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Teams versus individual accountability: solving multitask problems through job design

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Many organizations are structured so that workers are jointly accountable for performance, even though there exist alternative organizational structures that align incentive compensation more closely with each worker's tasks. I develop a multitask agency model that demonstrates that such organizations may be optimal when multitask problems are severe or risk considerations are not too important. I also show that, in some circumstances, it may be optimal to share poorly measured tasks among several agents, contrary to the results of the existing multitask literature.

1. Introduction

■ It seems straightforward that compensating workers on performance measures that reflect their own individual contributions is superior to compensating them on measures that confound the contributions of many other workers. However, firms often and increasingly choose to organize work in a way that makes individuals jointly accountable for the efforts of a larger team (Rynes and Gerhart, 2000; Shaw and Schneier, 1995; Bartol and Hagmann, 1992). While the agency theory literature has studied optimal contracts in partnerships (Legros and Matsushima, 1991) and in settings of team production (Holmström, 1982), it has emphasized the difficulties presented by these organizations when they arise as an exogenous result of the technology of production and monitoring. In this article, I argue that team-based organizations may arise endogenously as optimal organizational forms, even when there exist performance measures that reflect each worker's contribution alone. The joint accountability of teams increases the risk that each worker bears, but it also enriches the performance measures available to the manager, which helps to mitigate multitask problems. When the increased risk burden is not too costly or the multitask problem is severe, teams are the optimal organizational form.

The managerially oriented human resources literature (Shaw and Schneier, 1995; Bartol and Hagmann, 1992) and the academic management literature (Wageman, 1995) consistently characterize teams by two features: an allocation of tasks that requires collaboration and joint accountability for outcomes through incentive pay that reflects group performance rather than only individual contributions. Dunlop and Weil (1996) provide evidence of the importance of team-based pay in a study of U.S. apparel manufacturing. Among firms they study, they find that 98% of the firms using traditional assembly lines employ individual piece-rate compensation schemes

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and 0% use group-based incentives; in contrast, 80% of team-based manufacturing organizations use group incentives while only 30% use individual piece rates as part of their incentive scheme. My analysis of teams focuses on the role of such group incentives. Throughout the article, I assume that the contributions of each task to the principal's profit are additively separable, so complementarities and "cooperation" in the usual sense play no role. This focuses attention on the role of team-based compensation, and the allocation of tasks here serves only to alter the richness of the signals available for each agent.

In contrast, Hemmer (1995) and Besanko, Regibeau, and Rockett (2005) focus on the impact on optimal job design of spillovers between tasks. They show that these interrelationships can create an incentive to organize work in a way that induces cooperation by internalizing these spillovers. For Hemmer, this means organizing a manufacturing operation as production teams rather than an assembly line; for Besanko, Regibeau, and Rockett, it means organizing a multiproduct firm around product lines rather than functional areas. In both cases, as in my model, the more team-like structure provides richer and more complete performance measures by basing compensation on team output rather than individual output.

To foreshadow the model, consider the problem of organizing a sales force to sell industrial equipment to two customers. Suppose there are two tasks that determine the sales of the firm to any given customer: selling (providing information on product characteristics, etc.) and customer care (order processing, follow-up calls, etc.). Further, suppose that the only performance measures available are the sales to each customer; that is, revenues generated by each customer are well measured, but it is impossible to observe the extent to which these are influenced by the effort allocated to selling effort or to customer care. It is also not possible to accurately measure the precise costs of serving each customer, so the measure of sales may not accurately reflect the firm's benefit from the workers' efforts.

There are two natural alternative organizations. In the "individual accountability" configuration, each salesperson has full responsibility for the provision of selling effort and customer care to his or her designated customer. In this case, the firm can craft a compensation scheme in which each worker's pay reflects only his or her own effort because an individual customer's sales are observable. In the alternative "team" configuration, both workers are responsible for both customers. For simplicity, suppose that one worker is responsible for selling to both customers while the other worker is responsible for customer care for both customers. Because the workers share joint responsibility for each customer, the team-based incentive compensation scheme rewards each worker on the sales to both customers—that is, on a larger number of performance measures, each of which is determined by both workers' efforts.[1]

The advantage of the individual accountability model is that it compensates each worker on a smaller number of performance measures. If performance measures are noisy and workers are risk averse, this is desirable. Moreover, each worker fully determines his or her own pay (give or take some noise) because each performance measure depends on only one agent's efforts. This is desirable if workers are risk averse and unsure of other workers' ability or motivation.[2] The disadvantage of the individual accountability model is that the firm must induce each worker to perform two tasks with an incentive scheme that uses only one performance measure. There is no way to manipulate the relative effort given to selling and to customer care using only sales as a performance measure, which creates a multitask problem if sales are not perfectly aligned with the firm's profit. The team model alleviates this multitask problem by providing the manager a richer set of performance measures to work with in crafting an incentive scheme. The choice between teams and individual accountability therefore embodies a fundamental tradeoff between

[1] This characterization of the alternatives is consistent with both actual employment practices and prior academic work. For an example, see Dunlop and Weil's (1996) description of the "bundle system" (the individual accountability model) and the "modular system" (the team model) in apparel manufacturing.

[2] Uncertainty over the other agent's ability or motivation is not present in the formal model of this article. Although it may in fact be an important source of risk in teams, it is analytically analogous to the exogenous noise modeled here, and it is therefore omitted for expositional simplicity.

using more signals to fine tune incentives on multiple tasks and using fewer signals in order to mitigate risk exposure.

