Optimal Team Composition: Diversity to Foster Implicit Team Incentives

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Abstract

We study optimal team design. In our model, a principal assigns either heterogeneous agents to a team (a diverse team) or homogenous agents to a team (a specialized team) to perform repeated team production. We assume that specialized teams exhibit a productive substitutability (e.g., interchangeable efforts with decreasing returns to total effort), whereas diverse teams exhibit a productive complementarity (e.g., cross-functional teams). Diverse teams have an inherent advantage in fostering desirable implicit/relational incentives that team members can provide to each other (tacit cooperation). In contrast, specialization both complicates the provision of cooperative incentives by limiting the punishment agents can impose on each other for short expected career horizons and fosters undesirable implicit incentives (tacit collusion) for long expected horizons. As a result, expected compensation is first decreasing and then increasing in the discount factor for specialized teams, while expected compensation is always decreasing in the discount factor for diverse teams. We use our results to develop empirical implications about the association between team tenure and team composition, pay-for-performance sensitivity, and team culture.

Keywords: team composition, assignment problem, cooperation, collusion, team diversity

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1. Introduction

Team diversity has become increasingly pervasive in organizations (Williams and O'Reilly, 1998; Barak, 2016).[1] Such diversity can be beneficial. Diverse teams are less likely in their comfort zone, which can lead to innovation (Nathan and Lee, 2013). Diverse team members may also process information more carefully (Phillips, Liljenquist, and Neale, 2008). In corporate governance too, the trend has been toward greater board diversity (Miller and Triana, 2009; Deloitte, 2017). Broadly, team diversity can be seen as creating productive complementarities. At the same time, team diversity can be costly. It can make communication within the team more challenging (Hamilton, Nickerson, and Owan, 2012). Also, team identity may be weakened by team diversity (Towry, 2003).

We study a team assignment problem to explore how an organization optimally groups multiple agents into a team. By comparing specialized to diverse team compositions under repeated play, we provide a new theory—one based on implicit incentives that agents provide to each other—that can potentially add to our understanding about when team diversity is desirable and when it is not. Our theory highlights the role of implicit incentives and its dependence on both productive complementarities/substitutabilities and the expected tenure of individuals in the team. By embedding repeated interactions and close work relationships (mutual observability of actions) between agents into a team assignment model, we show how implicit incentives from repeated work relationships affect the choice of optimal team composition. In short, diverse teams have an inherent advantage in fostering desirable implicit/relational incentives for working that team members can provide to each other (tacit cooperation). In contrast, specialization both complicates the provision of cooperative incentives by limiting the punishment agents can impose on each other for short expected career horizons and creates an opportunity for tacit collusion for long expected horizons.

Every organization faces team composition problems.[2] Before composing its top management team, a board of directors needs to consider whether executives with similar or

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[1] For example, building successful data products requires grouping diverse professionals into data science teams, such as data scientists, engineers, developers and business analysts, (IBM Analytics, 2016). Successful adoption of artificial intelligence into business also relies on the right mix of functionally diverse professionals, including artificial intelligence researchers, programmers and business leaders (Loucks, Davenport, and Schatsky, 2018).

[2] One typology in the management literature classifies teams as being of one of four types (Cohen and Bailey, 1997): (i) work teams refer to continuing work units such as audit teams, manufacturing teams, or service teams; (ii) parallel teams denote advising and consulting teams such as employee involvement groups or quality circles; (iii)

different work experience will result in the best performance. For new product development teams, an organization needs to ask if it is better to group a set of engineers who are specialized in a particular technology into a team or instead to construct a cross-functional team. In an academic context, research teams can be composed of members from the same discipline or from multiple disciplines. Audit firms need to find the appropriate structure of audit engagement teams to improve audit quality (IAASB, 2014). Although research in the fields of management and organizational behavior has provided evidence suggesting that team performance is significantly influenced by team composition, the evidence on whether diverse teams outperform specialized teams is mixed.[3]

Repeated work relationships among team members are also common in practice. In the C-suite, top management teams work together for 4.35 years on average (Guay, Kepler, and Tsui, 2019).[4] For research teams in academia or product development teams, they often work together repeatedly on multiple projects.[5] Audit engagement teams may also work for the same client for multiple years or work together on other client engagements.

Building on a repeated team production setting, our model has the following additional features. The first (and key) assumption in our model is that specialized teams exhibit a productive substitutability (e.g., interchangeable actions with decreasing returns to overall effort), whereas diverse teams exhibit a productive complementarity (e.g., cross-functional teams where each team member contributes a unique and important skill to the project).[6] Second, because of their proximity to each other as members of the same team, we assume the agents

project teams represent temporary work units such as new product development teams; and (iv) management teams are in charge of improving overall performance and providing strategic directions to the sub-units.

[3] For evidence on a variety of team settings, including project, top management, and service teams, see Gibson and Vermeulen (2003). For evidence on cross-functional sales teams, see Murtha, Challagalla and Kohli (2011). For evidence on R&D teams, see Zenger and Lawrence (1989) and Hoegl, Weinkauf, and Gemueden (2004). For surveys on the effectiveness of team diversity, see Milliken and Martins (1996), Williams and O'Reilly (1998), and Reiter-Palmon, Wigert, and de Vreede (2012). For experimental evidence, see Hoogendoorn, Oosterbeek, and Van Praag (2013).

[4] Guay, Kepler, and Tsui (2019) define the top management team length as the number of years the top executives (typically, five members) work together until two of the members depart the team.

[5] Using data from various academic disciplines in social and natural sciences, Guimera, Uzzi, Spiro, and Amaral (2005) report that more than 70% of research teams exhibit repeated collaboration for multiple projects. For repeated collaboration in new product development teams, see Taylor and Greve (2006) and Schwab and Miner (2008).

[6] One interpretation is that interactions within the team generate the complementarity. For example, by learning from each other, innovative approaches to solving a problem may emerge from an interdisciplinary team. For projects with separable components, a different interpretation comes to mind. The efficient division of labor could generate the complementarity if the team self-assigns those best suited to each component to complete it. However, this second interpretation seems somewhat at odds with very nature of team production.

observe each other's actions and can potentially use implicit incentives to motivate each other. Third, before considering incentive problems, we assume it is always efficient to assign the same types to a team to exploit the assumed productive synergy from specialization.[7] However, our focus is not on the exogenous productive advantage of specialized teams, which is an assumption we make largely to ease the presentation of our results, but rather on the endogenous incentive properties of specialized vs. diverse teams. In Appendix C, we consider the other cases, including those in which diverse teams have a productive advantage over specialized teams. Finally, we assume the agents are permanently assigned to a team for all future periods. We discuss the possibility of termination or job rotation in Section 4.

Holding the ability of agents to observe each other's actions constant, specialization complicates the provision of incentives for cooperation (for short expected career horizons) and/or encourages collusive behavior (for long expected career horizons), whereas there is no collusion problem for diverse teams for any expected career horizon. As a result, for specialized teams, expected compensation is first decreasing and then increasing in the discount factor, whereas, for diverse teams, it is always decreasing. Taking these implicit incentives (cooperation and collusion) into account can lead to an optimal composition that favors diversity.

We study the role of diversity in fostering desirable implicit incentives that agents provide to each other. As Milgrom and Roberts (1992, p. 416) point out, "[g]roups of workers often have much better information about their individual contributions than the employer is able to gather…[g]roup incentives then motivate the employees to monitor one another and to encourage effort provision or other appropriate behavior." As Barker (1993) puts it, one consequence of the introduction of teams to an organization can be a tightening of the "iron cage" of control when compared to bureaucracy, as workers are no longer monitored by supervisors but instead monitored by everyone.[8] Nevertheless, the outcome of mutual monitoring can be viewed as a form of cooperation. While the explicit incentives agents face do not provide them with

[7] Some examples of productive synergies exhibited by specialized teams are a team of sweep-oar rowers or a team of synchronized swimmers. With similar physical attributes, rowers are more likely to sustain mutual coordination of strokes (when to pull/catch the oar) and synchronized swimmers are likely to perform better-coordinated routines.
[8] Knez and Simester (2001) study the effectiveness of Continental Airlines' team-based incentives and the role played by mutual monitoring. Using the personnel records of workers at the Koret Company, Hamilton, Nickerson and Owan (2003) study the effectiveness of team-based incentives depending on team compositions. Using data from service and manufacturing firms, Siemsen, Balasubramanian, and Roth (2007) find that team-based incentives encourage employees to share their work-related knowledge with coworkers. Based on experiments, Chen and Lim (2013) show that team-based contests outperform individual-based contests when team production is preceded by social activities.

individual (Nash) incentives to work, the agents use a tacit (self-enforcing) side agreement to ensure that they both work, which is in the team's best interest in the sense of Pareto optimality.[9]

To elaborate on our results, we show that, depending on the productive interdependence and the expected career horizons of agents (captured by the discount factor), the qualitative nature of the implicit incentives teams employ are different. The productive substitutability of the agents' actions under specialized teams complicates the provision of cooperation incentives because it creates a greater free-riding temptation in the spirit of Holmstrom (1982). In the implicit contract the agents use to motivate each other (under diverse team assignment or under specialized team assignment with an intermediate discount factor), the punishment for free-riding is to play the stage-game equilibrium that has both agents shirking. Under specialized team assignment, the shirking equilibrium does not exist for low discount factors. Instead, the stage-game equilibrium has one of the agents working and the other shirking, which makes the punishment less powerful and increases the principal's cost of providing incentives for cooperation. For high discount factors, specialized teams face the possibility of a collusion problem, where the agents take turns free-riding (one agent shirks in odd periods and the other in even periods).[10] Once these various implicit incentives are taken into consideration, the principal may find diverse teams efficient as they make it less costly to create a common interest in non-shirking (Alchian and Demsetz, 1972). Although the main trade-off we study is driven by assumptions we make about the production technologies, our focus is not on the production technologies per se. Instead, our goal is to develop a link between team design (and, more broadly, organizational forms) and the distinct nature of implicit incentives that arise in long-term relationships.[11]

By illustrating a novel trade-off between productive efficiency from specialization and incentive efficiency from repeated work relationships, we develop a role for implicit incentives in explaining why and when diverse teams are preferred over specialized teams. Our theory provides two testable predictions. 1) For diverse teams, pay-for-performance sensitivity is

[9] Itoh (1992) studies similar cooperation in teams, modeling it as incentives to help enforced by explicit side contracts.
[10] This is akin to collusive equilibria that can arise in auction, where firms agree to take turns winning auctions. General Electric and Westinghouse, for example, used such a scheme in the 1950s (Porter, 2005). This kind of turn-taking collusive equilibrium can also arise under relative performance evaluations (Che and Yoo, 2001).
[11] We assume perfect monitoring between agents in both compositions to highlight the distinct nature of implicit team incentives the agents employ depending on productive complementarities/substitutabilities. The agents' monitoring ability may also depend on team composition. While introducing imperfect monitoring will alter our findings quantitatively, the main trade-off remains qualitatively unchanged. We discuss more on this in Section 4.

monotonically decreasing in expected team tenure, whereas, for specialized teams, pay-for-performance sensitivity is initially decreasing in expected team tenure; however, once a critical threshold of expected tenure is reached, pay-for-performance sensitivity is increasing in tenure because longer tenure facilitates collusion. 2) If expected team tenure is short, then the nature of the sanction (interpreted below as a feature of the team's culture) the agents use to punish free-riding depends on the team composition.

Our article builds on Arya, Fellingham, Glover (1997), Che and Yoo (2001), Kvaloy and Olsen (2006), Glover (2012), and Baldenius, Glover, and Xue (2016), which also study implicit contracts between agents.[12] However, these articles are silent about team composition as agents are homogenous. The role of mutual monitoring developed in these articles and ours can be viewed as designing contracts and assigning agents to teams (in our article) to foster a team-oriented culture rather than an individualistic one. Following Kreps (1996), culture can be viewed as the choice to coordinate on one of multiple equilibria. In the selection of a particular equilibrium to play, we appeal to Pareto optimality in the agents' overall subgame but make the standard assumption of allowing for punishments that are not Pareto optimal off the equilibrium path. As we will show, the nature of a team-oriented culture hinges on team composition. In the case of diverse teams, the team-oriented equilibrium has the agents threatening to punish free-riding with the stage-game equilibrium that has both agents shirking in response to free-riding—a culture that has everyone giving up on the project once free-riding is first observed. In contrast, for specialized teams and low discount factors (short expected horizons), the punishment for free-riding has the free-rider working in all future periods with the punishing agent free-riding—a culture of reciprocity in that free-riding by one agent triggers free-riding by the other. For intermediate discount factors, the punishment equilibrium is the same under specialized and diverse teams. For high discount factors, the culture can again be seen as different in diverse and specialized teams—specialized teams are plagued by collusion problems that do not arise under diverse team assignment.

This article is also related to the literature on job design problems (e.g., Holmstrom and Milgrom, 1991; Itoh, 1992; Hemmer, 1995). The main insight from these static models is the importance of technological parameters (either performance signals, production costs or

[12] Although Itoh (1992, 1993) study explicit rather than implicit side contracting, they are seminal papers in this line of research.

productive synergy) in assigning tasks to multiple agents.[13] In a multi-period setting, Mukherjee and Vasconcelos (2011) study the trade-off between the (principal's) dynamic enforcement constraint and the multitasking problem. A team assignment that resolves the multitasking problem requires larger bonuses (paid out less often), which increases the principal's gain from reneging on her promised bonus. Building on Itoh (1991), Ishihara (2017) studies an optimal task structure—either specialization or teamwork—with relational contracting between a principal and agents in a repeated game setting. Instead of relational contracting between a principal and agents, our study focuses on relational (implicit) contracts between agents and examines the impact of team composition on those implicit contracts.

Kaya and Vereshchagina (2014) study endogenous team composition. They analyze how the cost of upsetting free-riding affects a team assignment problem depending on the organizational form (partnerships vs. corporations). Slivinski (2002) studies a free-riding problem within a team depending on the organizational form (for-profit and not-for-profit). In the context of strategic alliances among multiple firms, Amaldoss and Staelin (2010) show how individual firms' investment behaviors change depending on alliance structures, i.e., same-function or cross-function alliances. However, these articles study single-period models with no role for implicit contracts between the agents. In contrast, the focus of our article is implicit contracts between the agents built upon repeated interactions. Glover and Kim (2020) study an optimal team composition problem with career horizon diversity. In a setting where the production technology exhibits a productive substitutability and the principal can use asymmetric contracting, they show that a more complicated (asymmetric) collusion problem arises within a team and that grouping agents with different discount factors into the same team (another form of diverse team assignment) is optimal because diverse assignment lowers both the total collusion-proof wages and mutual-monitoring wages.

