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Team Leadership and Performance: Combining the Roles of Direction and Contribution

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Abstract. In knowledge-intensive projects, one of the challenges project team leaders often face is how to combine their roles of direction and contribution. In this paper, we propose a game-theoretic model of team leadership of coproductive projects and study how team leaders should combine their directing and contributing efforts depending on the team and project characteristics. Our analysis reveals that two types of team leadership approaches arise in equilibrium, namely, "participatory" team leadership, under which the team leader gives the team members full discretion on their choice of effort, and "directive" team leadership, under which the team leader demands team members exert higher effort than what they would choose to exert voluntarily. We find that directive team leadership is optimal when the team members have low incentives, that is, when their rewards are low, the size of the team is large, or failure is not too costly (e.g., continuation is possible); otherwise, participatory team leadership is optimal. Moreover, we show that a higher degree of effort complementarity (as in innovative projects) leads to greater alignment between the team leader's and team members' contributing efforts, which, under directive team leadership, also implies greater alignment between the team leader's directing and contributing efforts. Finally, the team leader should set the team size and team members' rewards in a way that accentuates the difference between the two team leadership approaches. That is, under directive team leadership, she should set a large team size and offer the team members low rewards whereas under participatory team leadership she should set a small team size and offer the team members high rewards.

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1. Introduction

In many knowledge-intensive projects (e.g., software development, new product development), team leaders often need to combine the roles of direction and contribution. That is, team leaders are not only responsible for directing the team members' activities (e.g., by setting daily meetings, requesting reports of progress, and monitoring presence), but they are also expected to contribute to project tasks to accelerate progress (e.g., by collaborating and brainstorming with the team members to resolve problems and taking on responsibilities for certain tasks). In fact, a recent survey reports that 50% of management activities are in "administrative coordination and control" while 40% are in "strategy and innovation" and "solving problems and collaborating" (Kolbjørnsrud et al. 2016). Although the management theory literature has paid little attention to the operational role of leaders, "middle managers" in knowledge-intensive businesses "may have greater impact on company performance than almost any other part of the organization" (Mollick 2011).

As an example, consider "development leads" in software development projects. These team leaders "were once developers themselves and instead of spending all day every day coding their own tasks, they now lead and mentor [other] developers." As part of their leadership role, they are expected to "encourage team members full participation" by "setting one-on-one meetings" and "bringing passion and energy" to the team project (Dewhurst et al. 2009, Zwilling 2012, Messenger 2014). They also often use "the source control system . . . to assess progress of every developer . . . [and] to make sure that the developer is both delivering what the specification calls for and is following appropriate coding standards" (Bogue 2005). However, they also write code themselves and take on responsibility for certain modules, and their contributing role is in fact "an important aspect of their technical leadership" (Kua 2014, p. 4).

One of the biggest challenges these project team leaders often face is "how to combine their roles as individual contributors and managers" and specifically to decide "when and how to use their formal authority" (Hill and Lineback 2011, p. 45). One reason is lack of familiarity with management skills given that "only part of the skills and experience [tech leads] had as a developer prepares [them] for the expectations of a new role . . . , [which involves] dealing with people, both technical and non-technical" (Kua 2015). In fact, many tech leads in the software industry highlighted that, while they have "never stopped writing code" since they became leads, they "are constantly thinking about coding or not coding," i.e., dealing with steering their team (Kua 2014, p. 237). More generally, Edmondson (2012) suggests that team leaders often need to "shift their roles from order-giver to team member." However, there are very few guidelines about when and how such a shift would help improve team performance.

Motivated by the above examples, we propose a game-theoretic model to study how team leaders who are responsible for the day-to-day operations of a team project should combine their contributing and directing roles to improve the performance of the team. Specifically, we study the following research questions: (i) How should team leaders combine their roles of direction and contribution, depending on the project and team characteristics? (ii) How should such team leaders, if given the authority, set the team size and team members' rewards?

The key features of the model are as follows: The team consists of n symmetric members and a team leader, who jointly undertake a coproductive project.[1] The project is stochastic with a binary outcome, and its success probability depends on the mean contributing efforts exerted by the team leader and members. Specifically, we consider a generalized mean production function (Hardy et al. 1952), which allows efforts to be complementary or substitutable, and we focus on conjunctive tasks. In addition, the team leader and members are rewarded differently. The team leader can engage in two types of efforts, namely "contributing" and "directing," which differ in terms of their cost and effect on the project's success rate. Specifically, the team leader's contributing effort directly increases the project's success rate whereas her directing effort increases the team members' contributing efforts and thus indirectly increases the project's success rate. We initially consider a one-shot project and then extend our analysis to a setting where the project consists of a finite number of sequential independent trials.

Our analysis reveals that, in equilibrium, one of the following two team leadership approaches arises: (i) Directive team leadership, where the team leader exerts both directing and contributing efforts and demands that team members exert more effort than what they would choose to exert voluntarily. (ii) Participatory team leadership, where the team leader only exerts contributing effort and gives the team members full discretion on their choice of efforts, and they choose to voluntarily contribute.

The team leader's choices of team leadership and efforts depend on the team and project characteristics (i.e., team size, team members' rewards, and the degree of effort complementarity). In particular, the directive team leadership approach tends to be optimal when the size of the team is large and the team members' rewards are low; otherwise, the participatory team leadership approach is optimal. The reason is that, in the former case, the team members have low incentives to contribute to the project when they receive a low reward in case of success either collectively (low team reward) or individually (large team size). In those circumstances, the team leader should direct the team members' efforts in addition to contributing to the project to enhance the team's performance. Otherwise, the team leader should only contribute to the project and avoid engaging in unnecessary directing activities.