This article presents a model in which it is possible to analyze this tradeoff while taking into account the nature of the optimal linear compensation scheme under each regime. The optimal contract compensates for the weaknesses of each configuration of tasks, mitigating the multitask problem and the costs of exposure to risk. The analysis of this model demonstrates that the tradeoff persists under the optimal linear contract: teams are more attractive relative to individual accountability the more severe the multitask problem and the less important the costs of increased risk.

I also demonstrate that, when one set of tasks is accurately measured and the other is not, it is preferable to split the accurately measured tasks between the agents. This stands in stark contrast with the predictions of the existing multitask literature. Holmström and Milgrom (1991) argue that tasks should be grouped together to create relatively homogeneous groups in terms of the precision with which the tasks are measured. In their model, this ensures that some effort is devoted to the poorly measured tasks by giving them to an intrinsically motivated agent who is compensated with a flat salary. Because in my model there is no intrinsic motivation (no effort is expended in the absence of incentive compensation), it is less attractive to simply give up on incentive contracting with one agent, and splitting the easily measured tasks between the workers may be preferable.

Section 2 lays out a simple model of the choice between teams and individual accountability and establishes the basic results. Section 3 extends the analysis to an arbitrary number of tasks and agents. This sheds light on the generality of a common assumption in multitask models—specifically, the assumption that there is a single performance measure for each task and that each performance measure reflects a single task. Section 4 concludes.

2. A simple model

■ This section lays out a simple model in which a principal delegates four tasks to two agents, each of which is compensated on at most two noisy performance measures. This model demonstrates the main point of the article, which is that the choice between teams and individual accountability embodies a tradeoff between solving multitask problems and minimizing the risk burden.

□ **Tasks and performance measures.** A principal has a project consisting of four tasks, i, each of which involves the choice of an effort level, e_i. The noncontractible value of the project, which accrues directly to the principal, is $V(e) = \sum_i e_i$. There are two identical agents; each agent is limited to performing two of the tasks. Following Dewatripont, Jewitt, and Tirole (2000), I assume that the costs of effort on the tasks are separable in order to facilitate comparison of alternative allocations of tasks.[3] I relax this separability assumption in Section 3. Costs are also assumed to be identical across tasks. The cost of any task, i, which is borne directly by the agent responsible, is $e_i^2/2$, which implies that the marginal cost of effort level e_i is equal to e_i.

There are two contractible performance measures (or signals), x_j, available to the principal for incentive contracting.[4] Each performance measure reflects exactly two of the tasks, and they contain independently distributed noise terms, ε_j, which have mean zero and variance $\sigma_j^2 > 0$. The signals are given by

$$x_1 = e_1 + \gamma e_2 + \varepsilon_1$$
$$x_2 = e_3 + \gamma e_4 + \varepsilon_2.$$

[3] Most multitask models in the literature involve effort substitution, meaning that expending more effort on one task raises the marginal cost of effort on the other. However, as Dewatripont, Jewitt, (2000) point out, this is not an appropriate assumption for analyzing alternative allocations of tasks.

[4] This approach of modeling signals as separate functions of efforts, rather than as noisy observations of the principal's value function or of individual efforts, is consistent with the model of Baker (1992) and with what Dewatripont, Jewitt, and Tirole call a model of "conflicts between tasks."

It will become clear that the parameter $\gamma \geq 1$ measures the severity of the multitask problem. When $\gamma = 1$, there is no multitask problem (even under individual accountability) because e_1 and e_2 have the same marginal effect on the project value ($\partial V(e)/\partial e_1 = \partial V(e)/\partial e_2 = 1$) and the same effect on the one performance measure they affect ($\partial x_1/\partial e_1 = \partial x_1/\partial e_2 = 1$). However, when $\gamma > 1$, a multitask problem may arise because the second of these equalities does not hold.[5] Loosely, the symmetry of e_1 and e_2 in the project value and cost functions indicates they should be compensated similarly; however, this is not possible because they affect x_1 differently. Any compensation scheme that gives first-best incentives for e_2 will give excessively strong incentives for e_1, which is, in a sense, "overrepresented" in performance measure x_1.

□ **Contracts and job design.** In keeping with the literature, I appeal to Holmström and Milgrom (1987) in restricting attention to linear compensation schemes.[6] The incentive contract for agent $k = A, B$ is denoted as $\beta^k + \sum_j \alpha_j^k x_j$. The first term is a lump-sum transfer, while the α_j^k's are the marginal rewards to agent k associated with higher values of performance measure j. The principal is risk neutral. The agents are risk averse with constant coefficient of risk aversion, r. This implies that the risk burden reduces the project value by $(r/2)\sum_k \sum_j \alpha_j^{k2}\sigma_j^2$.

There are two meaningfully different configurations of tasks available to the principal, given the constraint that no agent can perform more than two tasks. "Individual accountability" will refer to the case in which one agent (agent A, without loss of generality) performs tasks e_1 and e_2 while the other agent (agent B) performs tasks e_3 and e_4. Such agents are individually accountable in the sense that each is responsible for the set of tasks that fully determine (aside from the noise) one of the performance measures. Such an agent's compensation is in no way affected by the work of the other agent. "Teams" will refer to the case in which one agent (agent A, without loss of generality) performs tasks e_1 and e_4 while the other agent (agent B) performs tasks e_2 and e_3. In this case, each agent performs one task that affects each performance measure. Thus, their effort choices are reflected in a richer set of signals. However, their compensation will now depend on two signals and therefore two noise terms.[7] Such agents are team members in the sense that their compensation is jointly determined, with both agents' efforts affecting both agents' compensation.[8]

The general approach to solving this problem is simple. I first solve the agents' maximization problems for arbitrary contracts. I then choose contract terms to maximize joint surplus. Because lump-sum transfers can be made through β^k, the negotiation between the principal and the agents yields the contract that maximizes the joint surplus regardless of their respective bargaining power. I do this for both team and individual accountability configurations and then finally compare the joint surplus to determine whether optimal job design yields teams or individual accountability.