In a repeated oligopoly setting, Bertomeu and Liang (2014) show that, depending on industry concentration, the presence of future competition fosters tacit cooperation or collusion among firms by influencing the informed firm's disclosure behavior and, thus, all firms' pricing decisions. Unlike their emphasis on the number of competitors (which can be broadly interpreted as team size), we focus here on the type of teammates that agents interact with.

[13] Che and Yoo (2001) provide a job design interpretation of their results; however, they are silent about team composition, since their agents are identical.

2. Model

A principal hires four agents to conduct two tasks in each period. Each task requires two agents who each make a binary effort decision $e \in \{0,1\}$ at cost ce, where $e = 1$ denotes *work* and $e = 0$ denotes *shirk*. The agents have publicly observable types, A or B, and there are two agents of each type. There are two possible team assignments: two of agent A perform one task together and two of agent B perform the other task, which we call specialized teams, or two sets of agent A and B perform each task, which we call diverse teams. If type $i, j \in \{A, B\}$ are matched to perform the same task as a team with unobservable effort e_i, e_j, then the task generates $S > 0$ with probability $f_k(e_i, e_j) \in (0,1)$ or $F = 0$ with probability $1 - f_k(e_i, e_j)$, $k \in \{s, d\}$, where s and d represent a specialized team and diverse team, respectively. $f_k(e_i, e_j)$ is increasing in the agents' efforts. The production technology for each task is independent and identical. Within a team, each agent's effort contributes to production symmetrically ($f_k(0,1) = f_k(1,0)$ for all i, j). As the agents' contributions are symmetric within a team, for notational convenience, we use $f_s(\sum_i e_i), f_d(\sum_i e_i)$ to denote the probability of success for the specialized team and the diverse team, respectively. We relax the assumption of symmetric contributions (by asymmetric agents in diverse teams) in Section 4. We assume that there is productive efficiency associated with specialized assignment: $f_s(2) > f_d(2)$. We call this the benefit of specialization. This assumption is meant to highlight the advantage to diversity we derive comes from incentive properties. In Appendix C, we show how our results will change if $f_s(2) \leq f_d(2)$. In short, the assumption that $f_s(2) \leq f_d(2)$ strengthens the overall efficiency of diverse assignment, but the economic forces illustrated in our main analysis remain qualitatively unaffected.

Although the marginal contribution is symmetric within a team, each agent's marginal productivity is affected by his teammate's type and effort choice—the productive complementarity or substitutability of the agents' actions. Our main trade-offs are driven by this interdependence, which will be discussed in more detail shortly.

Due to their close work interactions, we assume that each agent can observe the effort choice of the other agent within the team, but communication from the agents to the principal about their observations of each other's actions is blocked.[14] Moreover, to focus on the role of implicit

[14] See Arya, Fellingham, Glover (1997), Che and Yoo (2001), Kvaloy and Olsen (2006), and Baldenius, Glover, and Xue (2016) for related discussions. Allowing for communication between the principal and agents would constitute a digression from our focus on implicit incentives for effort to implicit incentives for messages (collusion constraints

incentives within a team, we suppose that there are no explicit side payments between agents, which are considered in Itoh (1992, 1993).

The agents' effort strategies map any possible history of past actions (efforts) into current actions. We focus on pure strategy subgame-perfect equilibria. Without loss of generality, we restrict attention to grim trigger strategies for the agents. That is, any deviation from an implicitly agreed action profile triggers the play of the harshest punishment that is sustained as a stage game equilibrium in all future periods.

We assume the principal's decision on team composition is made at the start of the relationship and cannot be changed in subsequent periods. In particular, assume the agents are essential in that they cannot be replaced. We discuss the possibility of agent replacement in Section 4. To highlight the principal's trade-off between productive efficiency and implicit incentives, we assume the agent's productivity from effort is sufficiently greater than the static incentive cost that the principal always wants to elicit $e = 1$ from both agents in each period.[15] For tractability, we confine attention to stationary wage contracts that have wages depending only on current period performance, and that are applied to all subsequent periods once designed at the beginning of the relationship.

Let $w_k \geq 0$ and $v_k \geq 0$ denote the principal's payments to agents in team $k \in \{s, d\}$ contingent on performance S, F, respectively.[16] The non-negativity constraint can be interpreted as capturing the agents' limited liability and is the source of the contracting friction, along with the unobservability of their actions by the principal. The role of the incentive contract is to foster mutual monitoring: bilateral working is not required to be a Nash equilibrium of the one-shot

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on message games). Nevertheless, the principal's payoff from introducing a message game will be bounded below from her payoff in our model because she can always ignore the messages whenever they are not useful. The work of Baliga and Sjostrom (1998) suggests that the role of message games is severely limited once collusion is allowed for. This is because collusion constraints limit the principal's ability to use a message game to induce the agents to play an equilibrium that is not Pareto optimal.

[15] The condition is $f(2)S - 2\frac{c}{f(2)-f(1)} > \max\left\{f(1)S - \frac{c}{f(1)-f(0)}, f(0)S\right\}$. In our multi-agent setting, the cost of eliciting effort depends on the implicit incentives the agents provide to each other, which in turn depends non-monotonically on their discount factors. Since the cost of providing incentives is never greater than in the static case, our assumption is a sufficient condition to ensure that the principal wants to motivate both agents to work for all δ.

[16] We focus on symmetric contracts that treat agents equally within a team. In a static setting with imperfect monitoring where agents cannot observe other agents' effort choices, Winter (2004) shows that asymmetric contracts for symmetric agents are optimal given that the contracts are public; Halac, Lipnowski, and Rappoport (2020) show that symmetric contracts for symmetric agents are optimal when the contracts are private. The common economic force in these two papers is based on agents' beliefs about others' efforts. Such benefit of controlling agents' beliefs does not exist in our setting because agents perfectly monitor others' effort choices.

game. Instead, each agent must find the temptation to free-ride by shirking ($e = 0$) when the other agent is working ($e = 1$) less appealing than the punishment of reverting from bilateral working, $(1,1)$, to an equilibrium of the one-shot (stage) game used by the agents to punish each other.

All parties are risk neutral and share the same discount factor $\delta \in [0,1]$. Each agent's reservation utility is normalized to zero. In our complete and perfect information setting, the team assignment (players), the agents' strategies, and the wage contracts and discount factors (payoffs) specify the (normal form) game the agents play.

The principal's objective is to maximize her payoff by solving an assignment and contracting problem: (permanently) assigning agents to teams at the beginning of the relationship and designing a (stationary) wage contract to induce each agent to work (e = 1) as a Pareto-undominated subgame-perfect equilibrium. In each team composition, the wage contracts are said to be optimal if $(1,1)$ is induced as an equilibrium at the minimum cost. The principal either assigns the same types for each task, (A, A) and (B, B), or mixes the types, (A, B), for each task. The former resembles a positive assortative assignment, whereas the latter resembles a negative assortative assignment.[17] A team composition is said to be optimal if the principal's expected payoff (with optimal contracts) under that team composition is the highest among all other compositions.

3. Productive Diversity

Consider a benchmark in which there is no moral hazard. As specialized teams dominate diverse teams in terms of productivity without any frictions, this leads to a positive assortative assignment: A and A for one task and B and B for the other. To see this, suppose that agents' efforts are observable to the principal and verifiable/contractible. Thus, each agent is paid c for effort $e = 1$, and the principal's expected payoff (depending on team composition) is:

$$\left(f_k(2) + f_k(2)\right)S - 4c \; for \; k \in \{s, d\}.$$

As $f_s(2) > f_d(2)$, the principal's payoff obtains its maximum under specialized assignment.

[17] Becker (1973) shows that the equilibrium matching (the assignment in this case) is positive (negative) assortative if the match output function is supermodular (submodular).

Mutual Monitoring We assume that a team with homogeneous types exhibits a strategic substitutability in their efforts, whereas a team with heterogeneous types exhibits a strategic complementarity. By productive substitutes, we mean that each agent's marginal productivity is greater when the other agent is shirking. For productive complements, the relationship is reversed—each agent's marginal productivity is higher when the other agent is working rather than shirking. For example, a team consisting of two production managers will likely find shirking by one of them less harmful in terms of the impact on their output than a team comprised of a production manager and a sales manager.[18] Formally:

$$f_s(2) - f_s(1) < f_s(1) - f_s(0) \text{ and}$$

$$f_d(2) - f_d(1) > f_d(1) - f_d(0).$$

Productive efficiency in types holds the agents' actions constant while varying their types, while effort complementarity holds the agents' types constant while varying their effort levels.

When agents' efforts are strategic complements, both agents' choice of $e = 0$ (i.e., playing *(shirk, shirk)*) is not only the harshest possible punishment the agents can impose on each other, it is also self-enforcing because it is the unique stage-game equilibrium.[19] When the agents' efforts are strategic substitutes, whether both agents' choice of $e = 0$ is self-enforcing is unclear. It turns out that the answer depends on the magnitude of the productive substitutability and the discount factor. In particular, if the production function exhibits a weak substitutability and the discount factor is not too low, then both agents choosing $e = 0$ is self-enforcing. If the discount

[18] As a concrete example of productive substitutability/complementarity, consider grouping four authors, two theorists and two empiricists, into two teams for research projects. The research projects require both theoretical and empirical evidence, so depending on team composition, there are two possible scenarios: 1) one theory project and one empirical project, or 2) two projects that have both theoretical and empirical analyses. When grouping two theorists into one team for a theory paper and two empiricists as another team for an empirical paper (specialized assignment), efforts are substitutes. However, when grouping one theorist and one empiricist for a paper that has a theory section and an empirical section (diverse assignment), efforts are complements: one author's effort is of small value when the other author is not working. Under diverse assignment, one author's unilateral effort is unlikely to result in the completion of the project (thus, $f_d(1)$ is close to $f_d(0)$), and the paper is much more likely to be completed when the two authors contribute effort (thus, $f_d(2)$ is far greater than $f_d(1)$). This implies that $f_d(e)$ is convex. These assumptions are consistent with Milgrom and Roberts (1995) and Lazear (1999), who point out that, when there are multiple types of agents working together as a team (like cross-functional teams), such diverse skills and/or expertise are likely to render productive complementarity. Under the specialized assignment, one author's unilateral high effort (either a theory paper or an empirical paper) is likely to enable them to complete the project, thus, $f_s(1)$ is much greater than $f_s(0)$. However, additional effort put forth by his teammate is less likely to have the same incremental contribution (i.e., the completion of the paper). For this argument, we conceptually appeal to the notion of diminishing returns to effort of *a* type. We thank an associate editor and an anonymous referee for developing this example.

[19] We provide the proof of this argument in Lemma 1.

factor is sufficiently low, then both agents choosing $e = 0$ is no longer the stage-game equilibrium. Instead, there are two stage-game equilibria in which one agent chooses $e = 0$ while the other chooses $e = 1$ and vice versa: *(work, shirk)* or *(shirk, work)*. As the discount factor becomes small, the wage contract converges to one that provides Nash (or individual) incentives. Because of the productive substitutability, such a wage scheme also ensures that both agents choosing $e = 0$ cannot be an equilibrium. Thus, depending on the discount factor, the mutual monitoring incentives differ. We consider both potential stage game equilibria, *(shirk, shirk)* and *(work, shirk)* in analyzing the explicit incentives that induce mutual monitoring because the stage game equilibrium serves as the punishment that the non-deviating agent can impose on the deviating agent.

Although not considered until the next section of the article, the possibility of collusion can also upset the *(shirk, shirk)* stage-game equilibrium under productive substitutes. To avoid this possibility, we assume that the productive substitutability is a weak enough one that this does not occur. We also assume that the productive complementarity is large enough that static (Nash) incentives favor diverse assignment, which is captured by a likelihood ratio comparison. This assumption fixes the starting point of our analysis (the stage game).[20] These assumptions are formalized below.

Assumptions.

A.1 The agents' efforts are productive substitutes under specialized team assignment and productive complements under diverse team assignment: $\frac{f_s(2)-f_s(0)}{f_s(2)-f_s(1)} > 2 > \frac{f_d(2)-f_d(0)}{f_d(2)-f_d(1)}$.

A.2 For any δ, the collusion-proof wage does not upset the (shirk, shirk) equilibrium: $\frac{f_s(1)-f_s(0)}{f_s(2)-f_s(1)} < 2$*, i.e., the productive substitutability is a weak one.*

A.3 In the one-shot game, diverse teams are less costly to incentivize: $\frac{f_s(1)}{f_s(2)} > \frac{f_d(1)}{f_d(2)}$.

[20] The incentive efficiency is determined by the comparisons between $\frac{f_s(1)}{f_s(2)}$ and $\frac{f_d(1)}{f_d(2)}$ for Nash incentives and $\frac{f_s(0)}{f_s(2)}$ and $\frac{f_d(0)}{f_d(2)}$ for team incentives. Conditional on $\frac{f_s(1)}{f_s(2)} > \frac{f_d(1)}{f_d(2)}$, we analyze the model for $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$ and $\frac{f_s(0)}{f_s(2)} < \frac{f_d(0)}{f_d(2)}$ throughout the article. The other case (given $\frac{f_s(1)}{f_s(2)} < \frac{f_d(1)}{f_d(2)}$, consideration of $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$ and $\frac{f_s(0)}{f_s(2)} < \frac{f_d(0)}{f_d(2)}$) can be similarly analyzed.

Thus, for a team k, the mutual monitoring incentive compatible (M-IC) constraints are:

$$f_k(2)w_k - c \geq \big((1-\delta)f_k(1) \ + \delta f_k(0)\big)w_k,$$
$$f_k(2)w_k - c \geq (1-\delta)f_k(1)w_k \ + \delta(f_k(1)w_k - c). \tag{M-IC}$$

We present the program for the principal's contracting problem in Appendix A. Throughout the paper, we normalize both sides of the constraints by multiplying by $(1-\delta)$. The left hand side represents the present value of the expected payoff from working and the right hand side the agent's payoff from deviating and being punished by the worst outcome, either bilateral shirking or the deviating agent's working accompanied by the non-deviating agent's shirking. Note that for $\delta = 0$, the (M-IC) constraint becomes the standard Nash incentive constraint of the one-shot contracting relationship.

