to employees in modern organizations, humans have worked together to achieve desired outcomes. Employees today are expected to collaborate within numerous workgroups, including production cells on factory floors, marketing and sales units, R&D groups, and administrative task forces. But employees in such workgroups may not act in a coordinated manner, tuning their task-related efforts to work in lock-step with coworkers, or in a cooperative manner, whereby they help or share knowledge with coworkers. In this paper, we examine how managers can design optimal, task-sensitive incentives to promote such coordination and cooperation. Specifically, we derive optimal incentives that accommodate three distinct types of interemployee linkages, and some combinations thereof, that exist in many workgroup contexts: (1) outcome linkages—the outcome of one employee's task is influenced by that of another; (2) help linkages—one employee can assist in the performance of some of a coworker's tasks; and (3) knowledge linkages—one employee can share job-related knowledge with a coworker that can make the latter more productive at work.

Outcome linkages call for coordination among workgroup members so that their combined outputs are balanced and their work is synchronized. Help and knowledge linkages call for cooperation among employees, so that they assist with each other's tasks and share knowledge with each other.1 The need to coordinate employee actions, tasks, and decisions within workgroups and organizations is well established (Simon 1976, Chandler 1990, Williamson 1996). Although workgroup conflict may have some positive implications (e.g., see Jehn 1995, Jehn and Mannix

1 We use the term "workgroup" rather than "team" because the team, as conceptualized in the management literature (e.g., see Cohen and Bailey 1997), can embed certain interemployee dependencies, including social dependencies, which we do not study explicitly.
Second, a parallel stream of literature in the economics tradition has examined incentive design using the principal-agent (P-A) approach (see Laffont and Martimort 2002 for a review). This literature highlights a fundamental trade-off: Strong (variable) incentives lead the agent to exert a high task-related effort but also expose the agent to excessive risk. For example, a salesperson may work hard at his job, but he may not land any customer orders in a given quarter. Therefore, risk-averse agents must be compensated to undertake this risk. If agents share common external uncertainty, incentives based on the outcome levels of other agents as well as individual outcomes enable better risk sharing, compared with those based solely on the latter (Holmström 1982). Although such competitive incentives can lead to sabotage, they manage agent-related risks better than do noncompetitive incentives (Lazear 1989). In a repeated game, the potential for sabotage makes group-level incentives more effective, because the threat of sabotage if shirking behavior is observed among peers makes employees work harder (Che and Yoo 2001). These theoretical results are supported by the empirical finding that groups can tightly control their members’ actions (Barker 1993).

The economics literature has also examined cooperative behavior and incentives (Itoh 1991). If agents help other agents, their behaviors can reduce the task-related effort that both the helper and the receiver of help put into their own work. Itoh concludes that if helping other agents increases the amount of task-related effort that these agents will put into their own work, the principal (manager or firm) prefers such helping behavior. Although this P-A approach allows for the modeling of cooperative behavior in a general way, it offers only limited insights into optimal incentive design. According to Itoh (1991, p. 632), "A shortcoming of this approach is that we cannot obtain many clear predictions on real management policies." Further, and unlike our approach, existing work on optimal contracts generally limits cooperation to one agent helping another without changing the latter’s productivity (Itoh 1992, Holmström and Milgrom 1990, Auriol et al. 2002).

Moreover, models in economics do not systematically capture and compare the implications of distinct interemployee linkages for incentive design. For example, existing models generally assume that outcome levels are independent. Itoh (1991, p. 614) describes his model by indicating that "task n is independent of task k (k ≠ n) in the sense that the outcome of task n, which is a random variable, is stochastically independent of the outcome of task k." Such independence may not hold in many real-life situations, for example, in serial production lines, where output is passed from one worker to another, or in sales teams,
where the demonstration phase is followed by the sale closing phase. Our work addresses such outcome linkages.

The contributions of this paper can be summarized against this backdrop of literature. First, we examine how three types of interemployee linkages—those related to task outcomes, to helping, and to knowledge sharing—influence optimal incentive design in workgroups. Although the importance of employee linkages in the context of incentive design has been established (Wageman 1995, Itoh 1991), a systematic analysis of how incentives should be optimally designed to take advantage of each specific linkage type, and combinations thereof, is lacking. We address this gap. Second, our analytic results help explain some of the seemingly contradictory findings in the literature by exploring how optimal incentive systems differ based on the types of linkages present. Third, we empirically test some of the behavioral insights developed from the analytical models. Fourth, by combining constructs and methodologies (empirical versus analytical) from the organizational behavior and economics areas, our work bridges streams of research that have largely proceeded in independent directions (with the notable exception of Wageman and Baker 1997). Likewise, although researchers in operations management (OM) have recognized employee linkages as a key job design choice (Hayes et al. 1988, Hueté and Roth 1988), our research highlights the role of incentives as a closely associated job design parameter. Our findings suggest that planned interemployee linkages in workgroups may be ineffective if the proper incentives are not in place. In that context, our research also contributes to the OM-OB interface, which has been recognized as an area of growing importance to theory and practice (Boudreau et al. 2003).

We develop five analytic models. The first three models derive optimal incentives when, respectively, outcome, help, and knowledge linkages exist among employees. The fourth and fifth models consider optimal incentives when, respectively, both help and outcome linkages, and both knowledge and outcome linkages, exist. For each model we also characterize tasks according to the individual and shared uncertainty associated with outcomes. Taken together, these models allow us to examine how interemployee linkages affect the design of two incentives components—individual and group—over and beyond insights from the extant literature.

Some empirical literature suggests that the reward system has little effect on cooperation, helping behavior, and job satisfaction among employees (e.g., Wageman 1995). Yet other research indicates that a deeper investigation of interemployee linkages is required to explain employee behavior under different incentive plans (DeMatteo et al. 1998). Our results highlight the subtle tensions between the induction of cooperation among employees and the management of incentive-related risks they face. When employees are help linked, group performance should be rewarded. In contrast, when employees are outcome linked, individual performance should be rewarded, and it may be optimal to penalize group performance. Across all types of interemployee linkages, our results also show that workgroup and individual incentives exhibit different degrees of substitutability, in which case one incentive component can achieve the objective of the other, or complementarity, in which case one incentive component cannot achieve an objective without the other. Whereas outcome linkages create substitutability between the incentive components, knowledge linkages create complementarity between them. By carefully examining the fit between the incentive system and the type of linkage, we elucidate and reconcile some seemingly contradictory findings in the literature.

One provocative insight that emerges from our analysis is that knowledge-linked employees must optimally be provided with both individual and group incentives. This analytical insight is contrary to Deming’s directive (1993, p. 29) to “abolish incentive pay and pay based on performance” in group situations because they promote selfish behavior. Therefore, we also subject this particular result to empirical scrutiny.

In §2, we define the three types of interemployee linkages. The five models are presented and analyzed in §3. In §4, we empirically test the analytical finding that individual and group incentives play complementary roles in motivating knowledge sharing. We discuss the implications of our findings in §5.

2. Defining Interemployee Linkages

In Figure 1 we depict the three kinds of interemployee linkages related to outcome, help, and knowledge.

2.1. Outcome Linkages

We operationally define an outcome linkage as follows: The outcome of one employee is influenced to some

![Figure 1: A Conceptual Framework of Interemployee Linkages](image-url)
extent by the outcome of another employee. Outcome can be broadly defined as some variable of monetary value to the firm (e.g., output volume, output quality, or production time). Our notion of outcome linkages is generally consistent with the concept of task interdependence described by Wagaman (1995). Further, outcome linkage is sometimes termed “reciprocal dependence” if it exists mutually (Thompson 1967) or “sequential dependence” if it is unidirectional (Thompson 1967, Kiggundu 1981). Outcome linkages are commonly observed in DM contexts. For example, in assembly lines with limited work-in-process inventory, upstream workers can starve downstream workers, and downstream workers can block upstream workers. Likewise, in a marketing context, industrial customers often wait for evidence of adoption by peer firms before adopting a new product. If in this case two salespeople market the product to different customers, and one of them makes a sale, the subsequent word of mouth makes it easier for the other to close the deal.

2.2. Help Linkages
Our notion of help linkages applies when one employee can take an action that affects the outcome of a coworker without directly affecting his own outcome. Consistent with the concept of helping behaviors (Wagaman 1995, Perlow and Weeks 2002), help-linked employees can “pitch in” to assist each other. Here, an employee must decide to allocate effort both to his own task and to that of another. To illustrate the concept of a help linkage, consider the case of a food marketing company that divided up a large urban market into two contiguous but non-overlapping retail territories. The company allocated one salesperson to each of these areas to visit retailers. The salesperson focused mainly on their own territories, but one salesperson would help his colleague by visiting retailers in the colleague’s territory when convenient. Thus, if a retailer served by one salesperson was located close to the border of the other’s territory, the latter would often visit this retailer as well if he was working in a proximate area. In a factory context, similar help linkages are frequently observed in cellular-manufacturing shop floor situations. Coworkers may pitch in to help each other during slack periods.

2.3. Knowledge Linkages
Knowledge linkages exist when one employee can share useful, job-related knowledge with another employee. The following story reported in the Wall Street Journal illustrates such a case (Aeppele 2002). A manufacturer of industrial pumps used a small metal liner to position parts within the pump to create the vacuum that was essential to transport fluids. If the liner thickness was not right, the pump would have insufficient drawing power. More experienced employees noticed that the liners were too thick, although they met the plant’s specifications. These employees began grinding the liners to the right thickness. As the plant never changed its product specifications, only informal knowledge sharing ensured that the pumps met performance standards better, thereby reducing rework and increasing productivity.