□ **Teams.** Recall that, in teams, agent A performs tasks 1 and 4, while agent B performs tasks 2 and 3. Given an incentive contract, agent A solves the following problem:

$$\max_{e_1, e_4} \alpha_1^A x_1 + \alpha_2^A x_2 - \frac{1}{2}\sum_{i=1,4} e_i^2.$$

Agent B maximizes exactly the same maximand over the other two tasks. The linearity of the signals in effort and the convexity of the cost of effort together imply that the first-order conditions suffice to characterize the solutions. This yields

$$e_1^* = \alpha_1^A; e_2^* = \gamma\alpha_1^B; e_3^* = \alpha_2^B; e_4^* = \gamma\alpha_2^A.$$

[5] A similar problem arises when $\gamma < 1$. I restrict $\gamma \geq 1$ because the analysis for $\gamma < 1$ is difficult to interpret due to conflicting effects. As γ gets smaller, the multitask problem gets more severe; however, the associated tasks also become irrelevant because the optimal contract induces no effort on those tasks as $\gamma \to 0$.

[6] They show that linear compensation schemes are optimal in a dynamic version of a standard agency problem that has nonlinear optimal contracts in the static version.

[7] Note also that their compensation depends on outcomes affected by the other agent's effort. While this is not stochastic in this model, in reality it likely further increases the risk burden associated with team-based compensation.

[8] A third configuration would pair tasks e_1 and e_3 for one agent and tasks e_2 and e_4 for the other. Under the optimal contracts, this turns out to yield exactly the same effort levels and joint surplus as the definition of teams given above.

The optimal contract maximizes joint surplus, which is the project value less the cost of effort and the cost of the risk burden:

$$\max_{\alpha} \sum_i e_i^* - \frac{1}{2} \sum_i e_i^{*2} - \frac{r}{2} \sum_k \sum_j \alpha_j^{k2} \sigma_j^2,$$

where the functional dependence of the e_i^* on γ and α_j^k is suppressed. The linearity of the project value in e and the convexity of the cost of effort, together with the convexity of the risk burden in α and the linearity of the implemented efforts in α, imply that the first-order conditions suffice to characterize the solutions. This yields

$$\alpha_1^{A*} = \frac{1}{1 + r\sigma_1^2}; \alpha_2^{A*} = \frac{\gamma}{\gamma^2 + r\sigma_2^2};$$
$$\alpha_1^{B*} = \frac{\gamma}{\gamma^2 + r\sigma_1^2}; \alpha_2^{B*} = \frac{1}{1 + r\sigma_2^2}.$$

Substituting these expressions into the maximand in the previous equation (taking account of the dependence of e_i^* on α_j^k) yields the joint surplus under the optimal team contract, for comparison with the individual accountability solution derived below.

□ **Individual accountability.** Recall that, under individual accountability, agent A performs tasks 1 and 2, while agent B performs tasks 3 and 4. Given an incentive contract, the agents maximize the same expression as under teams but over the tasks assigned them in this new regime. Solving the first-order conditions yields

$$\widetilde{e}_1 = \alpha_1^A, \quad \widetilde{e}_2 = \gamma\alpha_1^A, \quad \widetilde{e}_3 = \alpha_2^B, \quad \widetilde{e}_4 = \gamma\alpha_2^B.$$

The optimal contract maximizes joint surplus, which is given by exactly the same expression as for teams. Solving the first-order conditions yields the optimal contract,

$$\widetilde{\alpha}_1^A = \frac{1 + \gamma}{1 + \gamma^2 + r\sigma_1^2}, \quad \widetilde{\alpha}_2^B = \frac{1 + \gamma}{1 + \gamma^2 + r\sigma_2^2}, \quad \widetilde{\alpha}_2^A = \widetilde{\alpha}_1^B = 0.$$

Substituting these expressions into the joint surplus expression (taking account of the dependence of $\widetilde{e}_i$ on α_j^k) yields the joint surplus under individual accountability.

□ **Optimal job design: risk aversion and multitask problems.** While the model is tractable in the sense that it allows analytical solutions for the optimal contracts, the expressions that arise when these are substituted back into the joint surplus expression are extremely complicated, due in part to the fact that risk premium is quadratic in the α's. For this reason, I present comparative statistics for subsets of the four parameters $(r, \gamma, \sigma_1^2, \sigma_2^2)$, holding other variables constant; in particular, throughout this subsection, the precision of the signals (σ_1^2, σ_2^2) is held constant. Note that this is, in fact, a restriction only that the relative precision of the signals is held constant, as a scaling up of these variances by a common factor is equivalent to change in r.[9]

The results of this section derive from a single analysis of this contracting problem. It is straightforward, though somewhat involved, to substitute the optimal contract terms into the implemented effort expressions and both of these into the joint surplus expression, to obtain the maximal joint surplus for each of the two regimes. One can then take the difference to assess conditions under which teams are optimal. The gain in joint surplus achieved by adopting teams rather than the individual accountability regime is given by the following:

$$G(r, \gamma, \sigma_1^2, \sigma_2^2) = \frac{1}{2} \sum_{i=1,2} \left[\frac{2\gamma^2 + (1 + \gamma^2) r\sigma_i^2}{(1 + r\sigma_i^2)(\gamma^2 + r\sigma_i^2)} - \frac{(1 + \gamma)^2}{1 + \gamma^2 + r\sigma_i^2} \right].$$

[9] This is true because r and σ_i^2 do not appear in the agent's maximization problem and appear in the principal's maximization problem (i.e., the expression for the joint surplus) only when multiplied together.