Lemma 1. (Mutual Monitoring) *Let* $\delta^m \equiv \frac{2f_s(1)-f_s(2)-f_s(0)}{f_s(1)-f_s(0)} \in (0,1)$ *denote the value of* δ *at which the punishment equilibrium changes from (work, shirk) or (shirk, work) to (shirk, shirk) under specialized assignment. For a given team k, the optimal mutual monitoring contract is:*

$w_k^* = \frac{c}{(1-\delta)\left(f_k(2)-f_k(1)\right) + \delta\left(f_k(2)-f_k(0)\right)}$ *if k=d or k=s and* $\delta \geq \delta^m$,

$w_s^* = \frac{(1-\delta)c}{f_s(2)-f_s(1)}$ *if k=s and* $\delta < \delta^m$.

Mutual monitoring between the agents creates implicit incentives, which reduces the required explicit payment. This is due either to the team incentive term, $\delta\big(f_k(2)-f_k(0)\big)$ in w_k^*, or to $(1-\delta)$ in w_s^*, which makes the required wage less than the Nash incentive wage, $\frac{c}{f_k(2)-f_k(1)}$. When $\delta < \delta^m$, the form of the mutual-monitoring wage differs across team compositions because the agents in the specialized teams sustain a work equilibrium with a punishment of *(work, shirk)*. When $\delta \geq \delta^m$, the explicit pay in both compositions is determined by the ratio of $f_k(2)-f_k(0)$ (which captures the punishment the agents can impose on each other after free-riding) and $f_k(2)-f_k(1)$ (which captures the cost of free-riding). The magnitude of implicit incentives is determined by both the discount factor and the production technology. To distinguish these two, let $x_k = \frac{f_k(2)-f_k(0)}{f_k(2)-f_k(1)} > 1$ and rewrite the total expected wage $E[w_k^*]$ (based on the punishment *(shirk, shirk))*:

$$E[w_k^*] = \frac{1}{1+\delta(x_k-1)} \frac{f_k(2)c}{f_k(2)-f_k(1)}. \tag{1}$$

Here, x_k captures the role of the production technology in determining the magnitude of implicit incentives. It is defined as the ratio of team to Nash incentives, which we call a normalized punishment. Due to Assumption A1, $x_s > 2 > x_d$. Holding the Nash incentive wage constant, as x_k increases, the role played by the discount factor increases. Alternatively, as the probability of continuing in the work relationship (in the same team) becomes larger, the impact of the normalized punishment becomes greater, thereby strengthening the agents' implicit incentives.

Whereas the total expected wage, $E[w_k^*]$, depends both on the normalized punishment, x_k, and the Nash incentive wage, $\frac{f_k(2)c}{f_k(2)-f_k(1)}$, it turns out that splitting the expression for $E[w_k^*]$ as in (1) permits an analytically simple comparison between $E[w_s^*]$ and $E[w_d^*]$ with respect to δ. To see this, note that, due to assumption A3, the Nash incentive wage (when $\delta = 0$) under specialized teams is greater than under diverse teams: $\frac{f_s(2)c}{f_s(2)-f_s(1)} > \frac{f_d(2)c}{f_d(2)-f_d(1)}$. By assumption, the more expensive Nash incentive term can limit the efficiency of team incentives for specialized teams for small discount factors even if specialized teams have a greater normalized punishment: $x_s > 2 > x_d$. For large discount factors, however, the impact of x_s can dominate the Nash incentive term, which potentially makes the total expected wage for specialized teams lower than for diverse teams.

To summarize our discussion on mutual monitoring, as δ increases, the implicit incentives the agents can provide to each other depend on the team composition, which in turn affects the total expected wage. While the principal enjoys the reduction in the total expected wage because of mutual monitoring, the magnitude of a reduction depends on whether the agents are assigned to specialized or diverse teams. The following lemma focuses on whether the expected cost of providing incentives (i.e., per-period expected compensation) under specialized assignment eventually (for a large δ) becomes smaller than under diverse assignment—whether or not there is a crossing threshold. The crossing threshold is a way to capture the impact of the expected relationship duration on an optimal team composition.

Lemma 2. (Mutual Monitoring: Crossing) *Let* $\pi \equiv \frac{f_s(2)}{f_s(2)-f_s(1)} / \frac{f_d(2)}{f_d(2)-f_d(1)} > 1$ *and* $\pi_c \equiv \frac{(x_s-1)^2}{1+x_d(x_s-2)} > 1$. *If* $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$, *then* $E[w_s^*] - E[w_d^*] > 0$ *for all* $\delta \in [0,1]$. *If* $\frac{f_s(0)}{f_s(2)} < \frac{f_d(0)}{f_d(2)}$ *and*

(i) $\pi < \pi_c$, *then there exists* $\delta(\pi, x_d) \in (0, \delta^m)$ *such that* $E[w_s^*] - E[w_d^*] < 0$ *for all* $\delta > \delta(\pi, x_d)$.

(ii) $\pi \geq \pi_c$, *then there exists* $\delta(\pi, x_s, x_d) \in (\delta^m, 1)$ *such that* $E[w_s^*] - E[w_d^*] < 0$ *for all* $\delta \in (\delta(\pi, x_s, x_d), 1]$,

where $\delta(\pi, x_s, x_d) = \frac{\pi-1}{x_s-1-\pi(x_d-1)}$ *and the expression for* $\delta(\pi, x_d)$ *is presented in Appendix A.*

When $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$, the expected wage is lower under diverse assignment for both large and small δ, so there is no room for a crossing threshold. When the inequality is reversed, the expected wage is eventually (for large enough δ) lower under specialized assignment. Lemma 2's conditions (i) and (ii) determine where that crossing threshold is (as a function of δ). π is the ratio of the expected wages for specialized and diverse teams under static incentives ($\delta = 0$). $\pi < \pi_c$ ensures that the mutual-monitoring wage based on a stage-game equilibrium punishment of *(work, shirk)* or *(shirk, work)* under specialized teams is small enough that the crossing threshold occurs before δ reaches δ^m—the point at which the punishment equilibrium is instead *(shirk, shirk)* under specialized assignment. For $\pi \geq \pi_c$, the crossing threshold occurs for $\delta > \delta^m$. If $\delta \geq \delta^m$, the incentive to maintain (*work*, *work*) is stronger for specialized teams than for diverse teams because $x_s > x_d$.

When $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$, although there is no crossing threshold, the gap between the expected wage under specialized and diverse assignments is monotonically decreasing in δ, which is stated formally in the following proposition.

Proposition 1. (Mutual Monitoring: Monotonicity) *Suppose that* $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$. *Then* $E[w_s^*] > E[w_d^*]$, *and* $E[w_s^*] - E[w_d^*]$ *is monotone decreasing in* δ.

For $\delta \geq \delta^m$, a specialized team's incentive to sustain working as an equilibrium is stronger than the diverse team's as δ increases: the reduction in total expected wages is greater for specialized teams than for diverse teams, thereby reducing the wage gap as δ increases.

Collusion The previous section highlights the advantage of mutual monitoring. However, mutual monitoring between the agents within a team may also create opportunities for unwanted tacit collusion (implicit incentive that is harmful to the principal). In particular, the productive substitutability under specialized teams can generate a collusion problem that does not arise under diverse assignment. Given the nature of infinitely repeated interactions, there can be infinitely many ways the agents can collude by deviating from *(work, work)*. However, under productive substitutes, the most demanding collusion—from the principal's standpoint—among all possible collusions is the one in which the same type agents alternate their effort choices between *(work, shirk)* and *(shirk, work)*.[21] To prevent this, the principal must ensure that the following constraint is satisfied:

$$f_s(2)w_s - c \geq \frac{f_s(1)w_s - c}{1+\delta} + \delta \frac{f_s(1)w_s}{1+\delta}. \qquad \text{(No-cycling)}$$

The left hand side represents the present value of the expected payoff from working, whereas the right hand side captures the present value of the expected payoff from taking turns—viewed from the perspective of the agent who is supposed to work in the first period. To collude, the agents have to find the proposed collusion Pareto optimal relative to *(work, work)* and self-enforcing. The agent who will work in the first period receives the lowest payoff from the proposed collusion. So, as long as that agent would receive a higher payoff from *(work, work)*, he will not agree to the collusion. For the collusion to be self-enforcing, the shirking agent must be willing to shirk rather than deviate to work and face the stage-game equilibrium punishment of *(shirk, shirk)* in all future periods. It turns out that using the self-enforcing condition destroys mutual monitoring incentive too. Thus, the Pareto optimality condition is unique and sufficient to deter collusion. We prove this argument formally in Lemma 3. The (No-cycling) constraint yields $w_s \geq \frac{\delta\, c}{(1+\delta)\left(f_s(2)-f_s(1)\right)}$.

[21] See Baldenius, Glover, and Xue (2016, Lemma 1).

In contrast, under a productive complementarity (diverse teams), collusion is not an issue. The mutual monitoring constraints are sufficient to deter all possible collusive strategies.

Lemma 3. *Under specialized teams, the minimum collusion-proof wage is:*

$$w_s^{**} = \frac{c}{f_s(2) - f_s(1)} \times max\left\{(1-\delta), \frac{1}{1+\delta(x_s - 1)}, \frac{\delta}{1+\delta}\right\}.$$

Under diverse teams, the mutual-monitoring wage is collusion-proof: $w_d^{**} = w_d^*$.

The (No-cycling) constraint dominates the (M-IC) constraint if $\delta > \delta^C$, where $\delta^C \equiv \sqrt{\frac{f_s(2)-f_s(1)}{f_s(1)-f_s(0)}}$ is less than 1 due to substitutability. When the (No-cycling) constraint binds, the productive advantage of specialization in production decreases.

The presence of collusion under specialized teams changes the crossing results in Lemma 2. Due to the collusion-proof wage, there may be a second crossing threshold or no crossing threshold at all depending on whether the collusion constraints bind at the crossing threshold δ (characterized in Lemma 2). The following lemma characterizes the new result on the crossing threshold(s) when collusion is of concern under specialized teams. Here, crossing captures the impact of both mutual monitoring and collusion which gives rise to the possibility of a non-monotonic effect of the time horizon (captured by δ).

Lemma 4. (Mutual Monitoring and Collusion: Crossing) *If* $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$, $E[w_s^{**}] - E[w_d^*] > 0$ *for all* δ. *If* $\frac{f_s(0)}{f_s(2)} < \frac{f_d(0)}{f_d(2)}$, *a collusion problem may generate another crossing threshold or eliminate the existing threshold.*

i) (Single crossing) If $\pi \leq 2/x_d$, *then there is a single crossing threshold:*

a. $\delta(\pi, x_d)$ *for* $\pi < \pi_c$ *and* $\delta(\pi, x_d)$ *is always less than* δ^C,

b. $\delta(\pi, x_s, x_d)$ *for* $\pi \geq \pi_c$ *provided that* $\delta(\pi, x_s, x_d) < \delta^C$.

ii) (Double crossing) If $\pi > 2/x_d$, *then there are two crossing thresholds:*

a. $\delta(\pi, x_d)$ *and* $\delta_{DC1} \in (\delta^C, 1)$ *for* $\pi < \pi_c$,

b. $\delta(\pi, x_s, x_d)$ *and* $\delta_{DC2} \in (\delta^C, 1)$ *for* $\pi \geq \pi_c$ *provided that* $\delta(\pi, x_s, x_d) < \delta^C$.

iii) (Lost crossing) If $\delta(\pi, x_s, x_d) > \delta^C$, then there is no crossing threshold.

The conditions that characterize double crossing thresholds, δ_{DC1} and δ_{DC2}, are presented in Appendix A.

Intuitively, the binding collusion constraints reduce the efficiency of specialized teams as the collusion-proof wage increases in δ. The incentive to maintain (*work*, *work*) is stronger for specialized teams than for diverse teams (because $x_s > x_d$) if collusion constraints do not bind. If the collusion constraints do not bind at the crossing threshold, then the original crossing threshold (as presented in Lemma 2) is maintained, and $E[w_s^{**}] - E[w_d^*] < 0$ for δ greater than that threshold. However, the increase in compensation required by the collusion constraints may introduce another crossing threshold above which $E[w_s^{**}] - E[w_d^*] > 0$ depending on parameter values. This arises when π is sufficiently high. If the collusion constraints bind at the original crossing threshold, then the original crossing threshold no longer exists, and $E[w_s^{**}] - E[w_d^*] > 0$ for all δ.

Figure 1 depicts the double crossing example. In this example, high x_s makes the specialized team's expected (mutual monitoring) wage less expensive than the diverse team's for sufficiently high δ. However, once collusion becomes a pressing concern, the collusion-proof wage eventually makes the specialized team's wage exceed the diverse team's wage. Thus, the binding collusion constraint creates another crossing threshold. Clearly, our double crossing result depends on parameter values. We provide two more numerical examples (a maintained single crossing threshold and lost crossing threshold) to illustrate Lemma 4 in Appendix B.

The principal faces a trade-off between a superior productive efficiency and an increased incentive cost from collusive behavior under specialized assignment. Recall from Proposition 1 that the total expected wage difference between specialized teams and diverse teams under mutual monitoring is monotone decreasing in δ in the absence of collusion. However, once the collusion constraint binds, i.e., $\delta > \delta^C$, then the team incentive gap increases in δ.

Although the monotonicity of $E[w_s^{**}] - E[w_d^*] > 0$ with respect to δ makes specialized teams inferior, it is not enough to determine the optimal composition because the principal's payoff also depends on the probability of success, which is a function of agents' types. Let V_s, V_d denote the principal's total expected per-period payoff under the specialized and diverse team assignments, respectively:

$$V_s = 2f_s(2)S - 4E[w_s^{**}] \text{ and}$$
$$V_d = 2f_d(2)S - 4E[w_d^*].$$

The principal prefers the diverse (specialized) assignment if $V_d > (<)\ V_s$.

$$V_d > V_s \Leftrightarrow \Delta S < 2(E[w_s^{**}] - E[w_d^*]), \tag{2}$$

where $\Delta = \left(f_s(2) - f_d(2)\right)$.