These three types of task linkages appear to capture a substantial majority of interemployee linkages that are both theoretically interesting and practically relevant in many work environments. Further, our concepts of interemployee linkages extend or integrate some existing concepts of task and/or employee dependence. For example, our concept of outcome linkage captures Thompson’s (1967) sequential dependence (one part affects another, and not vice versa) and reciprocal dependence (the parts directly and mutually affect each other). In terms of other possible linkages that we do not explicitly study, one could conceptualize a “motivational linkage,” in which one employee cheers for a coworker from the sidelines. Here, the coworker potentially feels less tired, and, as with knowledge-sharing, the implicit cost of effort decreases. At a conceptual level, therefore, the implications of motivational linkages would be similar to those of knowledge linkages. “Network linkages” could also exist, whereby employees are indirectly linked because they are both directly linked to the same third person, possibly through distinct linkage types. For example, helping patterns among employees may be routed through the team manager (Perlow et al. 2004).

The following boundaries of our analyses are noted. First, our models are not applicable when individual task outcomes are unidentifiable (e.g., when workers jointly lift a heavy box onto a truck). Second, the role of group norms that may induce cooperation in workgroups is outside the scope of this research (e.g., Wagaman 1995). Likewise, we do not take into account the mutual monitoring of task-related efforts by group members (Barker 1993, Che and Yoo 2001). Such social controls may complement or substitute for the role of incentives. Third, we do not consider effects related to career concerns, which may again complement or substitute for the role of incentives (Gibbons and Murphy 1992). Finally, we exclude the possibility of “crowding out” effects in cooperative behaviors (Itoh 1991). Rather we assume that employees will choose to cooperate with each other in situations in which they have some slack in terms of

1 A third form of dependence proposed by Thompson (1967) is pooled dependence (the parts affect the whole, and vice versa, but direct dependencies between parts do not exist). This type of dependence is captured by our production function and not considered specifically as another form of task linkage.
time and energy, so that inputs into their own tasks are not adversely affected when they help or share knowledge with others.

3. Models

Our five models are variants of the two-agent, two-task model of Itoh (1992). We focus on two-person workgroups for reasons of analytical tractability. (We study $N$-person workgroups in the electronic supplement, which is provided in the e-companion.)

A principal (manager or firm) offers a contract ("incentive plan") to agents ("employees"), indexed by $i \in I = \{A, B\}$. Employees choose individual task-related effort levels $e_i$, which are unobservable to the principal. Monitoring is often difficult (for instance, when effort is exerted in the field). Even if some effort is observable, monitoring costs are sufficiently high that the principal does not track such effort. Task-related efforts $e_i$ are normalized; the least costly effort levels are zero. Zero task-related effort could be interpreted, for example, as working at a regular pace on an assembly line; positive task-related effort would then be the difficult-to-observe part of work in which the employee diligently checks for quality problems.

Perfectly observable outcome levels are denoted by $y_i$. The effort levels stochastically determine the employees' task outcomes. Whereas $y_i$ is most conveniently interpreted as production or sales volume, it may also represent product quality, production time, or service quality. In short, $y_i$ is any outcome of monetary value to the principal that can be stochastically influenced by the employee. We initially assume that the principal's profits are maximized when the sum of the employees' outcomes are maximized. This, for example, is the case with parallel production lines. We generalize our results later to other scenarios, including a scenario in which the profits depend on the minimum of the employees' outcomes, which reflects the case of serial production.

Employee incentives can be based on both outcomes $y_i$ and $y_j$, where $j \in I \setminus i$. The incentive component based on the outcome of an employee's own task is called the "individual incentive" ($a_i$), and that based on the outcome of the other employee's task is the workgroup incentive ($b_i$). Incentives can be positive (rewards) or negative (penalties). Negative group incentives are more naturally interpreted as "relative performance evaluations" (e.g., Holmström 1982). Such evaluations occur in incentive systems in which rewards are based on how impressive an employee's output appears when benchmarked against that of peers. In addition, employees may receive a fixed salary $\zeta_i$. Correspondingly, total wages are

$$w_i = a_i y_i + b_i y_j + \zeta_i.$$  

We restrict incentives to be linear in the task outcome levels: Unrestricted nonlinear contracts often preclude analytical solutions (Mirrlees 1974). A linear contract allows us to analyze a setting that is more complicated than that described by the standard moral-hazard model. An alternative to the assumption of a linear contract is the application of a first-order approach. But this approach also precludes analytical solutions and still requires restrictive assumptions on the uncertainty faced by the employees. Further, Holmström and Milgrom (1987) have shown that, under certain assumptions, if employees take a sequence of actions affecting a sequence of outcomes, the optimal aggregate pay is a linear function of the aggregate performance. In summary, although the restrictions we impose on the incentive plan place some limits on our results, our approach is descriptively reasonable, has precedence in the literature, and allows us to investigate a complex problem.

We further assume that task outcomes increase linearly with task-related effort. There is a stochastic noise term $e_i$ that is normally distributed with variance $\sigma^2_i$ and a mean of zero, which additively influences these outcomes. The error terms have a positive covariance $\sigma_{ij}$, capturing the shared environmental uncertainty faced by the employees. Incentives and the management of risk have traditionally gone hand in hand in the P-A literature. The fundamental idea is as follows: Consider two employees who put some effort into their tasks. The outcomes depend on their effort but also on external, uncontrollable events that cannot be observed by the principal. For example, employees may work hard at picking oranges, but bad conditions on the ground, which are not seen by the manager sitting in the office, may reduce the number of oranges picked. To the chagrin of employees, this uncertainty causes their wages to fluctuate significantly. An incentive plan that strongly depends on individual outcomes can induce hard work, but it also exposes employees to excessive risk.

Risk-averse employees require extra payments to compensate for such exposure. But if employees face common uncertainty, this added moral-hazard cost can be reduced if the total compensation is positive in the employee's own outcome and negative in the outcome of another employee in the workgroup (Holmström 1982). If there is a negative external shock, the outcomes of both employees decrease. The employee's realized compensation decreases because of his decreased outcome. However, the other employee's outcome also decreases, and that

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4 An electronic companion to this paper is available as part of the online version that can be found at http://mansci.journal.informs.org/.
outcome is negatively weighted in the employee’s own compensation. Thus, the employee’s compensation increases as his coworker’s outcome decreases. This effect buffers the employee’s realized compensation from a sharp decrease. The total received compensation is effectively more stable in the face of external, uncontrollable uncertainty, and the income-related risk faced by the employee is reduced. An added advantage of this configuration of incentives is reduced shirking behavior. That is, if the employee does not deliver a strong outcome and the coworker does, it is likely that a lack of employee effort is responsible for the employee’s poor performance. In this case, the employee’s compensation goes down sharply, and justifiably so.

In the following models we build in uncertainty in outcomes consistent with the moral-hazard literature. We then examine how interemployee linkages influence the design of incentive plans.

3.1. Outcome Linkages

Here, the task outcome of one employee can potentially influence that of the other, with \( t_i \) (0 ≤ \( t_i \) < 1) defined as the degree of outcome linkage. Correspondingly, the task outcomes can be described as follows:

\[
y_i = c_i + t_i y_j + e_i \quad \forall i \in I.
\]  

On substitution, the corresponding system of equations is

\[
y_i = \frac{c_i + e_i + t_i (e_j + e_i)}{1 - t_i t_j} \quad \forall i \in I.
\]

We assume that employees are risk averse and have a negative exponential utility function with an Arrow-Pratt measure of risk aversion \( r_i \), and that the cost of task-related effort is described by a quadratic cost function \( C_i(e_i) = c_i e_i^2 \); therefore, the second partial derivative of this function with respect to effort equals the constant \( c_i \). Under these conditions, the certainty equivalents of the employees’ incentive schemes are

\[
CE_i = \alpha_i E[y_i] + \beta_i E[y_j] + s_i - C_i(e_i) - (r_i/2)V[w_i]
\quad \forall i \in I.
\]

The variance of wages (\( V[w_i] \)) is as follows (all proofs are in Appendix A):

**Lemma 1.**

\[
V[w_i] = (\sigma_i^2 (\alpha_i + t_i \beta_i))^2 + \sigma_i^2 (t_i \alpha_i + \beta_i)^2
+ 2 \sigma_i \sigma_i \alpha_i (t_i \alpha_i + \beta_i)(t_i \alpha_i + \beta_i)(1 - t_i t_j)^{-2}.
\]

This variance does not necessarily increase in both incentive components. For example, if individual incentives are positive, negative workgroup incentives can potentially reduce the variance in wages (see Figure 2). The covariance between components \( \alpha_i y_i \) and \( \beta_i y_j \) can be negative if individual and group incentives are of opposite signs. Consider, for example, a large negative shock to employee \( i \)'s own outcome, caused by quality problems with the input materials associated with the employee’s task. If we reward individual outcome, \( \alpha_i y_i \), decreases because of the shock. If outcomes are mutually contingent, either through outcome linkages or through common uncertainty, this shock will also negatively affect the other employee’s outcome. With negative workgroup incentives, an employee’s total wages will decrease less, partially offsetting the reduction in \( \alpha_i y_i \). Thus, negative incentives can reduce the variance of total wages and lower the risk (see Holmström 1982).