For the first two propositions, I focus on the case of risk-neutral agents. In this case, $r = 0$ and $G(r, \gamma, \sigma_1^2, \sigma_2^2)$ simplifies to $G(0, \gamma, \sigma_1^2, \sigma_2^2) = (\gamma - 1)^2/(1 + \gamma^2)$. This is equal to 0 if $\gamma = 1$ and strictly positive if $\gamma > 1$. These observations prove the first two propositions.

Proposition 1. Suppose agents are risk neutral ($r = 0$) and there is no multitask problem ($\gamma = 1$). Then individual accountability and teams are equivalent.

Proposition 2. Suppose agents are risk neutral ($r = 0$) and there is a multitask problem ($\gamma > 1$). Then teams are preferred to individual accountability.

These results for risk-neutral agents clearly illustrate the benefit of teams. Note that there is a multitask problem under individual accountability when $\gamma > 1$: each agent is given a pair of tasks affecting a single signal, requiring that a single instrument is used to provide incentives for two tasks. In general, the marginal reward that induces efficient effort levels for one task will under- or overprovide incentives for the other task. Only when there is no multitask problem ($\gamma = 1$) can individual accountability induce agents to choose first-best effort levels, even when risk aversion is not an issue so that arbitrarily strong incentives can be used costlessly.

In contrast, there is never in this model a multitask problem for teams. Team members are given one task affecting each signal, and each task affects only one signal. Thus, marginal rewards on the two signals can be set to achieve the first-best effort levels on each task independently. This strictly improves gross project values when there is a multitask problem and agents are risk neutral.

The next proposition demonstrates the costs associated with teams when agents are risk averse. Assume that agents are risk averse ($r > 0$) and there is no multitask problem ($\gamma = 1$). In this case, $G(r, \gamma, \sigma_1^2, \sigma_2^2)$ simplifies to $G(r, 1, \sigma_1^2, \sigma_2^2) = -\sum_{i=1,2} r\sigma_i^2/[(1 + r\sigma_i^2)(2 + r\sigma_i^2)]$. This is strictly negative if agents are risk averse ($r > 0$) because I have assumed that signals are noisy ($\sigma_i^2 > 0$ for all i). This proves the next proposition.

Proposition 3. Suppose agents are risk averse ($r > 0$) and there is no multitask problem ($\gamma = 1$). Then individual accountability is preferred to teams.

Because the benefit of teams is that they solve the multitask problem, teams offer no advantages over individual accountability in the absence of any potential for a multitask problem. However, teams require that the agents bear more risk even to replicate the effort levels achieved under individual accountability. Thus, when agents are risk averse (and signals are noisy), teams are strictly inferior to individual accountability. Note that this is not as straightforward as noting that agents are compensated on two signals under teams and one signal under individual accountability. The magnitude of the risk burden is determined by both the marginal reward (α_j^k) and the variance of the signal (σ_j^2), so one must also take account of the differences in the optimal contracts between the two regimes.

When there is no multitask problem, the two tasks associated with a given signal have exactly the same impact on the signal and exactly the same impact on the project value. Imagine that an agent already has responsibility for one task and that the marginal reward is set to induce efficient effort on that task. Then giving an agent the second task associated with a particular signal achieves the first-best effort level on the second task with no change in the marginal reward. That is, individual accountability can induce agents to perform a second task at first-best effort levels with no change at all in the risk burden, in the absence of a multitask problem.

The above discussion makes clear the fundamental tradeoff involved in choosing to organize agents as teams. Teams do a better job of addressing the multitask problem, though the optimal contracts will not fully eliminate it in the presence of risk-averse agents and noisy signals. Nonetheless, teams allow better control over the agents' choices through richer performance measurement, which comes at the cost of an increased risk burden. The extent to which the optimal team incentive contract both utilizes the additional information to mitigate the multitask problem and offsets the increased risk burden through lower marginal rewards is not intuitively clear, but is fully described by the model. The following propositions demonstrate that this basic tradeoff between the increased risk burden and the benefits of solving the multitask problem persists under the optimal contract in the presence of both risk aversion and a multitask problem.

Proposition 4. For any given levels of risk aversion and signal precision ($r > 0; \sigma_i^2 > 0$), teams are preferred to individual accountability if the multitask problem is severe enough (i.e., there exists some $\widehat{\gamma}(r, \sigma_i^2)$ such that teams are preferred to individual accountability if $\gamma > \widehat{\gamma}(r, \sigma_i^2)$).

Proposition 5. For any given severity of the multitask problem ($\gamma > 1$) and any given level of signal precision ($\sigma_i^2 > 0$), individual accountability is preferred to teams if agents are risk-averse enough (i.e., there exists some $\widehat{r}(\gamma, \sigma_i^2)$ such that individual accountability is preferred to teams if $r > \widehat{r}(\gamma, \sigma_i^2)$).

To prove the first of these propositions, consider the full expression for $G(r, \gamma, \sigma_1^2, \sigma_2^2)$ derived above. Recall (from Proposition 3) that this is negative when $\gamma = 1$. It is straightforward to show that $\lim_{\gamma \to \infty} G(r, \gamma, \sigma_1^2, \sigma_2^2) = (1/2) \sum_{i=1,2} 1/(1 + r\sigma_i^2) > 0$. Because $G(r, \gamma, \sigma_1^2, \sigma_2^2)$ is continuous for permitted parameter values ($r, \sigma_1^2, \sigma_2^2 \geq 0; \gamma \geq 1$), these two observations together imply the existence of a $\widehat{\gamma}(r, \sigma_i^2)$ such that $G(r, \gamma, \sigma_1^2, \sigma_2^2) > 0$ for $\gamma > \widehat{\gamma}(r, \sigma_i^2)$.