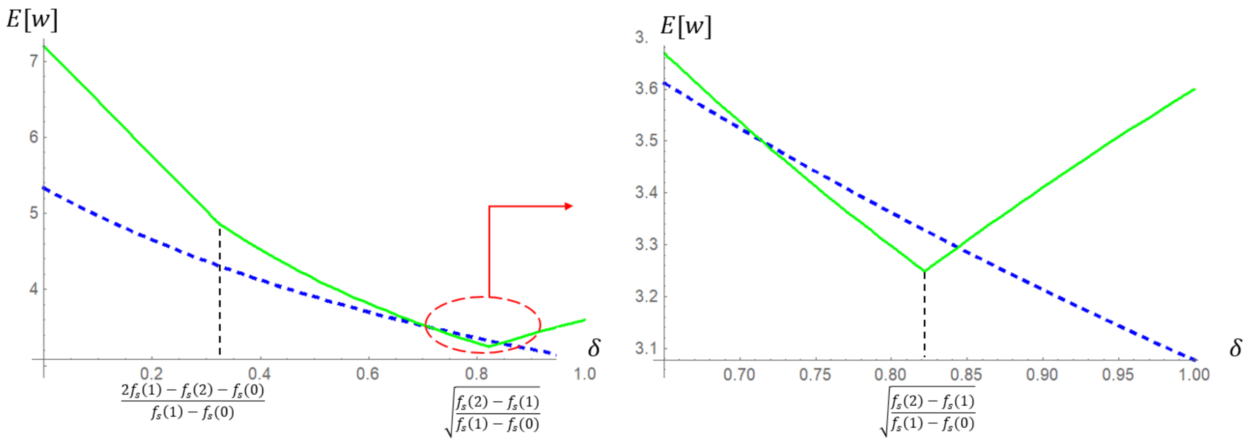

Figure 1 Optimal contracts and Double Crossing

Figure 1 depicts optimal contracts. The solid line is the expected wage under a specialized team, whereas the dashed line is the expected wage under a diverse team for the following parameter values: $c = 1$, $f_s(0) = 0.28, f_s(1) = 0.65, f_s(2) = 0.9, f_d(0) = 0.28, f_d(1) = 0.5,$ and $f_d(2) = 0.8$. Thus, $x_s = 2.48, x_d = 1.73, \pi = 1.35 > \pi_c = 1.195, \delta(\pi, x_s, x_d) = 0.714 < \delta^C = 0.821$, and $\pi = 1.35 > 2/x_d = 1.15$.

Due to productive efficiency ($\Delta > 0$), the left hand side of (2) is always greater than 0. The right hand side depends on $\delta \in (0,1)$: as δ increases, the right hand side also increases if the collusion constraint binds. Denote by $S^*(\delta)$ the value of S that equalizes the inequality (2):

$$S^*(\delta) = \frac{2}{\Delta}(E[w_s^{**}] - E[w_d^*]).$$

Then, for a given δ, diverse team assignment is optimal for all $S < S^*(\delta)$. Due to different implicit incentives, $E[w_s^{**}] - E[w_d^*]$ may not be monotonic across $\delta \in [0,1]$. However, the binding collusion constraint always makes $S^*(\delta)$ increase in δ. Proposition 2 summarizes the discussion.

Proposition 2. *Suppose the conditions ensuring that* $E[w_s^{**}] - E[w_d^*] > 0$ *(characterized in Lemma 4) are satisfied.*

i) *If $\delta \leq \delta^C$, then $E[w_s^{**}] - E[w_d^*]$ is monotone decreasing in δ.*

ii) *If $\delta > \delta^C$, then $E[w_s^{**}] - E[w_d^*]$ is monotone increasing in δ.*

Diverse teams are optimal for $\forall\, S < S^*(\delta)$. Specialized teams are optimal otherwise. As $\delta > \delta^C$ increases, the threshold $S^*(\delta)$ increases: $\left.\frac{\partial S^*(\delta)}{\partial \delta}\right|_{\delta > \delta^C} > 0$.

If δ is sufficiently high ($\delta > \delta^C$), then a turn-taking collusion problem arises under specialized teams. As the collusion-proof wage increases in δ, and the mutual-monitoring wage decreases in δ, the difference in total wages between the specialized teams and the diverse teams always increases in δ.

Recall that the incentive scheme (under either assignment) is designed to motivate the agents to play *(work, work)* as equilibrium play in their overall game in order to avoid the punishment of playing the stage-game equilibrium, which is *(shirk, shirk)* under both assignments (when the discount factor is not too low). The magnitude of x_k determines the agents' desire to maintain such a good equilibrium. Under diverse assignment, the qualitative nature of this incentive problem is the same for any δ. In contrast, under specialized assignment, another incentive problem arises once δ reaches a critical threshold, i.e., the collusion constraint binds. In this case, the magnitude of the normalized punishment, x_s, does not matter.

To summarize, the collusion problem does not arise under diverse assignment or for small δ under specialized assignment. The mutual-monitoring wage is decreasing in the discount factor, while the collusion-proof wage is increasing in the discount factor. As a result, under specialized teams, incentive efficiency is first increasing and then decreasing in the discount factor. In contrast, under diverse teams, incentive efficiency is always increasing in the discount factor.

4. Extensions and Discussions

In this section, we discuss the robustness of our results to (and, in some cases, extend them to incorporate): heterogeneous contributions, more frequent actions, continuous effort, imperfect monitoring, and relationship termination.[22]

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[22] We thank an anonymous reviewer for suggesting most of these extensions.

Heterogeneous contributions So far, we have viewed diversity as creating a productive complementarity. What if the agents are also heterogeneous in their contributions to production? We relax our assumption of symmetric contributions but maintain the assumption of productive complementarity. Without loss of generality, assume that agent A is more productive than agent B, i.e., given $f_d(e_A, e_B)$,

$$f_d(1{,}0) > f_d(0{,}1).$$

Due to complementarity, the agents sustain the working equilibrium using the stage game equilibrium *(shirk, shirk)*. Thus, the mutual-monitoring wage for each agent is:

$$w_d^A = \frac{c}{(1-\delta)\big(f_d(2) - f_d(0{,}1)\big) + \delta\big(f_d(2) - f_d(0)\big)},$$

$$w_d^B = \frac{c}{(1-\delta)\big(f_d(2) - f_d(1{,}0)\big) + \delta\big(f_d(2) - f_d(0)\big)}.$$

Because $f_d(1{,}0) > f_d(0{,}1)$, agent B's mutual-monitoring wage is greater than agent A's. To see our optimal composition results (including crossing) continue to hold, observe that:

$$w_d^A + w_d^B = \frac{2c}{(1-\delta)\big(f_d(2) - f^*(1)\big) + \delta\big(f_d(2) - f_d(0)\big)}$$

where $f^*(1) =$
$\frac{f_d(1{,}0)\Big((1-\delta)\big(f_d(2)-f_d(0{,}1)\big)+\delta\big(f_d(2)-f_d(0)\big)\Big)+f_d(0{,}1)\Big((1-\delta)\big(f_d(2)-f_d(1{,}0)\big)+\delta\big(f_d(2)-f_d(0)\big)\Big)}{(1-\delta)\big(2f_d(2)-f_d(1{,}0)-f_d(0{,}1)\big)+2\delta\big(f_d(2)-f_d(0)\big)}$, which is a weighted average of $f_d(1{,}0)$ and $f_d(0{,}1)$.[23] Then, we can define π using $f^*(1)$ instead of $f(1)$. The rest of the results remain qualitatively unaffected by this change.

More frequent actions Abreu, Milgrom, and Pearce (1991) and Sannikov and Skrzypacz (2007) are two important related papers. In a repeated game with imperfect monitoring where information arrives continuously over time, these two papers show that collusion may not be sustainable (cannot be sustained in Sannikov and Skrzypacz, 2007) in equilibrium as the frequency of actions increases. The intuition is that, as the frequency of actions increases, the accumulated information between actions—which helps agents monitor their teammates—becomes less informative about possible defections, thereby reducing agents' ability to punish a defector. Abreu, Milgrom, and Pearce (1991) also study perfect monitoring and show that increasing the frequency of actions has essentially the same effect as increasing the discount

[23] More precisely, it is the convex combination of $f_d(1{,}0)$ and $f_d(0{,}1)$.

factor, which seems to be the intuition that applies to our model. Without dampening the agents' ability to punish a defector, agents can sustain collusion more easily as the frequency of actions increases. If the cycling collusion has agent A working while agent B is shirking, agent A's temptation to free-ride would be smaller under more frequent (and less costly) actions, making collusion easier to sustain. If this is the case, then our results on optimal team composition would remain qualitatively (although not quantitatively) unchanged as the frequency of actions increases. From a quantitative perspective, the impact of more frequent interactions (an increase in the effective discount factor) seems to favor diverse teams if the collusion constraint binds.

Continuous effort Our results can also be extended to a continuous effort setting. To see this, consider the following stylized example. Suppose the production technology is characterized as $f_s(e_i, e_j) = \frac{2}{5}(e_i + e_j)^{1/2}$ for specialized teams and $f_d(e_i, e_j) = \frac{1}{6}(e_i \times e_j)$ for diverse teams, where $e_i, e_j \in [1,2]$ denote agent i's and j's effort, and $f_k(e_i, e_j) \in (0,1)$. Suppose that the cost of effort is a standard convex increasing function of effort, $e^2/2$, and the agents' productivity is sufficiently high that the principal wants to elicit the maximum effort 2. In this example, the agents' efforts are strategic substitutes under specialized teams and complements under diverse teams.

As we show in Appendix D, under specialized teams, the stage game equilibrium depends on δ: (e, e), where $e = \left(\frac{w_s^*}{5\sqrt{2}}\right)^{2/3}$ if $\delta < 0.825$ or $(1,1)$ if $\delta \geq 0.825$.[24] When the stage game equilibrium is $(1,1)$, the mutual-monitoring wage is $w_s^* = \frac{15}{4}\frac{1}{2-\sqrt{3}+(\sqrt{3}-\sqrt{2})\delta}$. When the stage game equilibrium $(e, e) \neq (1,1)$, we numerically solve for the mutual-monitoring wage.

For diverse teams, the mutual-monitoring wage is $w_d^* = 3\,\frac{4-\delta-\sqrt{3\delta(4-\delta)}}{2(1-\delta)}$, and the stage game equilibrium is $(1,1)$ for all $\delta > 0$. In both specialized and diverse teams, the agents sustain the effort pair $(2,2)$ using their stage game equilibrium as a punishment. Such a mutual-monitoring wage decreases with the agents' discount factor.

For tractability, we confine attention to symmetric collusion, i.e., the collusion that has the agents playing identical strategies. For a high discount factor ($\delta > 0.5$), agents in specialized teams can increase their aggregate stage game payoffs by playing $\left(0.43 \times w_s^{*2/3}, 0.43 \times w_s^{*2/3}\right)$.

[24] Given the symmetric wage contract, the stage game equilibrium is always symmetric. (Proof available upon request.)

For instance, if $\delta = 0.75$, then $w_s^* = 7.59$, and the stage game equilibrium is $(1.05,1.05)$. The agents are strictly better off playing $(1.66,1.66)$ instead of $(2,2)$:

$$\frac{2}{5}(2+2)^{\frac{1}{2}}w_s^* - \frac{1}{2}2^2 = 4.07 < \frac{2}{5} \times (1.66+1.66)^{\frac{1}{2}}w_s^* \ - \frac{1}{2}(1.66)^2 = 4.15.$$

Playing $(1.66,1.66)$ is also self-enforcing, i.e., there is a tacit collusion problem under specialized assignment. To prevent collusion, the principal must pay the collusion-proof wage of $w_s^{**} = 10$. That is, the qualitative nature of implicit incentives we develop can be extended to a continuous effort setting. For specialized teams, the punishment the agents employ depends on their discount factor, and collusion is a pressing concern for a high discount factor. For diverse teams, the punishment is unique, and the collusion problem does not arise.

Imperfect monitoring In our main analysis, we assumed that agents perfectly observe each other's effort. If the agents' monitoring were instead imperfect, then an agent's obedient (or disobedient) behavior would not be perfectly known by his teammate. As a result, we would observe punishments on the equilibrium path. In the context of cartels with imperfect monitoring, Porter (1983) finds the optimal length of a punishment phase and a collusion phase that maximize the firms' payoffs.[25,26] We conjecture that imperfect monitoring would lead to a larger mutual-monitoring wage than the mutual-monitoring wage we derived under perfect monitoring but would lead to a lower collusion-proof wage than the collusion-proof wage we derived under perfect monitoring. That is, when the collusion problem is binding (not binding), imperfect monitoring would reduce (increase) the cost of providing incentives. If this conjecture is correct, then, when the collusion constraint binds, specialized teams would become more attractive relative to diverse teams under imperfect monitoring than under perfect monitoring.

Relationship termination and job rotation With costless agent replacement, the principal could use random termination of the relationship, which effectively reduces the agents' discount factor, as a means of preventing collusion under specialized assignment. If the discount factor is small (thus, mutual monitoring is the only implicit incentive), then there is no role for random

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[25] See also Green and Porter (1984) and Abreu, Pearce, and Stacchetti (1986, 1990).

[26] These papers (and ours) take the monitoring technology as given. In contrast, Fong and Li (2017) view the monitoring technology as a design choice and show that imperfect monitoring can be optimal in a repeated subjective performance review setting. They introduce a supervisor who reports the realized performance of the agent and show that the supervisor's history-dependent biased reporting—good underlying (true) performance today increases the chance of a good review in the future—both improves the agent's incentives and lowers the principal's reneging temptation (by reducing the size of the required bonus).

termination—the longer the repeated play, the better. If the discount factor is high enough that collusion is a pressing concern, then a random termination would arise as part of an optimal contract under specialized assignment but not under diverse assignment.

Random termination can be interpreted as a job rotation program. Job rotation is viewed as beneficial because it eliminates employee boredom, encourages employees to acquire various skills, or helps employers learn employee talent (Campion, Cheraskin, and Stevens, 1994; Arya and Mittendorf, 2006). In our paper, there is another benefit from job rotation programs, namely, combatting collusion under specialized assignment. For diverse teams, there is no demand for job rotation because collusion never arises.

In fact, for diverse teams, the principal would like to find a way to effectively increase the agents' discount factors. For a team of top executives in the C-suite, one approach might be to give them (additional) equity incentives, so that any impact their actions have on the culture in the C-suite (e.g., triggering a punishment equilibrium) beyond their tenure is reflected in their payoffs.

Non-random termination (e.g., firing agents after a bad track record) may reduce the cost of providing incentives if the fired agents do not have an alternative employment opportunity that would provide them with equivalent rents. The reason that we say 'may' is that such history-dependent termination would also complicate the provision of incentives for cooperation/mutual monitoring.