We assume that the firm’s profit is determined by the sum of the task outcomes of the two employees, less the wages the firm needs to pay. The firm’s problem can be written thus:

\[
\max_{\alpha_i, \beta_i, s_i} \Pi = \sum_{i=1}^{m} (1 - \alpha_i - \beta_i)E[y_i] - s_i,
\]

subject to \( CE_i \geq 0 \) and \( e_i = \arg \max CE_i \quad \forall i \).

We apply a standard procedure to solve this problem (see Gibbons 2005). The degree of freedom provided by the fixed compensation is used to marginally satisfy individual rationality. Incentive compatibility can be guaranteed by solving the second-stage game of the employees, given the incentives (see the proofs in Appendix A). Under outcome linkages, the employees’ response functions yield the following proposition:

**Proposition 1.** Individual incentives increase task-related effort more than group incentives do; i.e.,

\[
\frac{\delta e_i}{\delta \alpha_i} = \frac{1}{(1 - t_i c_e)} \geq \frac{\delta e_i}{\delta \beta_i} = \frac{t_i}{(1 - t_i c_e)}.
\]

Thus, outcome linkages create imperfect substitutability between individual and group incentives. An increase in group incentives implies that employee \( i \) has an interest in increasing employee

![Figure 2 The Effect of Workgroup Incentives (β) on the Variance of Wages](image-url)
j's task outcome. When task outcomes are linked, employee i can achieve this by increasing his own task-related effort. Thus, workgroup rewards induce individual task-related effect. However, the effect of individual rewards on task-related effort is stronger than that of workgroup rewards when $t_i < 1$. This reflects a free-rider effect in that workgroup incentives induce individual task-related effort, but less effectively than do individual incentives.

**Proposition 2.** The optimal incentive plan is characterized by

$$
\hat{\alpha}_i = \frac{(1 + t_i)(\sigma_i^2 + t_i \sigma_{ij})}{(1 - t_i)(\sigma_i^2 + c_i r_i (\sigma_i^2 - \sigma_{ij} \sigma_{ji}))};
$$

$$
\hat{\beta}_i = \frac{(1 + t_i)(t_i \sigma_i^2 + \sigma_{ij})}{(1 - t_i)(\sigma_i^2 + c_i r_i (\sigma_i^2 - \sigma_{ij} \sigma_{ji}))}. \tag{8}
$$

The optimal incentive plan rewards (penalizes) one employee according to his own (another employee's) task outcome. Holmström (1982) noted that when there is shared uncertainty between two employees (e.g., the possibility that an economic downturn affects the sales of two salespersons), the optimal incentive scheme is based on both their outcomes. There is an interesting twist here. The costs of moral hazard can be reduced by using relative performance evaluations that jointly leverage the exogenous, shared uncertainty and the task outcome linkages, which are more endogenous to the work system. Thus, the optimal incentive plan described above generalizes the results of Holmström and Milgrom (1990) and Itoh (1992), which can essentially be reproduced by setting $t_i = t_j = 0$. In fact, Proposition 2 holds more generally:

**Theorem 1.** For any production function in which the expected total outcome is jointly concave in the individual task-related efforts of both employees, individual incentives are positive and workgroup incentives are negative, as long as there is either outcome linkage or shared uncertainty between employees.

Negative workgroup incentives reduce the overall variance in compensation and, correspondingly, the costs of managing moral hazard. In general, rewarding employees according to the total group outcome rather than the specific individual outcomes of their peers does not change this result under parallel production (see proof of Proposition 2 in Appendix A). Further, a special case of outcome linkage occurs in serial production lines, in which poor performance by a downstream worker can starve an upstream worker, and poor performance by the latter can block the former. Here, the total outcome will correspond to the minimum of the two outcomes. We can demonstrate that Theorem 1 applies here as well:

**Corollary 1.** Theorem 1 applies if the total outcome is the minimum of the outcomes of the two agents.

Theorem 1 should be interpreted with care. We do not advocate that employees must always be penalized if their peers do better. In other contexts, as demonstrated below, optimal workgroup incentives may be positive.

### 3.2. Help Linkages

Here, an employee $i$ can allocate effort both to his own task ($e_{ii}$ or task-related effort) and to that of the other employee $j$ ($e_{ij}$ or helping effort). We assume that an employee's helping effort linearly increases the outcome of the employee being helped with a productivity of $h_{ij}$, where $h_{ij}$ ($0 \leq h_{ij} \leq 1$) is interpreted as the degree of help linkage of employee $i$ to employee $j$. Similar to Equation (2), the production system is described as follows:

$$
y_i = e_{i} + h_{ij} e_{j} + e_i, \quad \forall i. \tag{9}
$$

We assume that there is no shared environmental uncertainty (i.e., $\sigma_{ij} = 0$), because such uncertainty would have a similar effect as outcome linkages. Following Itoh (1992) and Auríol et al. (2002), we assume that the cost function is convex, increasing, and additively separable into costs from each effort level:

$$
C_i(e_i, e_{ij}) = c_i (e_i^2 + e_{ij}^2)/2. \tag{10}
$$

Linearly separable costs reduce model complexity and are descriptively accurate in contexts in which employees assist coworkers during their less busy or idle times. In addition, the assumption of an effort allocation cost function [$i.e., C_i(e_i, e_{ij}) = c_i (e_i + e_{ij})^2/2$] implies that competing efforts can crowd each other out. Perlow and Weeks (2002) analyze a situation in a collaborative software engineering setting where crowding out exists. In such situations, helping may not be preferred by the employer (Itoh 1991). Because we focus on designing incentives that induce cooperation, we have set up our model so that helping is generally desired by management. A “crowding out” cost function would raise the complexity of our analysis without yielding substantial new insights. Therefore, we constrain our analysis to separable costs.

**Proposition 3.** Individual incentives increase only individual task-related effort, and group incentives increase only collective helping effort, i.e.,

$$
\frac{\partial e_{ii}}{\partial \alpha_i} = \frac{1}{c_i}, \quad \frac{\partial e_{ij}}{\partial \beta_i} = 0, \quad \frac{\partial e_{ij}}{\partial \alpha_i} = 0, \quad \frac{\partial e_{ij}}{\partial \beta_i} = \frac{h_{ij}}{c_i}. \tag{11}
$$

In contrast to Proposition 1, individual and workgroup incentives are not substitutable here. Each incentive component has a different purpose when only help linkages are present.
Proposition 4. The optimal incentive plan is given by

\[ \hat{\alpha}_i = \frac{1}{1 + c_i r_i \sigma_i^2}, \quad \hat{\beta}_i = \frac{h_i^2}{h_i^2 + c_i r_i \sigma_i^2}. \] (12)

This result can be contrasted with Proposition 2. With outcome linkages, it is optimal to penalize employees when peers perform relatively better; the opposite is true with help linkages.

3.3. Knowledge Linkages

Employees can work more efficiently when they learn the "tricks of the trade" from coworkers. Such knowledge can reduce the cost of employees' task-related effort. Under this interpretation, the production function is identical to that in Equation (2), with \( \theta_i = 0 \), but the employees' cost functions are modified:

\[ C_i(e_i, e_{ij}, e_{ji}) = (f_i(e_i)e_i^2 + c_i r_i e_i^3)/2. \] (13)

The knowledge-sharing effort \( (e_{ij})_i \) of employee \( j \) affects the cost of employee \( i \) through the learning function \( f_j(x) \) that is continuous and differentiable, with \( f_j(x) > 0, f_j'(x) < 0, f_j''(x) > 0 \), and \( \lim_{x \to \infty} f_j(x) = 0 \). Intuitively, Equation (13) implies that when an employee gains knowledge before proceeding to work, he potentially becomes more productive. But there are decreasing returns to learning, and the total cost of effort is nonnegative. To ensure concavity, we assume \( f_j(x)/f_j'(x) \leq 2f_j''(x)/f_j'(x) \). We also assume that an employee first decides whether or not to share job-related knowledge with a coworker and then allocates effort to his own work. The additive components of effort imply that the knowledge-sharing effort does not crowd out task-related effort. This reflects the notion that much knowledge sharing occurs during "off times," such as work breaks, production downtimes, or slack times, and at social events, when employees meet at the water cooler or in the cafeteria (Davenport and Prusak 1998; Roth et al. 1994).