To prove the second of these propositions, consider again the full expression for $G(r, \gamma, \sigma_1^2, \sigma_2^2)$ derived above. Recall that, in this case, it is required to show that $G(r, \gamma, \sigma_1^2, \sigma_2^2) < 0$ for large r because this proposition is about the superiority of individual accountability, while $G(r, \gamma, \sigma_1^2, \sigma_2^2)$ measures the net benefit of teams. It is easy to see that $\lim_{r \to \infty} G(r, \gamma, \sigma_1^2, \sigma_2^2) = 0$, reflecting the fact that optimal incentives are so weak for extremely risk-averse agents that the choice of task allocation becomes irrelevant. It follows that $G(r, \gamma, \sigma_1^2, \sigma_2^2) < 0$ for large r if $\partial G/\partial r > 0$ for large r—that is, if $G(r, \gamma, \sigma_1^2, \sigma_2^2)$ asymptotes to 0 from below. The general expression for $\partial G/\partial r$ is extremely complex, but it can be reduced to the quotient of a fourth-order polynomial in r in the numerator and a denominator that is always positive. Because a polynomial in r must approach $+\infty$ as $r \to \infty$ if the coefficient on the highest order term in the polynomial is positive, it remains only to check the sign of this coefficient. The coefficient on r^4 in the numerator is $2\gamma > 0$. This implies that $\partial G/\partial r > 0$ and $G(r, \gamma, \sigma_1^2, \sigma_2^2) < 0$ for large r; as before, the continuity of $G(r, \gamma, \sigma_1^2, \sigma_2^2)$ for permitted parameter values ensures the existence of an $\widehat{r}(\gamma, \sigma_i^2)$ such that individual accountability is preferred to teams if $r > \widehat{r}(\gamma, \sigma_i^2)$.

As a final comment on this analysis, it is important to point out that the model does *not* imply that observed team-based incentive schemes should be steeper than individual accountability schemes. Numerical computation of α_1^{A*} and $\widetilde{\alpha}_1^A$—the marginal rewards for performance measure 1 under teams and individual accountability, respectively—demonstrates this. Fix $r, \sigma_i^2 > 0$ and consider what happens to task allocation and optimal incentives as γ increases. For γ near 1, individual accountability is optimal and incentives are steep (if $r = \sigma_i^2 = 1$, $\widetilde{\alpha}_1^A$ can be as high as 0.67). As γ increases, individual accountability remains optimal but incentives get flatter in response to the multitask problem (if $r = \sigma_i^2 = 1$, $\widetilde{\alpha}_1^A$ can fall as low as 0.29). Eventually, the multitask problem becomes so severe that team compensation becomes optimal; at this point, incentives get somewhat steeper, but not as steep as they had been under individual accountability for γ near 1 (if $r = \sigma_i^2 = 1$, α_1^{A*} becomes 0.5).

□ **Optimal job design: signal precision.** The previous subsection holds constant the relative precision of the signals to derive comparative statics in the degree of risk aversion (r) and the severity of the multitask problem (γ). In contrast, this subsection holds these parameters fixed to examine how changes in relative precision of the signals affects the relative attractiveness of teams and individual accountability. Recall that common changes in the level of the precision of the signal are equivalent to changes in the degree of risk aversion, which was considered in the previous subsection.

This in some ways brings this article closer to the questions asked in other models of multitask problems. In particular, one of the main results of Holmström and Milgrom (1991) is that, when some tasks' consequences can be more accurately measured than others, it is optimal to group the easy-to-observe tasks together for one agent (who is compensated with steep incentives) and the hard-to-observe tasks together for another agent (who is paid a flat salary). In the present model, this will correspond to the individual accountability configuration. In that allocation of tasks, each agent is compensated on exactly one signal and is assigned the two tasks that affect that signal. As can be seen in a previous subsection, the optimal contracts will reflect the level of noise in each signal and the agent given the tasks associated with the noisier signal will in fact be compensated with much weaker incentives (and in the limit as the variance of that signal goes to infinity, with a flat salary).

As before, the analysis proceeds by examining the gain $G(r, \gamma, \sigma_1^2, \sigma_2^2)$ associated with using teams rather than the individual-accountability configuration. To aid in exposition, define the bracketed term in $G(r, \gamma, \sigma_1^2, \sigma_2^2)$ as presented above to be $g(r, \gamma, \sigma_i^2)$, so that $G(r, \gamma, \sigma_1^2, \sigma_2^2) = (1/2)\sum_{i=1,2} g(r, \gamma, \sigma_i^2)$. Note that $g(r, \gamma, \sigma_i^2)$ is continuous for all permitted parameter values and that $g(r, \gamma, 0) = (\gamma - 1)^2/(1 + \gamma^2) > 0$. Therefore, $g(r, \gamma, \sigma_i^2) > 0$ for small enough σ_i^2. Assume that one of the signals—without loss of generality, let it be signal 1—is precise enough that this holds; that is, σ_1^2 is small enough that $g(r, \gamma, \sigma_1^2) > 0$. Now note that $\lim_{\sigma_i^2 \to \infty} g(r, \gamma, \sigma_i^2) = 0$. This implies that, if the other signal—signal 2—is noisy enough, then teams will in fact be preferred to individual accountability because $|g(r, \gamma, \sigma_2^2)| < g(r, \gamma, \sigma_1^2)$ for σ_2^2 large enough. This yields the following proposition.

Proposition 6. Suppose agents are risk averse ($r > 0$) and there is a multitask problem ($\gamma > 1$). Then if one of the signals is very precise (σ_i^2 small enough that $g(r, \gamma, \sigma_i^2) > 0$), teams are preferred to individual accountability if the other signal is sufficiently noisy (σ_j^2 large enough that $|g(r, \gamma, \sigma_j^2)| < g(r, \gamma, \sigma_i^2)$).