5. Conclusion

In this paper, we studied a team assignment problem in which repeated interactions create opportunities for team members to mutually monitor each other's actions. We show that implicit incentives that team members provide to each other favor team diversity. When the expected time horizon is short, the punishment the agents can impose on each other under specialized teams is less powerful (and qualitatively different) than the punishment the agents can impose on each other under diverse teams. Once the expected time horizon reaches a certain threshold, both compositions enable the same punishment, and specialized and diverse team assignments can be seen as on the same footing when it comes to mutual monitoring. However, once the expected horizon reaches another threshold, specialized teams are vulnerable to an unwanted collusion problem that does not arise under diverse team assignment. The advantage of diverse teams over specialized ones in providing incentives for mutual monitoring and preventing collusion is present only when team tenure is sufficiently long.

A natural extension of our research is to consider the joint problems of team assignment and performance measurement.[27] To make the performance measurement problem richer, one could introduce a larger set of possible performance measures, including joint and individual performance measures. Recent research on relational contracts has started to address related problems. For example, Baldenius, Glover, and Xue (2016) show that the optimal use of verifiable team measures and non-verifiable individual measures in dynamic bonus pools is to use the individual measures to create an overall strategic independence in the agents' payoffs, because strategic independence is a desirable property of collusion-proof incentives. However, their individual measures are the principal's perfect observations of the agents' actions, and there is no role for beneficial (to the principal) mutual monitoring.[28] Also, they do not consider the team assignment problem.

In general, the role of mutual monitoring and the team incentive schemes designed to induce that mutual monitoring seem to be understudied aspects of incentives in organizations, both theoretically and empirically. The early papers of Itoh (1993), Arya, Fellingham, and Glover (1997), and Che and Yoo (2001) study models of exogenous teams, identical agents, blocked communication, infinitely repeated play by the same agents, and exogenous (and limited) performance measures. Recent empirical evidence suggests a broader role for team incentives than previous studies have recognized, for example, in the C-suite (Guay, Kepler, and Tsui, 2019; Li, 2018). Developing a more nuanced theoretical understanding of the role of mutual monitoring in organizations that incorporates additional design choices (e.g., performance evaluation system design), heterogeneity in agent characteristics (e.g., to capture the differing roles of CEOs and CFOs), and/or overlapping generations (e.g., younger generations that monitor older ones) seem important next steps.

[27] The accounting literature has a long history of studying the broad problem of interactions between organizational design and performance measurement design, although not in models of repeated interactions that foster implicit incentives (cooperation/collusion) that agents provide to each other.

[28] These assumptions are relaxed in Glover and Xue (2020), but at the cost of additional structure. In particular, their verifiable joint performance measure is a garbling of the non-verifiable individual measures.

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Appendix A.

For notational convenience, we use $\frac{f_k(2)c}{(1-\delta)\left(f_k(2)-f_k(1)\right)+\delta\left(f_k(2)-f_k(0)\right)}$ and $\frac{f_k(2)c}{f_k(2)-f_k(1)}\frac{1}{1+\delta(x_k-1)}$ interchangeably to denote the mutual-monitoring wage.

The Programs for Optimal Incentives

1) Specialized teams

$$\max_{w_s} 2f_s(2)(S-2w_s)$$

Subject to

$$f_s(2)w_s - c \geq 0 \qquad \text{(IR)}$$

$$f_s(2)w_s - c \geq (1-\delta)f_s(1)w_s + \delta f_s(0)w_s \text{ for } \delta \geq \delta^m, \qquad \text{(M-IC)}$$

$$f_s(2)w_s - c \geq (1-\delta)f_s(1)w_s + \delta(f_s(1)w_s - c) \text{ for } \delta < \delta^m$$

$$f_s(2)w_s - c \geq \frac{f_s(1)w_s - c}{1+\delta} + \delta\frac{f_s(1)w_s}{1+\delta} \qquad \text{(No-cycling)}$$

2) Diverse teams

$$\max_{w_d} 2f_d(2)(S-2w_d)$$

Subject to

$$f_d(2)w_d - c \geq 0 \qquad \text{(IR)}$$

$$f_d(2)w_d - c \geq (1-\delta)f_d(1)w_d + \delta f_d(0)w_d \qquad \text{(M-IC)}$$

Proof of Lemma 1.

To see *(shirk, shirk)* is self-enforcing in diverse teams, observe that the (M-IC) is binding at the wage scheme w_d^*,

$$f_d(2)w_d^* - c = (1-\delta)f_d(1)w_d^* + \delta f_d(0)w_d^* \Leftrightarrow f_d(2)w_d^* - c < f_d(1)w_d^*.$$

This is because $f_d(1) > f_d(0)$. If $f_d(2)w_d^* - c < f_d(0)w_d^*$, then the equality of the (M-IC) is never satisfied, thus $f_d(2)w_d^* - c > f_d(0)w_d^*$. Notice that due to productive complementarity,

$$f_d(2) + f_d(0) - \left(f_d(1) + f_d(1)\right) \geq 0.$$

Therefore,

$$\left(f_d(2) + f_d(0)\right)w_d^* - c \geq 2f_d(1)w_d^* - c \Rightarrow f_d(0)w_d^* > f_d(1)w_d^* - c.$$

Thus, *(shirk, shirk)* is self-enforcing in diverse teams.

Now, consider specialized teams. As discussed in the main text, the punishment is *(work, shirk)* or *(shirk, shirk)* depending on the parameters which we now characterize. In the case of *(work, shirk)*, the deviating agent plays *work* while the non-deviating agent plays *shirk* after the deviation conditional on that it is self-enforcing. Then, the (M-IC) is:

$$f_s(2)w_s - c \geq (1-\delta)f_s(1)w_s + \delta(f_s(1)w_s - c).$$

The minimum wage satisfying the above constraint is $w_s^* = \frac{(1-\delta)c}{f_s(2)-f_s(1)}$. To show that this is self-enforcing, plug w_s^* into:

1) $f_s(1)w_s^* - c \geq f_s(0)w_s^* \Leftrightarrow (1-\delta)\frac{f_s(1)-f_s(0)}{f_s(2)-f_s(1)} \geq 1 \Leftrightarrow \delta \leq \frac{2f_s(1)-f_s(2)-f_s(0)}{f_s(1)-f_s(0)} \equiv \delta^m$

2) $f_s(1)w_s^* \geq f_s(2)w_s^* - c \Leftrightarrow 1 \geq (1-\delta)\frac{f_s(2)-f_s(1)}{f_s(2)-f_s(1)}$, which is always true.

Thus, for $\delta \leq \delta^m$, *(work, shirk)* is self-enforcing. Similarly, for *(shirk, shirk)*, the (M-IC) is:

$$f_s(2)w_s - c \geq (1-\delta)f_s(1)w_s + \delta f_s(0)w_s$$

The minimum wage satisfying this is $w_s^* = \frac{c}{(1-\delta)(f_s(2)-f_s(1))+\delta(f_s(2)-f_s(0))}$. This is self-enforcing if:

$f_s(0)w_s^* \geq f_s(1)w_s^* - c \Leftrightarrow 1 \geq \frac{f_s(1)-f_s(0)}{(1-\delta)(f_s(2)-f_s(1))+\delta(f_s(2)-f_s(0))} = \frac{f_s(1)-f_s(0)}{f_s(2)-f_s(1)+\delta(f_s(1)-f_s(0))}$

$\Leftrightarrow 1 \geq \frac{1}{\frac{f_s(2)-f_s(1)}{f_s(1)-f_s(0)}+\delta} \Leftrightarrow \delta \geq \delta^m$.

Therefore, for $\delta \geq \delta^m$, *(shirk, shirk)* is self-enforcing.

Q.E.D.

Proof of Lemma 2.

If $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$, then regardless of the form of mutual-monitoring wage in specialized teams, $(E[w_s^*] - E[w_s^*])|_\delta > 0$. To see this, if the mutual-monitoring wage is based on *(shirk, shirk)* in both compositions, then $\frac{f_s(2)}{(1-\delta)(f_s(2)-f_s(1))+\delta(f_s(2)-f_s(0))} > \frac{f_d(2)}{(1-\delta)(f_d(2)-f_d(1))+\delta(f_d(2)-f_d(0))}$ because $\frac{f_s(1)}{f_s(2)} > \frac{f_d(1)}{f_d(2)}$ (Assumption A3). If the mutual-monitoring wage is based on *(work, shirk)* in specialized teams (i.e., for $\delta < \delta^m$), then we have $\frac{(1-\delta)f_s(2)}{f_s(2)-f_s(1)} > \frac{f_s(2)}{f_s(2)-f_s(1)}\frac{1}{1+\delta(x_s-1)}$, thus guaranteeing $\frac{(1-\delta)f_s(2)}{f_s(2)-f_s(1)} > \frac{f_d(2)}{(1-\delta)(f_d(2)-f_d(1))+\delta(f_d(2)-f_d(0))}$. Thus, regardless of δ, crossing never happens if $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$.

We derive conditions under which crossing happens when mutual monitoring is in place given that $\frac{f_s(0)}{f_s(2)} < \frac{f_d(0)}{f_d(2)}$. Then, we check the feasibility of the conditions.

(i) First, consider $\delta < \delta^m$ so that the mutual-monitoring wage is based on *(work, shirk)* in specialized teams and *(shirk, shirk)* in diverse teams. For $E[w_s^*] - E[w_d^*] < 0$:

$$E[w_s^*] - E[w_d^*] < 0 \Leftrightarrow \frac{(1-\delta)f_s(2)}{f_s(2) - f_s(1)} < \frac{f_d(2)}{f_d(2) - f_d(1)} \frac{1}{1 + \delta(x_d - 1)}$$

$$\Leftrightarrow \pi(x_d - 1)\delta^2 + \pi(2 - x_d)\delta - (\pi - 1) > 0, \text{where } \pi = \frac{f_s(2)}{f_s(2) - f_s(1)} \Big/ \frac{f_d(2)}{f_d(2) - f_d(1)}.$$

Solving for $\delta \in [0,1]$ yields:

$$\delta = \frac{\sqrt{(2 - x_d)^2 + 4\left(1 - \frac{1}{\pi}\right)(x_d - 1)} - (2 - x_d)}{2(x_d - 1)} \equiv \delta(\pi, x_d).$$

Thus, if δ is greater than $\delta(\pi, x_d)$, $E[w_s^*] - E[w_d^*] < 0$. For this to be feasible, the solution must be less than δ^m:

$$\delta(\pi, x_d) < \delta^m$$

$$\Leftrightarrow (2 - x_d)^2 + 4\left(1 - \frac{1}{\pi}\right)(x_d - 1) < 4(x_d - 1)^2 \delta^{m2} + (2 - x_d)^2 + 4(2 - x_d)(x_d - 1)\delta^m$$

$$\Leftrightarrow \pi < \frac{1}{(1 - \delta^m)^2 + x_d \delta^m (1 - \delta^m)} \equiv \pi_c.$$

As $\pi > 1$ (Assumption A3), for this to be feasible, $\pi_c > 1$ is required. This is true because:

$$(1 - \delta^m)^2 + x_d \delta^m (1 - \delta^m) < 1 \Leftrightarrow x_d < \frac{1 - (1 - \delta^m)^2}{\delta^m (1 - \delta^m)} = \frac{2 - \delta^m}{1 - \delta^m} = x_s.$$

The last step is by plugging $\delta^m = \frac{2f_s(1) - f_s(2) - f_s(0)}{f_s(1) - f_s(0)}$. Thus, $\pi < \pi_c$ is well-defined.

Using $\frac{2 - \delta^m}{1 - \delta^m} = x_s$, observe that δ^m can be written as $\delta^m = \frac{x_s - 2}{x_s - 1}$. Then, π_c can be written as:

$$\pi_c = \frac{1}{(1 - \delta^m)^2 + x_d \delta^m (1 - \delta^m)} = \frac{(x_s - 1)^2}{1 + x_d(x_s - 2)},$$

which increases in x_s, but decreases in x_d. Therefore, if $\pi < \pi_c$, then there exists $\delta(\pi, x_d) < \delta^m$ such that $E[w_s^*] - E[w_d^*] < 0$ for $\delta \in (\delta(\pi, x_d), \delta^m)$.

(ii) Now, consider $\delta \geq \delta^m$ so that the mutual-monitoring wage is based on *(shirk, shirk)* in both compositions. If collusion is not considered, then $(E[w_s^*] - E[w_d^*])|_{\delta=1} < 0$ because:

$$\frac{f_s(2)c}{f_s(2)-f_s(0)} < \frac{f_d(2)c}{f_d(2)-f_d(0)} \Leftrightarrow \frac{1}{1-f_s(0)/f_s(2)} < \frac{1}{1-f_d(0)/f_d(2)} \Leftrightarrow \frac{f_s(0)}{f_s(2)} < \frac{f_d(0)}{f_d(2)}.$$

Due to continuity, for a given δ, there exists $\delta \in [\delta^m, 1)$ that equalizes the two expected payments:

$$(E[w_s^*] - E[w_d^*])|_\delta = 0 \Leftrightarrow \frac{f_s(2)}{f_s(2)-f_s(1)} \frac{1}{1+\delta(x_s-1)} = \frac{f_d(2)}{f_d(2)-f_d(1)} \frac{1}{1+\delta(x_d-1)}$$

$$\Leftrightarrow \delta = \frac{\pi - 1}{x_s - 1 - \pi(x_d - 1)} \equiv \delta(\pi, x_s, x_d)$$

where $\pi = \frac{\frac{f_s(2)}{f_s(2)-f_s(1)}}{\frac{f_d(2)}{f_d(2)-f_d(1)}}$, $x_k = \frac{f_k(2)-f_k(0)}{f_k(2)-f_k(1)}$. To check if $\delta(\pi, x_s, x_d)$ is well-defined, observe that $\delta(\pi, x_s, x_d) < 1$ because:

$$\frac{\pi-1}{x_s-1-\pi(x_d-1)} < 1 \Leftrightarrow x_s - \pi x_d > 0 \Leftrightarrow \frac{f_s(2)-f_s(0)}{f_s(2)-f_s(1)} - \frac{\frac{f_s(2)}{f_s(2)-f_s(1)}}{\frac{f_d(2)}{f_d(2)-f_d(1)}} \frac{f_d(2)-f_d(0)}{f_d(2)-f_d(1)} > 0$$

$$\Leftrightarrow \frac{f_s(2)-f_s(0)}{f_s(2)} - \frac{f_d(2)-f_d(0)}{f_d(2)} > 0 \Leftrightarrow \frac{f_s(0)}{f_s(2)} < \frac{f_d(0)}{f_d(2)}.$$

Moreover, $\delta(\pi, x_s, x_d) \geq \delta^m$:

$$\frac{\pi - 1}{x_s - 1 - \pi(x_d - 1)} > \delta^m \Leftrightarrow \pi > \frac{1 + \delta^m(x_s - 1)}{1 + \delta^m(x_d - 1)} = \frac{x_s - 1}{1 + \delta^m(x_d - 1)}.$$

The last step uses $\delta^m = \frac{x_s-2}{x_s-1}$. Observe that:

$$\frac{x_s - 1}{1 + \delta^m(x_d - 1)} = \frac{x_s - 1}{1 + \frac{x_s - 2}{x_s - 1}(x_d - 1)} = \frac{(x_s - 1)^2}{1 + x_d(x_s - 2)} = \pi_c.$$

Therefore, $\delta(\pi, x_s, x_d) \geq \delta^m$ is equivalent to $\pi \geq \pi_c$. Provided that $\pi \geq \pi_c$, due to monotonicity, $(E[w_s^*] - E[w_d^*])|_\delta > 0$ for $\delta < \delta(\pi, x_s, x_d)$, and $(E[w_s^*] - E[w_d^*])|_\delta \leq 0$ for $\delta \geq \delta(\pi, x_s, x_d)$.