Theorem 2. Given positive incentives, knowledge-sharing effort is increasing in both the group incentives of the employee who shares knowledge and in the individual incentives of the employee who receives it. Further, the effect of one incentive component increases in the other incentive component:

\[ \frac{\partial e_{ij}}{\partial \alpha_i} = \frac{\beta_i f_i(e_i)f_j(e_{ij})}{c_i f_j(e_{ij})^3 + \alpha_i \beta_i f_j(e_{ij})f_j''(e_{ij}) - 2f_j(e_{ij})} \geq 0 \]

\[ \frac{\partial e_{ij}}{\partial \beta_i} = \frac{\alpha_i f_j(e_i)f_j(e_{ij})}{c_i f_j(e_{ij})^3 + \alpha_i \beta_i f_j(e_{ij})f_j''(e_{ij}) - 2f_j(e_{ij})} \geq 0 \]

\[ \frac{\partial e_{ij}}{\partial \sigma_i} = \frac{f_j(e_i)^3 + \alpha_i \beta_i f_j(e_{ij})f_j''(e_{ij}) - 2f_j(e_{ij})}{(c_i f_j(e_{ij})^3 + \alpha_i \beta_i f_j(e_{ij})f_j''(e_{ij}) - 2f_j(e_{ij}))^2} > 0. \]

(14)

The key finding here is that job-related knowledge will be shared only when both individual and group incentives are in place. Now the incentive components are complementary, and their interaction drives knowledge-sharing behavior. Intuitively, employees will share knowledge only when they believe that the recipients will apply it to increase their own outcomes, which in turn will enhance the realized incentives of the sharers (through the group incentive component). Another finding is that training the recipients to use knowledge more effectively, that is, increasing \( f_j(e_{ij}) \) in Equation (14), will result in more knowledge-sharing effort. These results are contrary to the conventional wisdom, which holds that to induce cooperation in groups, individual incentives should be abandoned (Deming 1993). Therefore, we subject this analytical result to an empirical test in §4. The exact incentive design for the firm is analytically intractable. In §3.5, we provide numerical solutions for this problem using a model that also incorporates outcome linkages.

3.4. Outcome and Help Linkages

We now assume that help and outcome linkages coexist and that task outcomes are correlated; that is, \( h_i, h_{ij}, t_i, t_{ij} \), and \( t_i \) are positive and \( \sigma_j \neq 0 \). The cost function is as in Equation (10). The production function is

\[ y_i = \frac{e_i + h_i e_{ij} + e_i + t_i (e_i + h_i e_{ij} + e_i)}{(1 - t_i t_j)} \quad \forall i. \] (15)

Under these conditions:

Proposition 5. Individual task-related effort increases more strongly in individual incentives than in group incentives, but helping effort increases more strongly in group incentives than in individual incentives:

\[ \frac{\partial e_i}{\partial \alpha_i} = \frac{1}{(1 - t_i t_j)c_i} \geq \frac{\partial e_i}{\partial \beta_i} = \frac{t_j}{(1 - t_i t_j)c_i}; \]

\[ \frac{\partial e_i}{\partial \sigma_i} = \frac{t_j}{(1 - t_i t_j)c_i} \geq \frac{\partial e_i}{\partial \sigma_i} = \frac{t_j}{(1 - t_i t_j)c_i}. \]

(16)

Proposition 5 is similar to Proposition 1 in that individual and group incentives are imperfect substitutes in the creation of individual task-related effort because of outcome linkages. However, they are also imperfect substitutes in the creation of helping effort. The optimal incentive plan is as follows:

Proposition 6. The optimal incentive plan is

\[ \hat{\alpha}_i = \Delta_i (H_i + c_i r_i [(1 + t_i)(\sigma_i^2 + t_i \sigma_i)]) - h_i^2 (1 + t_i)(\sigma_i^2 + \sigma_i)); \]

\[ \hat{\beta}_i = \Delta_i (H_i - c_i r_i [(1 + t_i)(\sigma_i^2 + \sigma_i)]) - h_i^2 (1 + t_i)(\sigma_i^2 + t_i \sigma_i)); \]

(17)

where \( H_i = h_i^2 (1 - t_i t_j) \) and

\[ \Delta_i = ((1 - t_i t_j)(h_i^2 + c_i r_i (h_i^2 \sigma_i^2 + \sigma_i^2)) + c_i r_i (h_i^2 \sigma_i^2 - \sigma_i^2))^{-1} > 0. \]
The optimal incentive plan balances the need to induce cooperation and the need to protect employees from risk. The sign of a particular incentive component depends on the structure of the tasks (i.e., the magnitudes of outcome linkage \( t_i \) and helping productivity parameter \( h_j \)) and the uncertainty associated with it. If tasks strongly differ in terms of structure, management can exploit these differences to better deal with outcome uncertainty. For example, if the task outcome of one employee is largely deterministic (e.g., technology paced) and weakly correlated with the outcome of the other, the firm will direct as much compensation as possible into the former employee's individual outcome. Conversely, if tasks are similar, management cannot exploit such asymmetry, and incentives will be primarily driven by cooperation-related concerns:

**Corollary 2.** With strong asymmetry in the uncertainty of employees' outcomes (i.e., let \( \sigma_i^2 = \sigma_j^2 = 0 \) and \( \sigma_i > 0 \)), it is optimal to reward group outcome in employee i's compensation. Further, if \( \sigma_i \) is relatively low (high), individual incentives for employee i are positive (negative). Thus,

\[
\hat{\beta}_i \geq 0, \\
\hat{\alpha}_i \leq 0, \text{ if } \sigma_i^2 \geq \frac{1 - t_i t_j}{c_r r_i (1 + t_i) t_j} \text{ and} \\
\hat{\alpha}_i > 0, \text{ if } \sigma_i^2 < \frac{1 - t_i t_j}{c_r r_i (1 + t_i) t_j}. \tag{18}
\]

The corollary illustrates how firms can exploit the low uncertainty in one employee's task when task outcome uncertainty varies across employees. Because the workgroup outcome is more stable than employee i's outcome when \( \sigma_i \) is high, employee i may be primarily compensated through group rewards, which reduces the risk that he faces. Note that even if \( \sigma_i^2 = \sigma_j^2 = 0 \), there is some outcome uncertainty in the task of employee j because of outcome linkage \( t_j \). Equation (17) indicates that the stronger this linkage, the lower the threshold for \( \sigma_i^2 \), above which the individual incentive component for employee i is negative.

**Corollary 3.** If tasks are similar in terms of linkages and uncertainty, it is optimal to reward individual outcomes. If the uncertainty associated with the outcomes is low (high), optimal workgroup incentives are positive (negative). Specifically, if \( t_i = t_j \) and \( \sigma_i^2 = \sigma_j^2 \), then

\[
\hat{\alpha}_i \geq 0, \\
\hat{\beta}_i \leq 0, \text{ if } \sigma_i^2 \geq \frac{h_j^2 (1 - t_i)}{c_r r_i (t_i + h_j^2) t_i} - \frac{1 + h_j^2 t_i}{t_i + h_j^2} \sigma_j \text{ and} \\
\hat{\beta}_i > 0, \text{ if } \sigma_i^2 < \frac{h_j^2 (1 - t_i)}{c_r r_i (t_i + h_j^2) t_i} - \frac{1 + h_j^2 t_i}{t_i + h_j^2} \sigma_j. \tag{19}
\]

Here, the firm cannot exploit asymmetries in the uncertainties to derive information about task-related effort. Managers may want to reward workgroup outcomes (i.e., set a positive \( \hat{\beta}_i \)) to promote cooperation. At the same time, they are pulled in the opposite direction by the desire to use shared outcome uncertainty to induce task-related effort by placing the employees in competition with each other. This is achieved by setting a negative \( \hat{\beta}_i \), which results in a relative performance evaluation. Specifically, if outcome uncertainty \( (\sigma_i = \sigma_j) \) is sufficiently high (or if outcome covariance \( \sigma_{ij} \) is relatively high for a given level of \( \sigma_i = \sigma_j \)), managing risk becomes more important, and workgroup incentives are negative. When \( \sigma_i^2 \) is sufficiently low (or if \( \sigma_{ij} \) is relatively low for a given \( \sigma_i = \sigma_j \)), the effects of individual task-related effort are more transparent and managing risk becomes less important. Therefore, the firm can apply positive group incentives to induce cooperation.

To examine the implications of help and outcome linkages, consider how individual and group compensation components react to changes in the linkage parameters. For simplicity, assume that \( \sigma_i = \sigma_j \):

**Corollary 4.** When the outcome linkage of employee j to employee i is greater than the degree of help linkage of employee j to employee i (i.e., \( t_j > h_j \)), the individual incentive component for employee i increases as the outcome linkage \( (t_i) \) of employee i to employee j increases. In contrast, when \( t_i < h_j \) and outcome uncertainty \( \sigma_i^2 \) is relatively low, the individual incentive component for employee i decreases as the outcome linkage \( (t_i) \) of employee i to employee j increases:

\[
(i) \quad \frac{\partial \hat{\alpha}_i}{\partial t_i} > 0 \text{ if } t_i > h_j, \]

\[
(ii) \quad \frac{\partial \hat{\alpha}_i}{\partial t_i} < 0 \text{ if } t_i < h_j, \text{ and} \\
\sigma_i^2 < \sigma_j^2 \frac{h_j^2 - t_i^2}{t_i (1 - h_j^2)}. \tag{20}
\]

The individual incentive component for employee i always increases with \( t_i \):

\[
(iii) \quad \frac{\partial \hat{\alpha}_i}{\partial t_i} > 0. \tag{21}
\]

The group incentive component for employee i decreases as either of the outcome linkages increases:

\[
(iv) \quad \frac{\partial \hat{\beta}_i}{\partial t_i} < 0 \quad \text{and} \quad (v) \quad \frac{\partial \hat{\beta}_i}{\partial t_i} < 0. \tag{22}
\]

The individual incentive component for employee i decreases as the degree of help linkage of employee j with employee i (i.e., \( h_j \)) increases. The reverse holds for the group incentive component:

\[
(vi) \quad \frac{\partial \hat{\alpha}_i}{\partial h_j} < 0 \quad \text{and} \quad (vii) \quad \frac{\partial \hat{\beta}_i}{\partial h_j} > 0. \tag{23}
\]
The more the employees are outcome linked, the more they will be rewarded (penalized) according to their own (their coworker's) outcome. Two effects drive these results. First, if employee $j$ depends more on employee $i$, the latter's task-related effort affects the task outcomes of both employees. This enhanced productivity justifies higher individual incentives. The second effect is more intricate. An increase in $t_{ij}$ and $t_{ji}$ increases the absolute value of the covariance between $\alpha_{ij}$ and $\beta_{ij}$. As $\beta_{ij} < 0$, this covariance is negative. Thus, an increase in outcome linkage enables the firm to reduce the cost of the moral hazard by decreasing group incentives and increasing individual incentives (i.e., making $\beta_{ij}$ more negative and $\alpha_{ij}$ more positive).