Here, teams are preferred when there is meaningful measurement of only two of the four tasks. Because team organization involves giving each agent one task associated with each signal, this optimal allocation of tasks requires giving each agent one of the accurately measured tasks and one of the essentially unobservable tasks. This proposition contrasts with the classic Holmström and Milgrom result, which suggests that one agent should get all of the accurately measured tasks and one agent should get all the essentially unobservable tasks—a configuration that corresponds precisely to individual accountability in the present model. The intuition for their result is that the former agent can be given strong incentives and will perform very well on its tasks, while the latter agent will be paid a flat salary and will therefore allocate some minimal fixed amount of effort among its tasks based solely on the agent's cost considerations.

Consider the options available to the principal in the present model. With teams, each agent can be induced to choose a high effort level on one task (the one it has been given that is associated with the low-variance signal), and this effort may optimally be quite close to the first-best effort level because the signal is not too noisy. Each agent will essentially ignore the other task because the optimal marginal reward will be very low due to the high variance of the corresponding signal.

With individual accountability, the principal will again effectively ignore the two poorly measured tasks, which are given to a single agent in this configuration. The other agent will be compensated according to the optimal contract, but this will not induce effort levels near the first-best regardless of how small the variance of that signal is. This is because even the agent with the nearly noiseless signal still faces a multitask problem, as the tasks have the same effect on the project value but different effects on the signal. Thus, teams are preferred to individual accountability because they allow the principal to induce nearly first-best effort levels on two tasks, while individual accountability induces a multitask problem and fails to elicit effort choices near the first best.

There are two important distinctions that drive the difference in results between this model and Holmström and Milgrom's. First, in their model, agents paid a flat salary allocate a fixed amount of effort among their tasks. This provides a discrete benefit to the individual accountability configuration, as it is the only configuration under which significant effort is given to the essentially unobservable tasks (assuming that the level of effort undertaken by an agent on a flat salary is not trivial). Second, in their model, there is no multitask problem for the agent given the accurately measured tasks. That agent has one noisy signal per task; in the limit as the variance of each signal goes to zero, there is clearly no multitask problem. More generally, their one-signal-per-task assumption eliminates the benefit of teams emphasized in this article. Because signals are already rich enough to allow unique inferences about each well-measured task (or, equivalently, to eliminate the multitask problem completely in the absence of risk considerations), nothing is gained by sharing the well-measured tasks between the two agents to provide richer signals. The contrast of these models demonstrates the importance of the Holmström and Milgrom assumption that signals correspond to unique tasks, which eliminates residual multitask problems once unobservable tasks have been taken away from an agent. The next section provides an analysis of a more general model that sheds some light on the underlying assumptions that could justify this modeling choice.

3. General considerations

■ One implication of the simple model in the previous section is that, when risk considerations are absent (signals are noiseless or agents are risk neutral), teams achieve the first-best effort levels on all tasks even when individual accountability does not. While the benefit of teams is the richer signals they provide, the cost of teams is the increased risk the agents bear. This section abstracts from the costs of teams to demonstrate the logic behind the advantage of teams without unnecessarily encumbering the model with complications introduced by explicit calculation of the risk burden. Thus, the goal of this section is to demonstrate in a model with risk-neutral agents the circumstances under which teams completely solve the multitask problem and achieve the first-best effort levels for all tasks. The answer turns out to reveal an interesting and perhaps problematic assumption hidden in much of the existing multitask literature.

□ **A model with arbitrary numbers of tasks and signals.** This subsection lays out a generalized version of the model in the previous section. Assume that the risk-neutral principal delegates a number of tasks, denoted $i = 1, \ldots, N_e$, to an arbitrary number of risk-neutral agents, denoted $k = 1, \ldots, N_a$.[10]

Agents choose effort levels e_i and incur cost of effort $c^i(e)$ for each task i. While the previous section maintained additively separable cost functions for expositional simplicity, it should be clear that this plays no crucial role in the analysis. The model is about the richness of signals, and the rich signals provided by teams are sufficient to implement the first-best effort levels regardless of cost interactions. In this section, I therefore relax the separability assumption, allowing the cost of effort applied to any particular task to depend on the entire effort vector, including effort on those tasks performed by the other agent.

Denote the marginal cost of effort on task i by $c^i_i(e)$ and assume that the marginal cost of effort is positive and increasing: $c^i_i(e) > 0$ and $c^i_{ii}(e) > 0$. In this section, subscripts such as i and j in $c^i_{ij}(e)$ represent first and second derivatives—here, the second derivative of the cost of effort on task i (the superscript) with respect to effort level e_i and e_j. A further assumption on these cost interactions is required in order to ensure the validity of the first-order approach. Specifically, I maintain the sufficient condition that $c^i_{jj} \geq 0$; while effort on one task may lower (or raise) the cost of effort on another task, it cannot lower that cost at an increasing rate.

The total project value accruing to the principal is $V(e)$, with $\partial V(e)/\partial e_i > 0$ and $\partial^2 V(e)/\partial e_i^2 \leq 0$ for all i. Together with the assumptions about the cost of effort $c^i(e)$, this ensures that the first-best effort level e^* maximizing $V(e) - \sum_i c^i(e)$ exists, is unique, and is determined by the first-order conditions. Therefore, e^* is defined implicitly by

$$\frac{\partial V(e_i^*)}{\partial e_i} = c^i_i(e^*) + \sum_{k \neq i} c^k_i(e^*).$$

[10] The analysis goes through unchanged if agents are risk averse but signals are noiseless. Note that, in a general agency problem where signals can reflect more than one effort level, assuming noiseless signals does not eliminate the agency problem.