Q.E.D.

Proof of Proposition 1.

Recall from Lemma 1 that if $\delta < \delta^m = \frac{2f_s(1)-f_s(2)-f_s(0)}{f_s(1)-f_s(0)}$, the mutual-monitoring wage under the specialized assignment is $\frac{(1-\delta)c}{f_s(2)-f_s(1)}$. Notice that both $E[w_s^*]$ and $E[w_d^*]$ are monotone decreasing in δ.

$$\frac{\partial}{\partial\delta}E[w_s^*] = \begin{cases} -\dfrac{f_s(2)c}{f_s(2)-f_s(1)} < 0 \text{ if } \delta < \delta^m \\ -\dfrac{1}{\delta}\dfrac{G_s(\delta)c}{1+\delta(x_s-1)} < 0 \text{ if } \delta \geq \delta^m \end{cases}$$

$$\frac{\partial}{\partial\delta}E[w_d^*] = -\frac{1}{\delta}\frac{G_d(\delta)c}{1+\delta(x_d-1)} < 0$$

where $G_k(\delta) = \frac{f_k(2)}{f_k(2)-f_k(1)}\left(1-\frac{1}{1+\delta(x_k-1)}\right)$, $x_k = \frac{f_k(2)-f_k(0)}{f_k(2)-f_k(1)} > 1$.

To see if $(E[w_s^*]-E[w_d^*])|_\delta$ is monotone increasing or decreasing in δ, recall our assumption in this proposition, $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$, which ensures that $E[w_s^*]-E[w_d^*] > 0$. For specialized teams, the qualitative nature of the mutual-monitoring wage depends on δ. Thus, we need to separately consider $(E[w_s^*]-E[w_d^*])|_\delta$ for $\delta < \delta^m$ and $(E[w_s^*]-E[w_d^*])|_\delta$ for $\delta \geq \delta^m$. Due to the monotonicity of the mutual-monitoring wage in δ, it is sufficient to check $(E[w_s^*]-E[w_d^*])|_{\delta=0} > (E[w_s^*]-E[w_d^*])|_{\delta=\delta^m}$ and $(E[w_s^*]-E[w_d^*])|_{\delta=\delta^m} > (E[w_s^*]-E[w_d^*])|_{\delta=1}$. For simplicity, we divide the pay difference by c throuought the analysis.

Claim 1) $(E[w_s^*]-E[w_d^*])|_{\delta=0} > (E[w_s^*]-E[w_d^*])|_{\delta=\delta^m}$

Proof of Claim 1: Suppose not. Then,

$$(E[w_s^*]-E[w_d^*])|_{\delta=0} < (E[w_s^*]-E[w_d^*])|_{\delta=\delta^m}$$

$$\Leftrightarrow E[w_s^*]|_{\delta=0} - E[w_s^*]|_{\delta=\delta^m} < E[w_d^*]|_{\delta=0} - E[w_d^*]|_{\delta=\delta^m}$$

$$\Leftrightarrow \delta^m \frac{f_s(2)}{f_s(2)-f_s(1)} < \frac{f_d(2)}{f_d(2)-f_d(1)}\frac{\delta^m(x_d-1)}{1+\delta^m(x_d-1)}$$

$\Leftrightarrow \pi < \frac{x_d-1}{1+\delta^m(x_d-1)} < 1$, which is a contradiction because $\pi = \frac{\frac{f_s(2)}{f_s(2)-f_s(1)}}{\frac{f_d(2)}{f_d(2)-f_d(1)}} > 1$. □

Claim 2) $(E[w_s^*]-E[w_d^*])|_{\delta=\delta^m} > (E[w_s^*]-E[w_d^*])|_{\delta=1}$

Proof of Claim 2: At $\delta = \delta^m$, the two forms of mutual-monitoring wage for specialized teams coincide. Thus, we use the mutual-monitoring wage based on *(shirk,shirk)*. Suppose that Claim 2 is not true. Then,

$$(E[w_s^*]-E[w_d^*])|_{\delta=\delta^m} < (E[w_s^*]-E[w_d^*])|_{\delta=1}$$

$$\Leftrightarrow E[w_s^*]|_{\delta=\delta^m} - E[w_s^*]|_{\delta=1} < E[w_d^*]|_{\delta=\delta^m} - E[w_d^*]|_{\delta=1}$$

$$\Leftrightarrow f_s(2)\left(\frac{1}{(1-\delta^m)\big(f_s(2)-f_s(1)\big)+\delta^m\big(f_s(2)-f_s(0)\big)}-\frac{1}{f_s(2)-f_s(0)}\right)$$
$$< f_d(2)\left(\frac{1}{(1-\delta^m)\big(f_d(2)-f_d(1)\big)+\delta^m\big(f_d(2)-f_d(0)\big)}-\frac{1}{f_d(2)-f_d(0)}\right)$$

$$\Leftrightarrow \frac{f_s(2)}{f_s(2)-f_s(0)}\left(\frac{1}{(1-\delta^m)\frac{1}{x_s}+\delta^m}-1\right)<\frac{f_d(2)}{f_d(2)-f_d(0)}\left(\frac{1}{(1-\delta^m)\frac{1}{x_d}+\delta^m}-1\right)$$

$$\Leftrightarrow \frac{f_s(2)}{f_s(2)-f_s(0)}\left(\frac{(1-\delta^m)\left(1-\frac{1}{x_s}\right)}{(1-\delta^m)\frac{1}{x_s}+\delta^m}\right)<\frac{f_d(2)}{f_d(2)-f_d(0)}\left(\frac{(1-\delta^m)\left(1-\frac{1}{x_d}\right)}{(1-\delta^m)\frac{1}{x_d}+\delta^m}\right). \tag{3}$$

As $\frac{f_s(0)}{f_s(2)}>\frac{f_d(0)}{f_d(2)}$, we have $\frac{f_s(2)}{f_s(2)-f_s(0)}>\frac{f_d(2)}{f_d(2)-f_d(0)}$. Moreover, due to $x_s>2>x_d$, we have both $1-\frac{1}{x_s}>1-\frac{1}{x_d}$ and $\left((1-\delta^m)\frac{1}{x_s}+\delta^m\right)^{-1}>\left((1-\delta^m)\frac{1}{x_d}+\delta^m\right)^{-1}$. Thus, the inequality (3) can never be satisfied. □

Therefore, provided that $\frac{f_s(1)}{f_s(2)}>\frac{f_d(1)}{f_d(2)}$ and $\frac{f_s(0)}{f_s(2)}>\frac{f_d(0)}{f_d(2)}$, $(E[w_s^*]-E[w_d^*])|_\delta$ is monotone decreasing in δ.

Q.E.D.

Proof of Lemma 3.

For agents to collude, the collusion must satisfy the two conditions: 1) collusion between agents Pareto dominates *(work, work)* and 2) no agent wants to deviate from collusion in any period. The agents sustain such collusion using the stage game equilibrium *(shirk, shirk)*. From the main text, the minimum incentive compatible payment that upsets the Pareto optimality condition is $w_s^{**}=\frac{\delta c}{(1+\delta)\left(f_s(2)-f_s(1)\right)}$. The constraint that upsets condition 2) targets the agent who is supposed to shirk:

$$(1-\delta)(f_s(2)w_s{}'-c)+\delta f_s(0)w_s'\geq\frac{f_s(1)w_s'}{1+\delta}+\delta\frac{f_s(1)w_s'-c}{1+\delta}. \tag{4}$$

(4) implies that

$$\begin{cases} w_s' \geq \dfrac{c\left(\dfrac{1}{1+\delta}-\delta\right)}{\left(f_s(2)-f_s(1)\right)-\delta\left(f_s(2)-f_s(0)\right)} \ \text{ if } \delta \leq \min\left\{\dfrac{\sqrt{5}-1}{2}, \dfrac{1}{x_s}\right\} = \dfrac{1}{x_s} \\ w_s' \leq \dfrac{c\left(\delta-\dfrac{1}{1+\delta}\right)}{\delta\left(f_s(2)-f_s(0)\right)-\left(f_s(2)-f_s(1)\right)} \ \text{ if } \delta \geq \max\left\{\dfrac{\sqrt{5}-1}{2}, \dfrac{1}{x_s}\right\} = \dfrac{\sqrt{5}-1}{2} \\ \text{no feasible } w_s' \ \text{ if} \dfrac{1}{x_s} < \delta < \dfrac{\sqrt{5}-1}{2}. \end{cases}$$

Recall that $2 < x_s < 3$, thus $\frac{1}{3} < \frac{1}{x_s} < \frac{1}{2}$, and observe that $\frac{\sqrt{5}-1}{2} \risingdotseq 0.62$. Note that the collusion problem arises for $\delta > \delta^C = \sqrt{\frac{f_s(2)-f_s(1)}{f_s(1)-f_s(0)}}$. Due to weak substitutability,

$$\delta^C > \sqrt{1/2} \risingdotseq 0.71.$$

Thus, $w_s' \leq \frac{c\left(\delta-\frac{1}{1+\delta}\right)}{\delta\left(f_s(2)-f_s(0)\right)-\left(f_s(2)-f_s(1)\right)}$ is the only relevant case. However, this upper bound is strictly less than the mutual-monitoring wage:

$$\frac{c\left(\delta-\dfrac{1}{1+\delta}\right)}{\delta\left(f_s(2)-f_s(0)\right)-\left(f_s(2)-f_s(1)\right)} < \frac{c}{(1-\delta)\left(f_s(2)-f_s(1)\right)+\delta\left(f_s(2)-f_s(0)\right)}$$

$$\Leftrightarrow \frac{\delta}{1+\delta}\Big(2\left(f_s(1)-f_s(0)\right)-\left(f_s(2)-f_s(1)\right)-\delta^2\left(f_s(1)-f_s(0)\right)\Big) > 0$$

$$\Leftrightarrow 2-\underbrace{\frac{f_s(2)-f_s(1)}{f_s(1)-f_s(0)}}_{<1} > \delta^2,$$

which is always true because the left hand side is greater than 1, but the right hand side is less than 1. Thus, using the self-enforcing collusion constraint destroys the incentive for mutual monitoring. Therefore, the unique way to upset collusion while inducing mutual monitoring is to use the (No-cycling) constraint.

Q.E.D.

Proof of Lemma 4.

We use w_s^{**} for the optimal mutual monitoring and collusion-proof wage under specialized teams and w_d^* for the optimal mutual-monitoring wage under diverse teams. Recall from Lemma 2 that if $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$, then there is no crossing threshold without collusion. As collusion increases the total expected wages (when the collusion constraint binds), the crossing never occurs with collusion provided that $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$. Thus, we check whether the existing crossing threshold (identified in Lemma 2) changes given that $\frac{f_s(0)}{f_s(2)} < \frac{f_d(0)}{f_d(2)}$. Then, we check the feasibility of the conditions.

(i) (Single crossing) We first check the case, $\pi < \pi_c$. Due to weak substitutability, $\frac{f_s(1)-f_s(0)}{f_s(2)-f_s(1)} < 2$, we have $\delta^m < \frac{1}{2}$:

$$\delta^m = \frac{2f_s(1) - f_s(2) - f_s(0)}{f_s(1) - f_s(0)} < \frac{1}{2} \Leftrightarrow f_s(1) - f_s(0) < 2\big(f_s(2) - f_s(1)\big).$$

Similarly, we showed in Lemma 3 that $\delta^C = \sqrt{\frac{f_s(2)-f_s(1)}{f_s(1)-f_s(0)}} > \frac{1}{2}$. Therefore, $\delta^C > \delta^m$, which implies that $\delta^C > \delta(\pi, x_d)$. Crossing does not happen again if the collusion-proof wage for specialized teams is less than the mutual-monitoring wage for diverse teams. That is, at $\delta = 1$,

$$\frac{1}{2}\frac{f_s(2)}{f_s(2)-f_s(1)} \leq \frac{f_d(2)}{f_d(2)-f_d(0)} \Leftrightarrow \pi \leq \frac{2}{x_d}, \text{ where } \pi = \frac{\frac{f_s(2)}{f_s(2)-f_s(1)}}{\frac{f_d(2)}{f_d(2)-f_d(1)}} \text{ and } x_d = \frac{f_d(2)-f_d(0)}{f_d(2)-f_d(1)}.$$

Because $\pi > 1$ (our Assumption A3), for $\pi \leq \frac{2}{x_d}$ to be feasible, $\frac{2}{x_d} > 1$ is required, which is true due to complementarity, $2 > x_d$. Therefore, if $\pi < \pi_c$ and $\pi \leq \frac{2}{x_d}$, there is only one crossing threshold at $\delta(\pi, x_d)$.

We now check for $\pi \geq \pi_c$. We need to check two cases: $\delta(\pi, x_s, x_d) < \delta^C$ and $\delta(\pi, x_s, x_d) > \delta^C$. Consider first $\delta(\pi, x_s, x_d) < \delta^C$.