Recall that to increase individual task-related effort, a firm can increase individual incentives, in which case it will simultaneously decrease group incentives to counter the increase in compensation variance. With outcome linkages, the firm will also want to increase employee activities that will increase other employees' outcomes. An employee can contribute toward this objective in two ways. First, the employee can directly help another by increasing $e_{ij}$; such helping effort translates into task outcomes with a productivity of $h_{ij}$. Second, the employee can work harder at his own task by increasing $e_{ii}$ and, given outcome linkages, this task-related effort will influence the other employee's task outcome with a productivity of $t_{ij}$. These two productivity metrics are compared in Equation (19). If increasing effort on the employee's own task is more productive than helping others, the firm will induce this action by increasing individual incentives. If not, the change in incentives will depend on the gap between the two productivities and the uncertainty and covariance associated with outcomes.

3.5. Outcome and Knowledge Linkages
We continue our analysis from §3.3 here. Assume that the learning function is $f_i(x) = (l_i x + 1)^{-1}$, where $l_i \geq 0$ is the degree of knowledge linkage. This function is convex decreasing in $x$, with $\lim_{x \to \infty} f_i(x) \to 0$. We also allow for outcome linkages between the employees. Under these conditions,

Proposition 7. Given an incentive plan, the optimal task-related and knowledge-sharing effort levels are

$$\hat{e}_{ij} = \frac{l_i (\beta_{ij} + t_{ij} \alpha_{ij}) (\alpha_{ij} + t_{ij} \beta_{ij})}{c (1 - t_{ij})^2};$$

$$\hat{e}_i = \frac{(1 + l_i \hat{e}_{ji}) (\alpha_{ij} + t_{ij} \beta_{ij})}{1 - t_{ij}} \quad \forall i \in I.$$  \hfill (24)

When $l_i = 0$, the shared knowledge is useless to employee $i$, whose task-related effort ($\hat{e}_i$) solely depends on individual and group incentives. The term $(1 + l_i \hat{e}_{ji})$, which captures the impact of knowledge sharing on employee $i$, scales up the effects of individual and group incentives on $\hat{e}_i$. Knowledge sharing serves as a "force multiplier" that enhances the effects of these incentives on the task-related effort.

In Theorem 2, we established the complementarity between group and individual incentives in enhancing knowledge sharing. These results can be reproduced in Proposition 7 by assuming $t_{ij} = t_{ji} = 0$. However, outcome linkages also create substitutability between incentive components, as described below:

Corollary 5. Individual task-related effort increases more strongly in individual than in group incentives, and knowledge-sharing effort increases more strongly in group than in individual incentives; i.e.,

$$\frac{\partial \hat{e}_i}{\partial \alpha_{ij}} > \frac{\partial \hat{e}_i}{\partial \beta_{ij}}, \quad \text{and}$$

$$\frac{\partial \hat{e}_{ij}}{\partial \alpha_{ij}} < \frac{\partial \hat{e}_{ij}}{\partial \beta_{ij}}.$$  \hfill (25)

The firm's optimal incentive plan is analytically intractable. We provide numerical solutions using a differential evolution algorithm to demonstrate how the parameters affect the optimal incentive scheme. We vary the degree of outcome and knowledge linkage, holding other parameters constant.

As seen in Figure 3 (plotted for $l_i = l_k = 0.5$, $r_A = r_B = 0.05$, $c_2 = 2$, $\sigma_A^2 = \sigma_B^2 = 2$, $\sigma_{AB} = 0.2$), optimal individual incentives for employee $i$ ($\hat{a}_i$) increase in the outcome linkage of the other employee ($t_i$) but can increase or decrease in his own outcome linkage ($t_{ij}$). This parallels the result from Corollary 3. Optimal workgroup incentives ($\hat{b}_{ij}$) decrease in the other employee's outcome linkage ($t_{ij}$) but can increase or decrease in the employee's own outcome linkage ($t_{ij}$). This counters the result from Corollary 4, which holds that group incentives strictly decrease in both outcome linkage parameters. Intuitively, outcome linkages increase the effect that individual and workgroup rewards have in motivating employees to share knowledge. Especially when $t_i$ is low, and thus risk-related concerns are minor, $t_{ij}$ is a major determinant of whether group incentives induce knowledge sharing.

In Figure 4 (plotted for $l_A = l_B = 0.2$, $r_A = r_B = 0.05$, $c_2 = 2$, $\sigma_A^2 = \sigma_B^2 = 2$, and $\sigma_{AB} = 0.2$), we see that optimal individual incentives ($\hat{a}_i$) increase in an employee's knowledge linkage to a coworker ($l_i$) and decrease in the coworker's knowledge linkage to the focal employee ($l_j$). The first effect originates from the fact that if employee $i$ can effectively use knowledge from employee $j$, the firm will give high individual incentives for employee $i$ to induce greater task-related effort. This in turn will encourage $j$ to share knowledge with $i$. The second effect is caused by risk-related concerns. If the knowledge linkage of employee $j$ on employee $i$ increases, the firm raises...
the group incentives for employee $i$. To reduce the moral-hazard cost of this incentive change, the firm simultaneously lowers the individual incentives of employee $i$.

Note that when help linkages exist between employees, the optimal incentives of one employee do not react to an increase of his own help linkage with the other employee (i.e., in Equation (17), $\hat{\alpha}_i$ and $\hat{\beta}_i$ are not functions of $h_j$). In contrast, with knowledge linkages, $\hat{\alpha}_i$ and $\hat{\beta}_i$ vary with both $I_i$ and $I_j$. Intuitively, with help linkages, the helping effort input by one employee into the task of another directly translates into task outcomes. In contrast, shared knowledge potentially increases the productivity of the knowledge recipient; however, incentives must be in place to ensure that the received knowledge is translated into task-related effort that yields higher outcomes. Thus, to encourage effective knowledge sharing, the firm must not just ensure that employees have an incentive to share knowledge, but also that the recipients of knowledge will apply it well.

4. Some Empirical Evidence in the Knowledge-Sharing Context

We now present empirical evidence that supports some of the insights in the context of knowledge sharing. We focus on knowledge sharing because of its great importance to managers today (Aeppli 2002). Our results here also are particularly interesting in that they contradict the conventional wisdom that individual incentives detract from group cooperation (Deming 1993). Although evidence from case research supports our result (Roth et al. 1994), formal empirical analyses on a broader sample can help validate our insights. Below, we describe our hypotheses, data, empirical model, and findings.

We define an employee’s rewards for sharing knowledge (RS) as his (perceived) benefit from knowledge sharing originating from the company. Further, we define individual rewards (IR) and group rewards (GR) as the perceived benefit for individual outcome and group outcome, respectively, originating from the company. Proposition 7 and Theorem 2 suggest that it is the combination of individual and group incentives that creates employee perceptions of being rewarded for knowledge-sharing efforts. Positive group rewards induce cooperation, but without proper individual rewards, employees will doubt that the knowledge recipient will put the knowledge to good use. Formally:

HYPOTHESIS 1. The effect of group rewards on an employee’s perception of being rewarded for sharing knowledge
Table 1  Sample Characteristics

<table>
<thead>
<tr>
<th>Company</th>
<th>Business unit process type</th>
<th>Product and organization type</th>
<th>Respondents</th>
<th>N*</th>
<th>Union (%</th>
<th>Tenure (avg. yrs.)</th>
<th>Age (avg. yrs.)</th>
<th>Male (%)</th>
<th>Education** (avg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Job shop—Assembly line</td>
<td>Aircraft components (private company)</td>
<td>Technicians</td>
<td>34 (11%)</td>
<td>0</td>
<td>6</td>
<td>37</td>
<td>88</td>
<td>3.26</td>
</tr>
<tr>
<td>2***</td>
<td>Project</td>
<td>Power station designs (public utility)</td>
<td>Engineers</td>
<td>106 (54%)</td>
<td>0</td>
<td>17</td>
<td>44</td>
<td>80</td>
<td>4.02</td>
</tr>
<tr>
<td>3</td>
<td>Assembly line—Continuous flow</td>
<td>Food manufacturing (private company)</td>
<td>Line workers and technicians</td>
<td>86 (18%)</td>
<td>84</td>
<td>16</td>
<td>46</td>
<td>65</td>
<td>2.81</td>
</tr>
<tr>
<td>4</td>
<td>Project—Job shop</td>
<td>IT services (public university)</td>
<td>IT professionals</td>
<td>54 (11%)</td>
<td>0</td>
<td>7</td>
<td>38</td>
<td>65</td>
<td>4.28</td>
</tr>
</tbody>
</table>

*N is the number of responses usable for analysis. The company response rates are given in parentheses.