It will simplify notation later to denote the left-hand side of this equation as v_i^*. Note that, with separable cost functions, the sum drops out and the right-hand side of this equation reduces to $c_i^i(e^*)$, the marginal cost of task i.

Project value V and effort levels e_i are noncontractible. The agents are compensated with linear functions of contractible signals $x^j(e)$, $j = 1, \ldots, N_x$.[11] Agent k's compensation is $\beta^k + \alpha^{k\prime}x$, where the prime denotes the transpose of the $N_x \times 1$ vector α^k and x denotes the vector of signals. The signals x are a linear transformation of the effort levels, with some noise term, e_i: $x = X'e + \varepsilon$. Thus, X is an $N_e \times N_x$ matrix; element x_{ij} gives the marginal effect of e_i on x_j. The linearity of the signals in the effort levels simplifies the notation dramatically, but it will be clear that the main points of the analysis hold in a model with concave signals (the concavity preserves the validity of the first-order approach to the agent's problem described below).

It should be clear that the simple model of Section 2 is a special case of this model. The timing of the model is as before. The principal's job design problem amounts to the allocation of the N_e tasks among the N_a agents. Each task must be allocated to exactly one agent, and each agent can be given any number of tasks. Let T^k denote the set of tasks allocated to agent k.

□ **Achieving first-best efforts through job design.** Each agent k chooses effort levels to solve $\max_{e_i \in T^k} \beta^k + \alpha^{k\prime}x(e) - \sum_{i \in T^k} c^i(e)$. The assumptions on costs, together with the linearity of $x(e)$, ensure that the first-order conditions characterize the agent's optimal effort levels. Therefore, the implemented effort levels $\widetilde{e}$ are defined implicitly by

$$\frac{\partial[\alpha^{k\prime}x(\widetilde{e})]}{\partial e_i} = c_i^i(\widetilde{e}) + \sum_{j \in T^k} c_i^j(\widetilde{e}),$$

where T^k will be understood throughout this section to refer to the set of tasks assigned to the agent k who is responsible for the task i whose first-order condition is being described. Note that, with separable cost functions, the sum drops out. In that case, comparing this expression to the first-best effort levels demonstrates that the first-best efforts are implemented by a particular contract only if $\partial[\alpha^{k\prime}x(\widetilde{e})]/\partial e_i = v_i^*$ for all i. That is, the marginal payment for effort on each task must equal the marginal impact of that task on project value.

With the more general cost functions that permit interactions, one additional complication arises, which is that each agent ignores the effect of its effort choices on the cost of effort on tasks that are the responsibility of other agents (note the $j \in T^k$ in the sum above). However, this does not in general impede the implementation of first-best effort levels; it requires only that the incentive compensation scheme take these cost externalities into account. Thus, in the general model of this section, comparison of the first-best and implemented effort levels as defined above demonstrates that the first-best is implemented by a particular contract only if $\partial[\alpha^{k\prime}x(\widetilde{e})]/\partial e_i = v_i^* - \sum_{j \notin T^k} c_i^j(\widetilde{e})$ for all i. Denote the right-hand side of this equation as $\overline{v}_i^*$.

Recall that $\alpha^{k\prime}x(\widetilde{e}) = \alpha^{k\prime}[X'e + \varepsilon]$. The derivative of this with respect to the ith element of e is the product of α^k and the ith column of X', which is the ith row of X. Thus, the left-hand side of the above first-order condition can be rewritten as $\alpha^{k\prime}X'_{i\cdot}$, which is equivalent to $X_{i\cdot}\alpha^k$, where $X_{i\cdot}$ denotes the ith row of X. This implies that the left-hand side of agent k's first-order conditions can be rewritten $[X_{i\cdot}]_{i \in T^k}\alpha^k$, and that the first-best effort levels are achieved if and only if

$$[X_{i\cdot}]_{i \in T^k}\alpha^k = [\overline{v}_i^*]_{i \in T^k}.$$

Note that $[X_{i\cdot}]_{i \in T^k}$ is a $|T^k| \times N_x$ matrix, while α^k is an $N_x \times 1$ vector and $[\overline{v}_i^*]_{i \in T^k}$ is a $|T^k| \times 1$ vector. Thus, for generic $\overline{v}^*$, an optimal contract that implements the first-best effort levels exists if and only if $[X_{i\cdot}]_{i \in T^k}$ has full rank. This yields the following proposition.

[11] Note that, with risk-neutral agents, the restriction to linear compensation schemes is without loss of generality because the only relevant characteristic of a compensation scheme is its slope at the implemented effort level.

Proposition 7. For a given allocation of tasks and generic project value and effort cost functions, the optimal contract induces first-best effort levels if and only if, for each agent, the signals span the set of tasks given that agent.

This condition requires that the signals are rich enough to solve the multitask problem (in algebraic terms, that the signals span the tasks). In general, this requires that there are at least as many signals as tasks and that no two tasks have colinear effects on the signals. If two elements of $\overline{v}^*$ are equal, then these conditions need not hold; this is the sense in which there was no multitask problem in the earlier model with $\gamma = 1$ and separable cost functions. This is the reason for the restriction to generic project value and effort cost functions.

Importantly, this condition under which the first-best can be achieved is a condition on the rank of the X matrix when restricted to the set of tasks allocated to a single agent. Given the available signals, the richness of the signals used to compensate a particular agent is a function of job design. The point of using teams in the simple model is to increase the richness of the signals that each agent is compensated on, though this comes at the cost of increasing the risk borne by each agent.