As we showed above, crossing does not happen again if $\pi \leq \frac{2}{x_d}$. For $\pi \leq \frac{2}{x_d}$ to be feasible under $\pi \geq \pi_c$, there must be parameter values such that $\pi_c \leq \frac{2}{x_d}$:

$$\pi_c \leq \frac{2}{x_d} \Leftrightarrow \frac{(x_s-1)^2}{1+x_d(x_s-2)} \leq \frac{2}{x_d} \Leftrightarrow x_d \leq \frac{2}{(x_s-2)^2+1}.$$

Because $1 < x_d$, there exist parameter values that satisfy the above inequality if $(x_s - 2)^2 + 1 < 2$, which is true because of weak substitutability, $x_s < 3$. Therefore, if $\pi \geq \pi_c$, $\pi \leq \frac{2}{x_d}$, and $\delta(\pi, x_s, x_d) < \delta^C$, then there is only one crossing threshold at $\delta(\pi, x_s, x_d)$. (We will consider $\delta(\pi, x_s, x_d) > \delta^C$ shortly.)

(ii) (Double crossing) Provided that there is crossing, another crossing threshold may happen again if the collusion-proof wage for specialized teams is sufficiently greater than the mutual-monitoring wage for diverse teams. Using the same logic above, at $\delta = 1$,

$$\frac{1}{2}\frac{f_s(2)}{f_s(2)-f_s(1)} > \frac{f_d(2)}{f_d(2)-f_d(0)} \Leftrightarrow \pi > \frac{2}{x_d}.$$

For $\pi > \frac{2}{x_d}$ to be feasible when $\pi < \pi_c$, we must have $\frac{2}{x_d} < \pi_c$, which can be written as $x_d > \frac{2}{(x_s-2)^2+1}$. Due to complementarity, $x_d < 2$, we must have $\frac{2}{(x_s-2)^2+1} < 2$, or $(x_s - 2)^2 + 1 > 1$, which is true because of substitutability, $x_s > 2$. Due to continuity, there exists $\delta_{DC1} > \delta^C$ such that $E[w_s^{**}] - E[w_d^*]|_{\delta_{DC1}} = 0$, or,

$$\frac{\delta_{DC1}}{1+\delta_{DC1}}\pi = \frac{1}{1+\delta_{DC1}(x_d - 1)}.$$

Notice that the left hand side increases in δ_{DC1}, but the right hand side decreases in δ_{DC1}, thus such δ_{DC1} (that satisfies the above equation) is unique. Therefore, for $\frac{2}{x_d} < \pi < \pi_c$, there is another crossing threshold $\delta_{DC1} \in (\delta^C, 1)$.

When $\pi \geq \pi_c$ and $\delta(\pi, x_s, x_d) < \delta^C$, the double crossing condition, $\pi > \frac{2}{x_d}$, is always feasible. Using the same continuity argument above, there exists $\delta_{DC2} > \delta^C$ such that $E[w_s^{**}] - E[w_d^*]|_{\delta_{DC2}} = 0$, or,

$$\frac{\delta_{DC2}}{1+\delta_{DC2}}\pi = \frac{1}{1+\delta_{DC2}(x_d - 1)}.$$

Therefore, for $\pi \geq \pi_c$ and $\pi > \frac{2}{x_d}$, there is another crossing threshold $\delta_{DC2} \in (\delta^C, 1)$.

(iii) (Lost crossing) Provided that there is a crossing threshold without considering the collusion problem (specified in Lemma 2), the collusion problem may eliminate the crossing threshold if the collusion constraint is binding at the crossing threshold.

When $\pi < \pi_c$, we showed that $\delta(\pi, x_d) < \delta^m$ and $\delta^m < \delta^C$. Thus, the collusion constraint is not binding at $\delta(\pi, x_d)$, and the single crossing threshold, $\delta(\pi, x_d)$, is maintained.

When $\pi \geq \pi_c$ and the crossing threshold is sufficiently large that $\delta(\pi, x_s, x_d) > \delta^C$, because $E[w_s^{**}] - E[w_d^*] > 0$ for $\delta < \delta(\pi, x_s, x_d)$, and for $\delta > \delta^C$, $E[w_s^{**}]$ is collusion-proof wage which increases in δ, $E[w_s^{**}]$ and $E[w_d^*]$ never cross each other for any δ. Therefore, if $\delta(\pi, x_s, x_d)$ is sufficiently large, $E[w_s^{**}] - E[w_d^*] > 0$ for any δ: binding collusion eliminates the crossing threshold.

Q.E.D.

Proof of Proposition 2.

Provided that $E[w_s^{**}] - E[w_d^*] > 0$, if the collusion constraints do not bind, i.e., $\delta < \delta^C$, then we showed in Proposition 1 that $E[w_s^{**}] - E[w_d^*]$ is monotone decreasing in δ. If the collusion constraints bind, i.e., $\delta > \delta^C$, then $E[w_s^{**}]$ increases as δ increases because:

$$\frac{\partial E[w_s^{**}]}{\partial \delta} = \frac{f_s(2)c}{(1+\delta)^2\big(f_s(2) - f_s(1)\big)} > 0.$$

But, the diverse team pay continues to decrease in δ (proof of Proposition 1). Therefore, $E[w_s^{**}] - E[w_d^*]$ is monotone increasing in $\delta > \delta^C$.

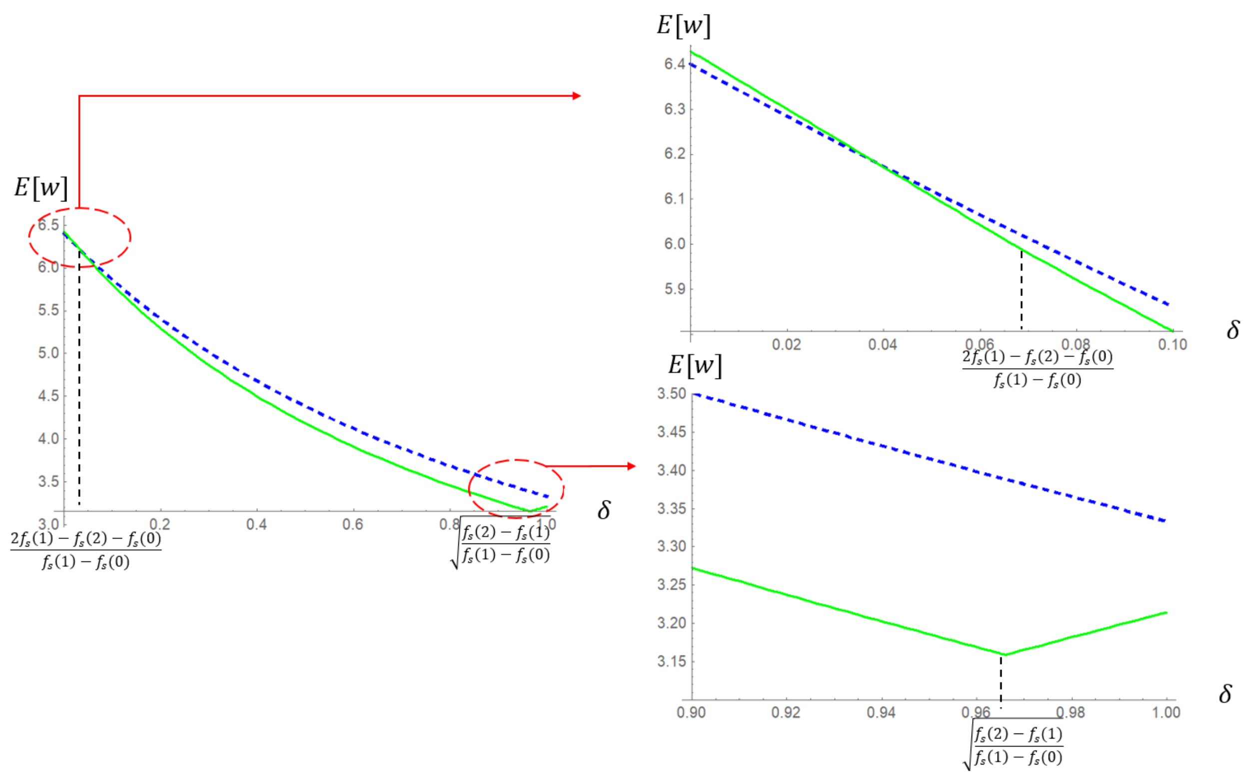
Provided that $E[w_s^{**}] - E[w_d^*] > 0$ for $\delta > \delta^C$, as δ increases, $E[w_s^{**}] - E[w_d^*]$ increases. So does $S^*(\delta)$ by definition.

Q.E.D.

Appendix B.

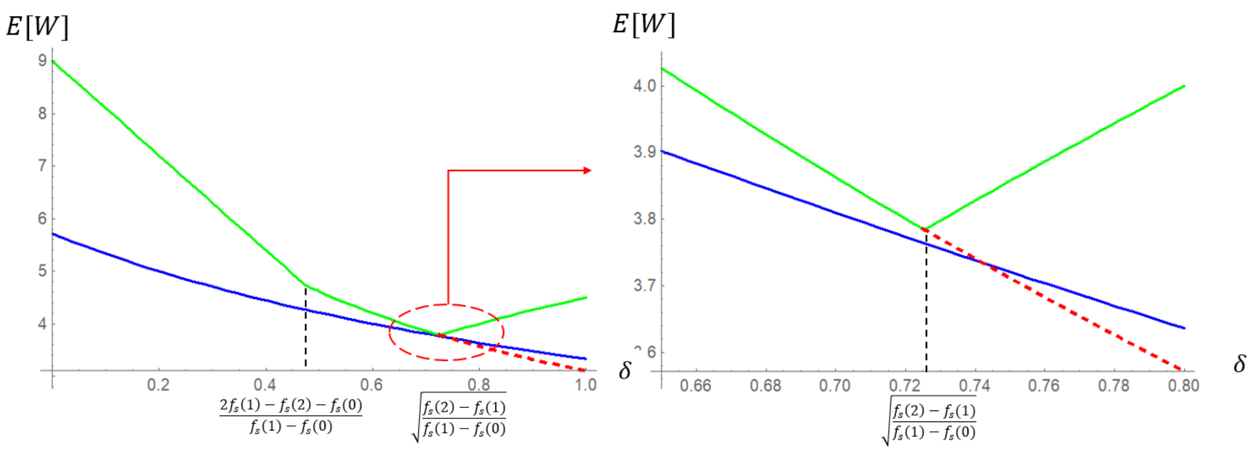
Figure of Crossing Results (Lemma 4)

Single crossing: Lemma 4 i).



This figure captures an early crossing case in which $E[w_s^{**}] - E[w_d^*] < 0$ for $\delta < \delta^m = \frac{2f_s(1)-f_s(2)-f_s(0)}{f_s(1)-f_s(0)}$. The solid line is the expected wage for specialized teams and the dashed line is the expected wage for the diverse teams for the following parameter values: $c = 1,\ f_s(0) = 0.32, f_s(1) = 0.62, f_s(2) = 0.9, f_d(0) = 0.32, f_d(1) = 0.55, f_d(2) = 0.8, x_s = 2.07,$ and $x_d = 1.92$. In this parameter region, $\delta^m = 0.067$ and $\delta^C = 0.966$, and $\pi = 1.004 < \pi_c = \frac{(x_s-1)^2}{1+x_d(x_s-2)} = 1.009$ and $\pi < \frac{2}{x_d} = 1.04$. Thus, the crossing happens before δ reaches δ^m and there is no more crossing even with the binding collusion constraint.

Lost crossing: Lemma 4 iii).



This figure depicts the total expected wage under each team composition, both exploiting mutual monitoring and preventing collusion. The solid lines are the expected wages for specialized teams (above) and for diverse teams (below), respectively, and dashed line is the expected wage for specialized teams without collusion for the following parameter values: $c = 1,\ f_s(0) = 0.32, f_s(1) = 0.7, f_s(2) = 0.9, f_d(0) = 0.32, f_d(1) = 0.52, f_d(2) = 0.8, x_s = 2.9,$ and $x_d = 1.714$. In this parameter region, $\delta^m = 0.473$, $\delta^C = 0.725$, and $\pi = 1.575 > \pi_c = \frac{(x_s-1)^2}{1+x_d(x_s-2)} = 1.42$. But, $\delta(\pi, x_s, x_d) = 0.742 > 0.725$. Thus, the binding collusion constraint eliminates the crossing threshold.

Appendix C.

Other Parameter Values of Production

In the main analysis, we assumed $f_s(2) > f_d(2)$. Combined with Assumption A3. $\frac{f_s(1)}{f_s(2)} > \frac{f_d(1)}{f_d(2)}$, this implies that $f_s(1) > f_d(1)$. We consider other cases and show which team composition is optimal. To allow for $f_k(2)$ and $f_k(0)$ to vary, we maintain our assumption that $\frac{f_s(1)}{f_s(2)} > \frac{f_d(1)}{f_d(2)}$ and $f_s(1) > f_d(1)$. Then, there are 9 cases as follows:

1	$f_s(2) > f_d(2)$	$f_s(0) = f_d(0)$
2	$f_s(2) > f_d(2)$	$f_s(0) > f_d(0)$
3	$f_s(2) > f_d(2)$	$f_s(0) < f_d(0)$
4	$f_s(2) < f_d(2)$	$f_s(0) = f_d(0)$
5	$f_s(2) < f_d(2)$	$f_s(0) > f_d(0)$
6	$f_s(2) < f_d(2)$	$f_s(0) < f_d(0)$
7	$f_s(2) = f_d(2)$	$f_s(0) = f_d(0)$
8	$f_s(2) = f_d(2)$	$f_s(0) > f_d(0)$
9	$f_s(2) = f_d(2)$	$f_s(0) < f_d(0)$

Case 1, 2, and 3 are what we considered in the main analysis. Under Case 4, 5, 7, and 8, we first show that the total expected wages for diverse teams are always less than those for specialized teams for any $\delta \geq 0$, and that diverse teams are always optimal.

Claim 3) Under Case 4, 5, 7, and 8, $E[w_s] > E[w_d]$ for any $\delta \geq 0$,
and diverse teams are always optimal.

Proof of Claim 3: Case 4, 5, 7, and 8 imply that $\frac{f_s(0)}{f_s(2)} \geq \frac{f_d(0)}{f_d(2)}$. When the collusion constraint does not bind and $\delta^m \leq \delta$, $E[w_s] > E[w_d]$ is equivalent to:

$$\frac{1}{(1-\delta)\left(1-\frac{f_s(1)}{f_s(2)}\right)+\delta\left(1-\frac{f_s(0)}{f_s(2)}\right)} > \frac{1}{(1-\delta)\left(1-\frac{f_d(1)}{f_d(2)}\right)+\delta\left(1-\frac{f_d(0)}{f_d(2)}\right)},$$

which is satisfied for any δ because $\frac{f_s(0)}{f_s(2)} \geq \frac{f_d(0)}{f_d(2)}$ and $\frac{f_s(1)}{f_s(2)} > \frac{f_d(1)}{f_d(2)}$.