**Education was measured as a rank-ordered variable: 1 = no high school, 2 = high school, 3 = some college, 4 = BA/BS, 5 = graduate degree.

***Pilot survey site.

with a coworker increases in the presence of individual rewards.

We also define motivation to share knowledge (MS) as an employee’s inner drive to share knowledge with a coworker (Boudreau et al. 2003) and usefulness of knowledge (UT) as an employee’s perception that his knowledge is of value to the coworker. Another insight from Proposition 7 and Theorem 2 is that incentives influence behavior only if this behavior enhances an outcome that yields higher realized incentives. Therefore, if an employee considers his knowledge to be useful, incentives will affect behavior more strongly:

HYPOTHESIS 2. The effect of an employee’s perception of being rewarded for sharing knowledge on his motivation to share increases when the knowledge to be shared is considered useful.

4.1. Samples and Measures

Data were collected from four companies to examine the knowledge-sharing behavior within workgroups (see Table 1). Our objective was to collect data from service and manufacturing firms, as well as within white-collar and blue-collar contexts. Because of the sensitive nature of the survey, a convenience sample of firms was employed. The four firms that agreed to participate conformed well to our design objective. Within each company, a whole department or plant was surveyed. In company 3, population demographics were available, and they revealed no large differences between the population and our sample in terms of age, gender, or job tenure.

The unit of analysis is a knowledge-sharing incident nested in a dyad of two employees. Respondents rated their motivation to share (MS) with respect to such a recently encountered situation. The survey was administered in pen-and-paper and web-based formats. Employees were provided with incentives to participate, and anonymity was assured. Response rates ranged from 11% to 54% (the 54% rate was obtained when we administered the survey during staff meetings). Table B1 (Appendix B) describes the constructs (MS, RS, UT, IR, and GR) and associated multi-item scales. Responses were collected using a 7-point Likert-like scale (from 1 = “strongly disagree” to 7 = “strongly agree”). A confirmatory factor analysis (CFA) conducted on the multi-item measurement scales for RS, UT, IR, and GR using data from all four samples indicated adequate measurement properties and overall model fit (Bollen 1989), with \( \chi^2_{df=48} = 94.94 \) \( (p < 0.01) \), \( \chi^2/df = 1.97 \), root mean square error of approximation (RMSEA) = 0.06 \( (p = 0.15) \), comparative fit index (CFI) = 0.99, and incremental fit index (IFI) = 0.99. The measures also passed tests of convergent and discriminant validity. (The psychometric properties of the one-item MS metric were assessed in a separate CFA.)

All measures used were newly developed, either because we could not find existing scales or because we were not confident that existing scales captured the constructs precisely. Independent rounds of Q sorting were used to align the initial item measures to the constructs (see Menor and Roth 2007, Roth et al. 2007). Successive refinement was achieved through six rounds of sorting exercises prior to the fielding of company surveys. Consistent with Proposition 7, we measure the group rewards component \( \beta_i \) as the perception of employee \( i \) that he is rewarded for workgroup outcomes (GR). Although \( \alpha_j \) should ideally reflect the perception of employee \( i \) that employee \( j \) is rewarded for the latter’s own outcome, that measure is difficult to obtain. A reasonable proxy for \( \alpha_j \), and one that we use for measurement purposes, is the perception of employee \( i \) that he is rewarded by the company for his own outcome (IR). In terms of controls, we coded three dummy variables to account for company (fixed) effects, one dummy (“Management”) that captures whether the respondent has other employees reporting to him or her, four dummies for education, one dummy for gender (male = 1), and other variables to capture job tenure (in years) and respondent age.
4.2. Methods
We estimated two equations, one predicting employee motivation to share (MS), and the other predicting an employee’s perceived rewards for knowledge sharing (RS). We estimated the MS equation using an ordered probit model because MS is a rank-ordered, single-item variable. RS is a multi-item measurement scale that represents the average of three 7-point, Likert-like scaled variables and therefore approximates interval data. We estimated the RS equation using ordinary least squares (OLS) regression with Huber-White standard errors to correct for heteroskedasticity. We included the interaction of RS and UT, and of IR and GR, in the respective equations as indicated by our hypotheses. We also included the corresponding square terms in our analysis for two reasons: (1) Some correlation among our independent variables was expected, and (2) Proposition 7 indicates the potential of squared effects. We used list-wise deletion to deal with missing data. All cardinal variables were standardized. Interaction/square terms were created by multiplying the standardized variables.

We did not use a structural equation modeling approach because the complexity of the equations resulted in nonconvergence using maximum likelihood estimation. But, given the high reliabilities for all variables (see Table B1), measurement error should have little impact. As both independent and dependent variables originate from the same source, we have the potential for common method variance in our data. On the other hand, the effect of common method variance on interaction effects is low (Evans 1985). In terms of robustness tests, we first allowed the slopes of RS/UT and IR/GR and their interaction and square terms to change between samples and tested whether this model yielded a better fit. We also conducted a bootstrap analysis using 1,000 replications and bias-corrected and accelerated standard errors to assess whether the normality assumptions implicit in our models affect our results.

4.3. Results
For each empirical model, we report the standardized coefficients and the Huber-White standard errors in Table 2. As the usefulness of knowledge (UT) increases, the effect of incentives (RS) on motivation to share (MS) increases. The effect of either group rewards (GR) or individual rewards (IR) on knowledge-sharing incentives increases in the other reward component. Both interaction effects are statistically significant ($p \leq 0.05$), whether or not control variables are included. These empirical results provide support for Hypotheses 1 and 2. In addition, the control variables showed some interesting results. Employees with undergraduate or graduate degrees perceive themselves to be less rewarded for sharing knowledge than those with no college degree. Future research can further explore how education influences perceptions and behavior in the context of knowledge sharing.

We also tested for a difference in intercepts between blue-collar and white-collar environments (or manufacturing and service contexts, which in our case is a similar comparison) by replacing the company dummies with a single dummy variable for "blue-collar environment." This variable was not statistically significant ($p = 0.26$ in the equation predicting RS, and $p = 0.31$ in the equation predicting MS), suggesting that the differences in perceived incentives are due more to firm-specific variables, such as corporate culture and infrastructure. Company 3 stands out from the rest—the estimates in Table 2 indicate that employees of company 3 perceive themselves to be less rewarded for sharing knowledge, yet at the same time they are more motivated to share knowledge with coworkers. This finding deserves an explanation. The plant is set in a remote location, and most employ-
ees live in the same small town. Their families have worked in the plant for generations. Recently, the plant was acquired by a large corporation. New management came in, and shop-floor workers regarded these new managers with some distrust. The large warehouse associated with the plant was just being outsourced at the time of the study. The invoked sense of solidarity and the ties of friendship and community among the workers, whose average job tenure was 16 years and who mostly lived in the same small town, arguedly provided them with a more intrinsic, socio-emotional motivation to share their knowledge with peers. Therefore, despite the fact that the workers did not perceive themselves to be rewarded for sharing job-related knowledge, they were more motivated to do so.

Additional analyses were performed to ensure robustness. First, the standard errors from the bootstrap analysis are slightly higher for all estimates, such that some of our hypotheses are upheld only at \( p \leq 0.10 \). A multigroup analysis on the MS equation revealed that freeing up the slopes of RS, UT, and their product/square terms across groups leads to a nonsignificant increase in model fit (\( \chi^2 = 6.13, p = 0.97 \)). Similarly, a multigroup analysis of the four companies revealed that freeing up the slopes of IR, GR, and their product/square terms across groups in the RS equation led to a nonsignificant increase in \( R^2 \) of 0.02 (\( F_{10} = 0.81, p = 0.66 \)). Finally, the antecedents of motivation to share knowledge have a relatively low overall explanatory power because only a limited set of economic antecedents is considered here. See Siemsen et al. (2007a, 2007b) for an analysis that also considers sociological and psychological antecedents that drive the motivation to share knowledge.

5. Conclusion
Our key findings are as follows. First, if employees are outcome linked, optimal individual incentives are positive and optimal group incentives are negative. We know from the literature on moral hazard in teams that negative group incentives reduce the risk faced by employees if the uncertainties to which they are subject are positively correlated. We add to this perspective: Even if these uncertainties are uncorrelated, group incentives still provide for a better risk structure in the incentive system if outcomes across employees are linked. In contrast, when help linkages exist among employees (absent external uncertainty), optimal group incentives are positive. Intuitively, one employee will help a coworker when that help ultimately increases the former’s realized incentives. We additionally find that when knowledge linkages exist between employees, individual and group incentives play important, complementary roles. Individual incentives ensure that the shared knowledge is put to good use to increase the productivity of the knowledge recipient; group incentives ensure that some of that increased productivity increases the realized incentives of the possessor of knowledge, so that he has the incentive to share knowledge in the first place. We provide empirical support for this particular finding.