Because the minimum number of signals needed to solve the multitask problem for a particular agent is the number of tasks given that agent, there is a close relationship between the richness of the signals and the number of agents required to avoid multitask problems. In general, there must be enough agents so that no agent is given more tasks than there are signals. In particular, one can see that the minimum number of agents required to achieve the first best is the smallest integer $N_a^* \geq N_e/N_x$.

The purpose of this more general model is not to derive specific results having to do with optimal job design; it is clear from the above discussion that making much progress on that front would require significant structure on the X matrix and cost interactions. Rather, the primary purpose here is to demonstrate the general logic behind the benefits of team-based job design demonstrated in the simple model. Another benefit of this model is that it allows an investigation of an ubiquitous, but not necessarily innocuous, assumption in the multitask literature.

□ **The one-signal-per-task assumption.** Much of the multitask literature assumes that there is a single signal for every task and that no tasks are confounded in any signal. Very often, this takes the form of an assumption that the vector of performance measures is simply a noisy measure of the effort level itself: in the present notation, $x(e) = e + \varepsilon$. This is, for example, the assumption made in Holmström and Milgrom (1991). Moreover, Holmström and Milgrom (p. 31) make a claim that is often repeated in the literature that follows: "this is not really a special case, since we can always reformulate the model by redefining the agent's choice variables so that [this assumption holds]." The question for this subsection is what assumptions lie behind this claim.

In the present model, there are two ways to think of this claim. One is to think of transforming the existing signals, x_i, so that the newly constructed signals, $\widehat{x}_i$, each correspond to exactly one task in this way ($\widehat{x} = e + \widehat{\varepsilon}$). Because $x = Xe + \varepsilon$, the required transformation involves premultiplying by X^{-1} so that $\widehat{x} = X^{-1}Xe + X^{-1}\varepsilon = e + \widehat{\varepsilon}$. A second way to envision the transformation in question (and closer to the wording of Holmström and Milgrom's claim, if perhaps less intuitive) is to think of redefining the tasks rather than the signals, so that performing one of the newly defined tasks, $\widehat{e}_i$, contributes in some way to the determination of each of the primitive tasks, e_i. This requires substituting some $\widehat{e}$ for e such that $x = X\widehat{e} + \varepsilon$, which requires that $e = X\widehat{e}$ or that $\widehat{e} = X^{-1}e$. In either case, X^{-1} must exist for such a transformation to be possible.

Proposition 8. There exists a transformation of a general agency problem into a problem with signals equated to noisy measures of single tasks ($x = e + \varepsilon$) if and only if the number of signals equals the number of tasks (X is a square matrix) and the signals span the tasks (X has full rank and is therefore invertible).

This result is at one level quite intuitive. It says that no matter how complex the relationship between the tasks and the signals, one can construct an equivalent model in which the efforts are observed with noise as long as the signals are rich enough. One needs only invert the signals to arrive at the underlying effort levels (by the first interpretation) or redefine the tasks so that signals are uniquely indicative of one task's effort level (by the second interpretation). This does not, however, seem to be an intuitive or unrestrictive assumption to maintain in a multitask model. In particular, in the limit as the agents become risk neutral, a model that satisfies this assumption exhibits no multitask problems whatsoever. In the context of this article's focus on job design with separable cost functions, a model that satisfies this assumption requires only one agent in order for the optimal contract to achieve the first best; job design is irrelevant and teams offer no advantages over individual accountability. That most of the multitask literature relies on this assumption demonstrates the extent to which those articles rely on risk-averse agents, cost-side interactions among tasks, and/or wholly unobservable tasks to create a multitask problem.

To be clear, I am not arguing that this assumption undermines in any essential way the Holmström and Milgrom results. Their multitask problem arises because there are tasks for which there is no signal whatsoever. This creates a situation in which X is not of full rank, even though $x = e + \varepsilon$ for the tasks that have some signal. Thus, their multitask problem arises for precisely the same reasons as in the present model, and it would persist even with a risk-neutral agent. What Holmström and Milgrom do not have is a residual multitask problem once those poorly measured tasks have been separated from the essentially unmeasurable tasks. The present analysis demonstrates how sensitive their result on the separation of measured and unmeasured tasks is to the strong dichotomy they assume and, in particular, to the assumption that each task is reflected in a unique signal that is uncorrupted by the performance of other tasks.

4. Conclusion

■ It may seem paradoxical that agency problems can be solved and agents compensated more effectively by assigning agents tasks in a way that makes the performances measures less directly informative of a single agent's task. Indeed, assigning agents tasks in this way does increase the risk that each agent bears under the optimal contract. However, it also gives the principal richer signals with which to compensate each agent, alleviating multitask problems. If the multitask problem is severe (the effects of efforts on performance measures and the project value are not closely aligned) or risk considerations are not too important (either because signals are not too noisy or agents are not too risk averse), then grouping tasks in this way may be optimal.

This corresponds to the choice of manufacturing teams over assembly-line production and the creation of corporate divisions organized around product lines or customer segments rather than traditional functional boundaries. Historical shifts toward manufacturing and service teams and cross-functional corporate divisions may reflect improved performance monitoring. As less noisy measures of performance are available, the increased risk burden associated with joint accountability diminishes, making that allocation of tasks more attractive.

The results also call into question the conventional wisdom that difficult-to-measure tasks should be grouped together for allocation to a single individual. In this model, this is often not optimal because it leaves the agent assigned the poorly measured tasks with little incentive to provide effort and leaves the agent assigned the precisely measured tasks with a multitask problem. In general, grouping poorly measured tasks in this way will *not* be optimal when intrinsic motivation is weak (agents on flat salary provide little or no effort) and the multitask problem is severe (because the precisely measured signals are not rich enough). In such cases, it is better to adopt the team model, in which multiple agents share joint responsibility for the poorly measured tasks.

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