For $\delta^m > \delta$, inequality $E[w_s] > E[w_d]$ is still maintained because $\frac{1}{(1-\delta)\left(1-\frac{f_s(1)}{f_s(2)}\right)+\delta\left(1-\frac{f_s(0)}{f_s(2)}\right)} < \frac{1-\delta}{1-\frac{f_s(1)}{f_s(2)}}$. When the collusion constraint binds, inequality $E[w_s] > E[w_d]$ is maintained because

$\frac{1}{(1-\delta)\left(1-\frac{f_s(1)}{f_s(2)}\right)+\delta\left(1-\frac{f_s(0)}{f_s(2)}\right)} < \frac{\delta}{1+\delta}\frac{1}{1-\frac{f_s(1)}{f_s(2)}}$. Moreover, we have $f_s(2) \leq f_d(2)$. Thus, from both incentive and productive standpoints, diverse teams dominate specialized teams. □

Under Case 6, while $f_s(2) < f_d(2)$ (i.e., diverse teams have a productive synergy), because of $f_s(0) < f_d(0)$, we have either $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$ or $\frac{f_s(0)}{f_s(2)} \leq \frac{f_d(0)}{f_d(2)}$. If $\frac{f_s(0)}{f_s(2)} > \frac{f_d(0)}{f_d(2)}$ under Case 6, then the specialized team's mutual-monitoring wage is more expensive than the diverse team's for any δ. The collusion-proof wage makes $E[w_s]$ even greater than $E[w_d]$. Thus, from both incentive and productive standpoints, diverse teams dominate specialized teams. If $\frac{f_s(0)}{f_s(2)} \leq \frac{f_d(0)}{f_d(2)}$ under Case 6, our crossing results are applied: both $E[w_s] < E[w_d]$ and $E[w_s] \geq E[w_d]$ are possible depending on δ. Because $f_s(2) < f_d(2)$, diverse teams are optimal if $E[w_s] \geq E[w_d]$. If, however, $E[w_s] < E[w_d]$, specialized teams can be optimal as long as the diverse team's productive advantage, $2 \times f_d(2) \times S$, is not too high relative to the specialized teams for the intermediate discount factor. When the discount factor is sufficiently high that the collusion constraint binds, then inequality $E[w_s] < E[w_d]$ is likely to be flipped, in which case the diverse teams are optimal.

Case 9, $f_s(2) = f_d(2)$ and $f_s(0) < f_d(0)$, implies that $\frac{f_s(0)}{f_s(2)} < \frac{f_d(0)}{f_d(2)}$. Thus, it is possible to have a lower mutual-monitoring wage for the specialized team than diverse team as shown in the main analysis for the intermediate discount factor. However, for a high discount factor, the specialized team's collusion-proof wage will eventually exceed the diverse team's mutual-monitoring wage. Thus, our crossing result is applied.

The table below summarizes the incentive efficiency and overall efficiency results. "Lemma 4" and "Proposition 2" mean our results in Lemma 4 and Proposition 2 are applied, and "$\succ$" denotes the principal's preference ordering.

			Incentive	Overall
1	$f_s(2) > f_d(2)$	$f_s(0) = f_d(0)$	Lemma 4	Proposition 2
2	$f_s(2) > f_d(2)$	$f_s(0) > f_d(0)$		
3	$f_s(2) > f_d(2)$	$f_s(0) < f_d(0)$		
4	$f_s(2) < f_d(2)$	$f_s(0) = f_d(0)$	Diverse $\succ$ Specialized	
5	$f_s(2) < f_d(2)$	$f_s(0) > f_d(0)$		

6	$f_s(2) < f_d(2)$	$f_s(0) < f_d(0)$	Lemma 4 and Proposition 2 if $\frac{f_s(0)}{f_s(2)} < \frac{f_d(0)}{f_d(2)}$, otherwise Diverse ≻ Specialized	
7	$f_s(2) = f_d(2)$	$f_s(0) = f_d(0)$	Diverse ≻ Specialized	
8	$f_s(2) = f_d(2)$	$f_s(0) > f_d(0)$		
9	$f_s(2) = f_d(2)$	$f_s(0) < f_d(0)$	Lemma 4	Proposition 2

Q.E.D.

Appendix D.

Continuous Effort

We first find the stage game equilibrium in each team. We then characterize the mutual-monitoring and collusion-proof wages. Consider the specialized team first. Given the teammate's effort e_j, find the first order condition for agent i:

$$\frac{2}{5}(e_i + e_j)^{\frac{1}{2}} w_s - \frac{1}{2} e_i^2 \Rightarrow \frac{1}{5}(e_i + e_j)^{-\frac{1}{2}} w_s = e_i \Rightarrow e_i = e_j = \left(\frac{w_s}{5\sqrt{2}}\right)^{\frac{2}{3}}.$$

One can show that, given the symmetric wage contract and the teammate's effort $\left(\frac{w_s}{5\sqrt{2}}\right)^{\frac{2}{3}}$ (or, 1 in case $\left(\frac{w_s}{5\sqrt{2}}\right)^{\frac{2}{3}} < 1$), the agent has no incentive to deviate from choosing the same effort. Depending on w_s, the above choice may not be feasible, thus we have three cases to consider. Let $e = \left(\frac{w_s}{5\sqrt{2}}\right)^{\frac{2}{3}}$.

$$\begin{cases} (1,1) & \text{if } e \leq 1, \\ (2,2) & \text{if } e \geq 2, \\ (e,e) & \text{otherwise.} \end{cases}$$

Note that the static Nash incentive wage is $w_s^N = 20$, and $\left(\frac{w_s}{5\sqrt{2}}\right)^{\frac{2}{3}} \geq 2$ is satisfied for $w_s \geq 20$. Thus, as long as the mutual-monitoring wage is less than 20, the case $e \geq 2$ never occurs. Similarly, $\left(\frac{w_s}{5\sqrt{2}}\right)^{\frac{2}{3}} \leq 1$ is satisfied for $w_s \leq 5\sqrt{2} = 7.07$ (or, $\delta \geq 0.825$). Thus, when the mutual monitoring wage is less than 7.07, the stage game equilibrium is $(1,1)$. When $w_s > 7.07$, the stage game equilibrium is (e, e). Let (e_s, e_s) denote the stage game equilibrium.

Let $e^*(e')$ denote the best one-shot deviation effort of the agent (i.e., free-riding) given his teammate's choice e'. We know that when $e' = \left(\frac{w_s}{5\sqrt{2}}\right)^{\frac{2}{3}}$ or 1, then $e^*(e') = e'$. But, when $e' \neq \left(\frac{w_s}{5\sqrt{2}}\right)^{\frac{2}{3}}$ and 1, then $e^*(e')$ is different from e' and found from the agent's first-order condition. Then the mutual-monitoring wage is found as follows:

$$\frac{2}{5}(2+2)^{\frac{1}{2}}w_s - \frac{1}{2}2^2 \geq (1-\delta)\left(\frac{2}{5}(2+e^*(2))^{\frac{1}{2}}w_s - \frac{1}{2}e^*(2)^2\right) + \delta\left(\frac{2}{5}(e_s+e_s)^{\frac{1}{2}}w_s - \frac{1}{2}e_s^2\right).$$

Because of feasibility of effort, whenever $e^*(2) < 1$, the agent's best one-shot deviation is choosing 1. We can show that given the teammate's effort 2, $e^*(2) < 1$ occurs when $w_s < 5\sqrt{3} = 8.66$. Thus, when the stage game equilibrium is $(1,1)$ (i.e., $w_s \leq 7.07$), $e^*(2) = 1$. With $(e_s, e_s) = (1,1)$ and $e^*(2) = 1$, the mutual-monitoring wage is $w_s^* = \frac{15}{4}\frac{1}{2-\sqrt{3}+(\sqrt{3}-\sqrt{2})\delta}$, which decreases as δ increases. When the stage game equilibrium is $(e,e) \neq (1,1)$ ($\Leftrightarrow w_s > 7.07$), there is no closed form solution for the mutual-monitoring wage. Numerically however, we can solve for the mutual-monitoring wage.

δ	w_s^*	(e_s, e_s)	$e^*(2)$
0.45	10.5	(1.3, 1.3)	1.18
0.6	8.92	(1.17, 1.17)	1.03
0.75	7.59	(1.05, 1.05)	1
0.9	6.77	(1,1)	1

To see if the agents can do better by colluding, we consider symmetric collusion that has the agents playing identical strategies. Let x denote the agents' collusive strategy, which can be found from the first order condition of their stage game payoffs:

$$2 \times \frac{2}{5} \times (x+x)^{\frac{1}{2}}w_s - \frac{1}{2}x^2 - \frac{1}{2}x^2 \Rightarrow x = 2^{\frac{1}{3}}5^{-\frac{2}{3}}w_s^{\frac{2}{3}}.$$

Observe that $x > \left(\frac{w_s}{5\sqrt{2}}\right)^{\frac{2}{3}}$. Here, $x = 2^{\frac{1}{3}}5^{-\frac{2}{3}}w_s^{\frac{2}{3}} = 0.43w_s^{\frac{2}{3}}$ is feasible (i.e., $x < 2$) for $w_s < 10$, which is true if $\delta > 0.5$.

To see if $x = 2^{\frac{1}{3}}5^{-\frac{2}{3}}w_s^{\frac{2}{3}}$ is better than joint working, compare one agent's joint working payoff to his collusion payoff. Suppose $\delta = 0.75$, then $w_s^* = 7.59$ and $x = 2^{\frac{1}{3}}5^{-\frac{2}{3}}w_s^{*\frac{2}{3}} = 1.66$:

$$\frac{2}{5}(2+2)^{\frac{1}{2}}w_s^* - \frac{1}{2}2^2 = 4.07 < \frac{2}{5} \times (1.66+1.66)^{\frac{1}{2}}w_s^* - \frac{1}{2}(1.66)^2 = 4.15.$$

To see if $(1.66,1.66)$ is self-enforcing, we need to find $e^*(1.66)$. When $w_s^* = 7.59$, we can show that $e^*(1.66) < 1$, thus the best one-shot deviation is 1. The collusion $(1.66,1.66)$ is self-enforcing if:

$$\begin{aligned} \frac{2}{5} \times (1.66+1.66)^{\frac{1}{2}}w_s^* \ - \frac{1}{2}(1.66)^2 = 4.15 & \\ & \geq (1-0.75)\left(\frac{2}{5}(1+1.66)^{\frac{1}{2}}w_s^* - \frac{1}{2}\right) + 0.75\left(\frac{2}{5}(1.05+1.05)^{\frac{1}{2}}w_s^* - \frac{1}{2}1.05^2\right) \\ & = 4.0. \end{aligned}$$

Thus, the collusion is self-enforcing for the mutual-monitoring wage $w_s^* = 7.59$. To prevent the collusion, the agents' payoff-maximizing effort must be 2, that is,

$$x = 2^{\frac{1}{3}}5^{-\frac{2}{3}}w_s^{\frac{2}{3}} = 2 \Leftrightarrow w_s^{**} = 10.$$

Now we consider diverse teams. As before, the agents can provide the mutual-monitoring incentive using the stage game equilibrium. Note that if w_d is such that $w_d/6 > 1$, then $(2,2)$ is a stage game equilibrium. To see this, given the teammate's effort $e_j = 2$:

$$\frac{4}{6}w_d - \frac{1}{2}2^2 \geq \frac{2}{6}e_i w_d - \frac{1}{2}e_i^2 \Leftrightarrow \frac{w_d}{6} \geq \frac{2+e_i}{4},$$

which is always satisfied because the left hand side of the last inequality is greater than 1 and the right hand side is less than or equal to 1 for any $e_i \leq 2$. Similarly, $(1,1)$ is a stage game equilibrium if $w_d/6 < 1$: given the teammate's effort $e_j = 1$, $\frac{w_d}{6} - \frac{1}{2} \geq \frac{1}{6}e_i \times 1 \times w_d - \frac{1}{2}e_i^2 \Leftrightarrow \frac{w_d}{6} \leq \frac{e_i+1}{2}$. The last inequality is true because the left hand side is less than 1 whereas the right hand side is greater than or equal to 1 for any $e_i \geq 1$. When $w_d/6 = 1$, there can be infinitely many stage game equilibria (e_d, e_d) where agents choose the same effort choice derived from each agent's first-order condition. Meanwhile, when the other agent plays $e_j = 2$, agent i's stage game payoff-maximizing effort is to choose $e^*(2) = w_d/3$. We will shortly see that $e^* = w_d/3 \ \in [1,2]$, and that $w_d/6 = 1$ is true only when $\delta = 0$ and $w_d/6 < 1$ for all $\delta > 0$. This ensures that the effort choice $e^* = w_d/3$ is feasible and that $(1,1)$ is a unique stage game equilibrium for $\delta > 0$. Then, the mutual monitoring constraint is,

$$\frac{1}{6}(2\times 2)w_d - \frac{1}{2}2^2 \geq (1-\delta)\left(\frac{1}{6}\left(2 \times \frac{w_d}{3}\right)w_d - \frac{1}{2}\left(\frac{w_d}{3}\right)^2\right) + \delta\left(\frac{1}{6}w_d - \frac{1}{2}\right),$$

which yields $w_d^* = 3\frac{4-\delta-\sqrt{3\delta(4-\delta)}}{2(1-\delta)}$. Observe that, at w_d^*, $w_d^*/3 \leq 2$ because $\lim_{\delta \to 0+} w_d^*/3 = 2$ and w_d^* is decreasing in δ. Moreover, $w_d^*/3 \geq 1$ because $w_d^*/3 \geq 1 \Leftrightarrow (\delta - 1)^2 \geq 0$. As in specialized teams, the agents can potentially play a symmetric strategy that maximizes their stage game payoffs: $x \in argmax 2 \times \frac{1}{6} x^2 w_d - \frac{x^2}{2} - \frac{x^2}{2}$. However, it is straightforward to see that, for $\frac{w_d}{3} > 1$, a unique payoff-maximizing effort is always x=2. To summarize, the optimal wage for diverse teams is $w_d^* = 3\frac{4-\delta-\sqrt{3\delta(4-\delta)}}{2(1-\delta)}$ and the optimal wage for specialized teams is paying the mutual-monitoring wage if $\delta \leq 0.5$, or paying the collusion-proof wage 10 if $\delta > 0.5$. Therefore, the qualitative nature of implicit incentives remain the same as in the binary effort case.

Q.E.D.