Several key findings of this research are directly pertinent to managers. We detail the structure of the optimal incentive plan under three interemployee linkage types and some combinations thereof that are inherent in many job designs and work processes. Our results show that incentive plans that do not take specific employee linkages into account can be counterproductive. In addition, our findings suggest how incentive plans can be designed to optimally balance the need to reduce moral-hazard costs with the need to induce cooperation. In regard to knowledge sharing, much of the discussion has focused on getting individuals to share knowledge. We highlight the need to focus on both the disseminators and the users of knowledge. Overall, our findings elucidate how linkage-sensitive incentive plans can enhance performance. This demonstrates that the complex nature of employee tasks must be accommodated to derive useful insights in the context of incentive design.

Our analysis has some limitations. One is that the individual outcome measures we employ may be difficult to obtain. Our key insights will likely hold even when only imperfect measures of individual output are available; however, if such measures were entirely absent, the analysis and resulting incentive designs would be quite different. Further, we did not focus on work-context variables beyond interemployee linkages. Therefore, we did not consider social influences, career concerns, or reputation-related issues that could influence incentive design. Finally, we assumed that helping and knowledge sharing are activities preferred by the firm and are performed by employees in a way that does not detract from regular work.

Much remains to be done in this area. Our models could be applied and evaluated in specific settings, such as product development workgroups and shop floor production cells. The role of nonmonetary incentives, such as promotions and tournament rewards, might also be studied under different linkage types. Further, our findings could be revisited in settings in which career concerns and social influences may come into play. On the empirical front, our analysis has served as a preliminary confirmation of analytical findings regarding individual and group incentives for knowledge sharing that were counter to conventional wisdom. Additional work is needed in the empirical context to establish the robustness of these results. Finally, we have exogenously specified...
the job design in our analysis. A study that simultaneously considers incentive and job design could yield useful insights. Overall, this research has shown the importance of specifically recognizing different forms of linkages between employees in the design of incentives. We hope that further research extends our results and tests our insights for their robustness.

6. Electronic Companion
An electronic companion to this paper is available as part of the online version that can be found at http://mansci.journal.informs.org/.

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Appendix A
Proof of Lemma 1.

\[ V[w_i] = V[\alpha_i v_i + \beta_i y_i + \xi_i] \]
\[ = \alpha_i^2 V[y_i] + \beta_i^2 V[y_i] + 2\alpha_i \beta_i \text{COV}[y_i, y_j]. \]  \hspace{1cm} (A1)

\[ V[y_j] = V(1 - t_j t_i)^{-1}(\epsilon_j + t_j \epsilon_i). \]
\[ = (1 - t_j t_i)^{-2}(\sigma_j^2 + t_j^2 \sigma_i^2 + 2t_j \sigma_i). \]  \hspace{1cm} (A2)

\[ \text{COV}[y_i, y_j] = (1 - t_j t_i)^{-2} \text{COV}[\epsilon_i, t_j \epsilon_i, \epsilon_j, t_j \epsilon_i] \]
\[ = (1 - t_j t_i)^{-2}(t_j \sigma_i^2 + t_j^2 \sigma_j^2 + (1 + t_j t_i) \sigma_i \sigma_j). \]  \hspace{1cm} (A3)

Further simplification yields the expression in Lemma 1. \( \square \)

Proof of Proposition 1. At the second stage, the employees optimize

\[ \max_{\alpha_i} CE_i = \alpha_i (1 - t_j t_i)^{-2}(\epsilon_j + t_j \epsilon_i) + \beta_i (1 - t_j t_i)^{-2}(\epsilon_i + t_j \epsilon_i) \]
\[ + \xi_j - C_\epsilon(\epsilon_i) - 0.5 \tau V[w_i]. \]  \hspace{1cm} (A4)

Taking the partial derivatives with respect to effort, we obtain

\[ \frac{\partial CE_i}{\partial \epsilon_i} = (1 - t_j t_i)^{-1}(\alpha_i + t_j \beta_i) - C_\epsilon'(\epsilon_i) = 0, \]
\[ \frac{\partial^2 CE_i}{\partial \epsilon_i^2} = -C_\epsilon''(\epsilon_i) = -c_\epsilon < 0. \]  \hspace{1cm} (A5)

Using the implicit function theorem, we can then derive the following:

\[ \frac{\partial \epsilon_i}{\partial \alpha_i} = (1 - t_j t_i)^{-1}c_\epsilon^{-1}, \]
\[ \frac{\partial \epsilon_i}{\partial \beta_i} = (1 - t_j t_i)^{-1}c_\xi^{-1}. \]  \hspace{1cm} (A6)

Proof of Proposition 2. Proposition 1 describes the optimal response by the employee, given an incentive scheme. To fulfill the individual rationality constraint, we can adjust the fixed wage such that the outside option of the employees is exactly met. Consequently, setting variable incentives comes at no additional cost to the manager, as she can simply lower fixed wages accordingly. Also, the firm bears the costs of both task-related effort and risk. Accordingly, we can rewrite the manager's original problem as follows:

\[ \max_{\alpha_i, \beta_i, \beta_i} E[\Pi] = \sum_{i=1}^{n} E[y_i] - C_\epsilon(\epsilon_i) - 0.5 \tau V[w_i]. \]  \hspace{1cm} (A7)

The second-order partial derivatives of \( \Pi \) with respect to the decision variables are as follows:

\[ \frac{\partial^2 \Pi}{\partial \alpha_i^2} = \frac{1 + c_i r_i (\sigma_i^2 + t_j (t_j \sigma_j^2 + 2t_j \sigma_j))}{c_i(1 - t_j t_i)^2} < 0, \]
\[ \frac{\partial^2 \Pi}{\partial \beta_j^2} = \frac{t_j (t_j + c_i r_j (t_j \sigma_j^2 + 2t_j \sigma_j)) + c_i r_i \sigma_j^2}{c_i(1 - t_j t_i)^2} \leq 0, \]
\[ \frac{\partial^2 \Pi}{\partial \alpha_i \partial \beta_j} = \frac{t_j (1 + c_i r_i (t_j \sigma_j^2 + 2t_j \sigma_j)) + c_i r_i (t_j \sigma_j^2 + \sigma_j)}{c_i(1 - t_j t_i)^2} \leq 0. \]  \hspace{1cm} (A8)

All other second-order derivatives in the Hessian are zero, and the Hessian is negative definite when employees are risk averse. Thus, the manager's maximization problem is jointly concave in the decision variables. Therefore, we can set the first-order partial derivatives to zero and solve for the optimal decisions, applying the conditions for incentive compatibility derived earlier.

We can extend this result to other definitions of group incentives. Defining \( w_i = y_i + \delta_i (y_j + \xi_j) \), we have \( \alpha_i = \gamma_i + \delta_i, \beta_i = \delta_i \). Therefore, \( \gamma_i = \alpha_i - \beta_i \). This yields

\[ \hat{\gamma}_i = \frac{(1 + t_j t_i) (1 + t_j t_i \sigma_j^2 + (1 + t_j t_i) \sigma_j)}{(1 - t_j t_i) (t_j \sigma_j^2 + t_i \sigma_i^2 - \sigma_i \sigma_j)}, \]
\[ \hat{\delta}_i = \frac{(1 + t_j t_i) (1 + t_j t_i \sigma_j^2 + (1 + t_j t_i) \sigma_j)}{(1 - t_j t_i) (t_j \sigma_j^2 + t_i \sigma_i^2 - \sigma_i \sigma_j)}. \]  \hspace{1cm} (A9)

Thus, Proposition 1 holds under this alternative accounting scheme. \( \square \)

Proof of Theorem 1. Assume the generic production function \( E[Y] = f(\hat{\alpha}, \hat{\beta}) \). Using the individual rationality conditions, the manager’s objective function is \( E[\Pi] = f(\hat{\alpha}, \hat{\beta}) - \sum_{i=1}^{n} C_\epsilon(\epsilon_i) + (\tau r_i/2) V[w_i] \). Assuming quasi-concavity, the following first-order conditions must hold at the optimum:

\[ c_i r_i (t_j (t_j \sigma_j^2 + 2t_j \sigma_j) + (1 + t_j t_i) \sigma_j + \alpha((1 + t_j t_i) \sigma_j + t_j \sigma_j)) \]
\[ = (1 - t_j t_i) (\partial_{\epsilon_i} f(y_i, y_j) - C_\epsilon'(\epsilon_i)). \]
\[ (c_i r_i t_j (t_j \sigma_j^2 + 2t_j \sigma_j) + (1 + t_j t_i) \sigma_j + \alpha(t_j \sigma_j^2 + (1 + t_j t_i) \sigma_j + t_j \sigma_j)) \]
\[ = (1 - t_j t_i) (\partial_{\epsilon_i} f(y_i, y_j) - C_\epsilon'(\epsilon_i)). \]  \hspace{1cm} (A10)

Both conditions can be combined and simplified to yield

\[ \alpha_i = -\beta_i (t_j \sigma_j^2 + \sigma_j) / (\sigma_j + t_j \sigma_j). \]  \hspace{1cm} (A11)

If we plug this result into one of the above first-order conditions, we can derive

\[ \hat{\beta}_i = (t_j \sigma_j^2 + \sigma_j) (c_i r_i (t_j \sigma_j^2 - \sigma_j^2))^{-1} (C_\epsilon'(\epsilon_i) - \partial_{\epsilon_i} f(\hat{\epsilon}_i, \hat{\xi}_i)) < 0. \]  \hspace{1cm} (A12)

The generality condition is obtained by investigating the four leading principal minors of the Hessian of \( E[\Pi] \) with respect to the four incentive components. Joint concavity of the production function in both effort levels is a sufficient
condition for the joint concavity of $E[\Pi]$ in all four incentive components.

Proof of Corollary 1. That $f(y_j, y_i) = \min(y_j, y_i)$ is covered by Theorem 1. To establish that $E[\min(y_j, y_i)]$ is jointly concave in the efforts, note that $y_j$ and $y_i$ are bivariate normal random variables with

$$\begin{align*}
E[y_j] &= (e_i + t_i e_i)(1 - t_i t_j)^{-1}; \\
V[y_j] &= (\sigma_i^2 + t_i \sigma_i)^2(1 - t_i t_j)^{-2}; \\
Cov[y_j, y_i] &= t_i \sigma_i^2 + t_i \sigma_i^2 + (1 + t_i t_i) \sigma_i(1 - t_i t_j)^{-2}.
\end{align*}$$

(A13)

According to Cain (1994), we can write

$$E[\min(y_j, y_i)] = E[y_j] \Phi((E[y_j] - E[y_i]) / \theta) + E[y_i] \Phi((E[y_i] - E[y_j]) / \theta) - \theta \phi[(E[y_j] - E[y_i]) / \theta],$$

(A14)

where $\Phi(\cdot)$ is the cumulative standard normal distribution, $\phi(\cdot)$ is the standard normal density, and

$$\theta = \sqrt{V[y_j] + V[y_i] - 2Cov[y_j, y_i]}.$$

Taking the second partial derivatives, we can establish that the expected production is concave in both effort levels.

Proof of Proposition 3. This follows the same procedure as the proof of Proposition 1. We omit further details.

Proof of Proposition 4. This follows the same procedure as the proof of Proposition 2. We omit further details.

Proof of Theorem 2. The employee's task-related effort is $e_i = a_i / f(e_i)$. There is no closed-form solution for the knowledge-sharing effort level. The relevant first-order condition is $\alpha_\beta / c = -e_i f_i(e_i) / f_i(e_i)$. As we do not allow for negative knowledge-sharing efforts, the right-hand side of this condition is nonnegative. Further,

$$\frac{\partial^2 CE_i}{\partial e_i^2} = -c + \frac{\alpha_\beta [2f_i(e_i) - f_i(e_i) f_i''(e_i)]}{f_i(e_i) ^3} < 0$$

$$= 2f_i(e_i) - f_i(e_i) f_i''(e_i) < \frac{cf_i(e_i)^3}{\alpha_\beta} = 0 \quad (A15)$$

$$2f_i(e_i) < f_i(e_i) f_i''(e_i) \Rightarrow \frac{2f_i(e_i)}{f_i''(e_i)} > \frac{f_i(e_i)}{f_i''(e_i)}.$$

This expression is true by assumption; thus the certainty equivalent is concave. Thus, the first-order condition is sufficient to determine the optimal level of knowledge sharing. Employees' responses are derived using the implicit function theorem.

Proof of Proposition 5. We begin, as before, by analyzing the incentive compatibility of the incentive scheme. Employees face the following problem in the second stage:

$$\max_{e_i, e_j} CE_i = \alpha_i E[y_i] + \beta E[y_j] + s_i - C_i(e_i) - 0.5 \gamma_i V[w_i]. \quad (A16)$$

Because of the additive nature of helping effort, employees make their effort-allocation decisions independently. The second-order partial derivatives with respect to effort are only determined by the cost function. As the cost function is assumed to be jointly convex in both effort variables, the maximization problem is jointly concave in both effort levels. The first-order partial derivatives are

$$\frac{\partial CE_i}{\partial e_i} = (\alpha_i + t_i \beta_i) / (1 - t_i t_j) - c_i e_i = 0,$$

$$\frac{\partial CE_i}{\partial e_j} = h_i(\beta_i + t_i \alpha_i) / (1 - t_i t_j) - c_i e_j = 0. \quad (A17)$$

The first-order conditions directly solve for the optimal effort levels. Taking partial derivatives of the optimal effort levels with respect to the incentive components yields the results of Proposition 5.

Proof of Proposition 6. As in Proposition 2, we determine the fixed wages and reduce the complexity of the manager's problem. The manager's choice of incentives is independent across employees. Thus, drawing on symmetry, solving for the optimal incentive scheme for one employee is sufficient. Further, it is sufficient to show joint concavity in the decision variables for one incentive scheme. Accordingly, we obtain

$$\begin{align*}
\frac{\partial^2 \Pi}{\partial e_i^2} &= -(1 + \rho_i^2 + c_i r_i(\rho_i^2 + t_i \alpha_i + t_i \rho_i^2)) / c_i (1 - t_i t_j)^2 < 0 \\
\frac{\partial^2 \Pi}{\partial e_j^2} &= -(\rho_i^2 + t_i^2 + c_i r_i(t_i^2 \rho_i^2 + t_i \alpha_i + \rho_i^2)) / c_i (1 - t_i t_j)^2 < 0 \\
|D^2 \Pi| &= (h_i^2 (1 + c_i r_i \rho_i^2) + c_i r_i (\rho_i^2 + t_i \rho_i^2 - \alpha_i \rho_i^2)) / c_i (1 - t_i t_j)^2 > 0. \quad (A18)
\end{align*}$$

Thus, the problem is jointly concave and we can apply a first-order approach to derive the solutions.

Proof of Corollary 2. This follows from substituting $\sigma_i^2 = \sigma_j = 0$ into the results from Proposition 5.

Proof of Corollary 3. This follows from taking the first partial derivatives of the optimal incentive schemes derived in Proposition 3 with respect to the outcome and help linkage parameters.

Proof of Corollary 4. This follows from taking the first partial derivatives of the optimal effort levels derived in Proposition 6 with respect to the incentive levels.

Proof of Proposition 7. Taking the first-order derivatives of the certainty equivalent for a given collective action with respect to the individual action yields the following first-order condition:

$$\frac{\partial CE_i}{\partial e_i} = (\alpha_i + t_i \beta_i) / (1 - t_i t_j) - c_i f_i(e_i) = 0. \quad (A19)$$

This condition has only one solution for $e_i$. Using the assumed functional form for $f(x)$ and solving for the effort level yields Proposition 7. To derive optimal knowledge-sharing effort, we use the partial derivative:

$$\frac{\partial CE_i}{\partial e_j} = h_i(\beta_i + t_i \alpha_i) (\alpha_i + t_i \beta_i) (1 - t_i t_j)^2 - c_i = 0. \quad (A20)$$

This expression can be directly solved for the optimal knowledge-sharing effort.

Proof of Corollary 5. Corollary 4 follows from taking the first partial derivatives of the response functions derived in Proposition 7 with respect to individual and group incentives.
### Table B1  Constructs, Items, and Reliability Statistics

<table>
<thead>
<tr>
<th>Construct</th>
<th>Construct definition</th>
<th>Measurement scale items</th>
<th>Standardized factor loadings</th>
<th>Reliability coefficient α</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rewards for sharing knowledge (RS)</td>
<td>A perceived benefit from knowledge sharing that the sender believes originated from the company</td>
<td>My company rewards me for sharing knowledge with my coworkers. My company provides added compensation if I share what I know with my coworkers. My company provides incentives to share knowledge with my coworkers.</td>
<td>0.77  0.84  0.84</td>
<td>0.86  0.83  0.84</td>
</tr>
<tr>
<td>Individual rewards (IR)</td>
<td>A perceived benefit for individual performance that the sender believes originated from the company</td>
<td>My company rewards me according to my performance. My payment is dependent on how well I perform. If I perform well, my company will provide me with added compensation.</td>
<td>0.93  0.89  0.88</td>
<td>0.93  0.89  0.88</td>
</tr>
<tr>
<td>Group rewards (GR)</td>
<td>A perceived benefit for group performance that the sender believes originated from the company</td>
<td>My company rewards me according to the performance of my workgroup. My payment is dependent on how well my workgroup performs. If my workgroup performs well, my company will provide me with added compensation.</td>
<td>0.90  0.91  0.92</td>
<td>0.93  0.91  0.92</td>
</tr>
<tr>
<td>Motivation to share (MS)</td>
<td>The sender’s inner drive to share knowledge with the recipient</td>
<td>I meant to share this knowledge with my coworker.</td>
<td>0.80  0.641</td>
<td>0.80  0.641</td>
</tr>
<tr>
<td>Usefulness (UT)</td>
<td>The sender’s perception that the knowledge he or she possesses is of particular value to the recipient</td>
<td>My coworker would have benefited from having this knowledge. My coworker would have valued this knowledge. This knowledge would have been useful to my coworker.</td>
<td>0.76  0.75  0.56</td>
<td>0.76  0.75  0.56</td>
</tr>
</tbody>
</table>

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*Items were measured on 7-point scales; 1=“strongly agree,” 4=“neutral,” and 7=“strongly agree.”

*Estimates from CFA as reported in §4.1. All factor loadings are significant (p ≤ 0.01), indicating that the items are related to the same construct.

*Cronbach’s α measures the internal reliability or consistency of the scale items (range 0–1, where 1=perfect agreement in the way that individuals respond to the scale questions). A value of α > 0.70 is a good indicator of reliability for new scales.

*This estimate of item reliability is the percentage of construct variance captured by the item.

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### References


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