We find that greater effort complementarity leads to greater alignment of contributing efforts between the team leader and members. This implies that, under directive team leadership, the team leader should align her directing and contributing efforts when the team's contributing efforts are complementary (as in innovative projects) and have them imbalanced when they are substitutable (as in routine projects). In the latter case, the team leader should put higher weight on the (directing or contributing) role in which she is the most efficient. Similarly, under participatory team leadership, the team leader's and the team members' contributing efforts should be more aligned when efforts are complementary and imbalanced when they are substitutable, and the direction of imbalance depends on their relative rewards.

When the team leader is given the authority to choose the team size and team members' rewards, we find that she should set them in a way that accentuates the difference between the two team leadership approaches. Specifically, under directive team leadership, she should offer the team members low rewards since they exert no voluntary effort and set the team size in a way that balances the effectiveness of her contributing effort (which has lower weight in larger teams) and her directing effort (which has higher weight in larger teams). In contrast, under participatory team leadership, the team leader should offer the team members high rewards to motivate them to voluntarily contribute to the project and work with a small team to mitigate free riding and maximize the effectiveness of everyone's efforts.

Finally, we generalize the single-shot project model to a setting with multiple independent sequential trials. For that case, we show that it is optimal for the team leader to be directive in the early trials and participatory in the later trials. As with our analysis of the single-shot project, the intuition behind this result is related to the team members' incentives. In the early trials, the team members' incentives are low because, should they fail, they still have many opportunities to succeed. As a result, the team leader should be directive to increase the chances of early success. In the later trials, the deadline provides enough incentives for the team members to contribute to the project, and the team leader can switch to a more participatory mode.

The paper is organized as follows. We review the related literature in the next section. We present our model of project and team leadership in Section 3. The results are presented in Sections 4 and 5. Section 6 presents our conclusions. All proofs are presented in the online appendix.

2. Literature Review

In this section, we review the literature on team leadership from the economics and operations management perspectives as well as the organizational behavior perspective.

2.1. Economics Models of Teams and Leadership

Most of the economics and operations management literature has studied leadership as it relates to a leader's strategic decisions, such as setting policies (Rotemberg and Saloner 1993), planning resources (Chao et al. 2009, Hutchison-Krupat and Kavadias 2015), or designing organizational hierarchies (Wernerfelt 2007, Mihm et al. 2010). In contrast, there has been less work on team leadership as it relates to a leader's tactical decisions, that is, day-to-day management of a team to enhance its performance. Moreover, most of the attention on the tactical decisions has been on the role of leaders as project managers who aim to improve team performance by designing incentives or setting deadlines, and there has been only limited work on the role of a leader as an internal project contributor. We next review these three areas of research.

2.1.1. Leaders as Project Designers and Resource Planners. Considering the strategic decisions of leaders, Chao et al. (2009) and Hutchison-Krupat and Kavadias (2015) study how delegating a project's funding authority to middle managers affects a firm's success, focusing, respectively, on the middle managers' incentives and career concerns (Chao et al. 2009) and on information asymmetry (Hutchison-Krupat and Kavadias 2015). Similarly, Wu et al. (2008) and Mihm et al. (2010) study the effect of organizational hierarchy and delegation of the project-selection process when top and middle managers have information asymmetry about the potential outcomes of various projects. Focusing on committee decisions, Wernerfelt (2007) and Dessein (2007) contrast a decision-making process centrally led by a leader with one in which a decision is reached through a decentralized majority vote. We complement these studies by considering a leader's tactical, rather than strategic, decisions that are aimed at improving the team's performance via enhancing the team members' participation and efforts.

2.1.2. Leaders as Project Managers. Considering team leaders' tactical decisions toward enhancing team performance, a large group of studies has focused on the alignment of incentives as a way to mitigate moral hazard in teams (Holmström 1982), using either contractual or operational mechanisms. Considering contractual mechanisms, Rotemberg and Saloner (1993) study how team leaders with different personalities (profit maximizer or empathic) should incentivize subordinates' efforts to maximize a firm's shareholders' value, and Siemsen et al. (2007) explore the design of optimal incentives that induce task-related effort, helping, and knowledge sharing within workgroups. Similarly, Georgiadis (2014) shows that it is optimal for a manager to pay team members only when the project is completed while Wu et al. (2014) show that, with cost salience, rewarding agents in the early stages of a project can reduce procrastination. In addition to (or instead of) contractual mechanisms, leaders can use operational mechanisms to mitigate moral hazard and improve team performance as studied in an emerging stream of research; those operational mechanisms can involve decisions on knowledge development and transfer (Ozkan et al. 2015), project size (Georgiadis et al. 2014), and timelines (Bonatti and Hörner 2011, Rahmani et al. 2017). In this paper, we also study the effect of operational levers on team performance but with the focus on the team leader's directing activities as a way to enhance the team members' efforts.[2] In addition, unlike the aforementioned studies, we consider a team leader who, in addition to leading and managing the team, is also an active contributor to the project.

2.1.3. Leaders as Project Contributors. Despite the practical evidence (Hill and Lineback 2011, Kua 2014) that shows team performance is affected by both a team leader's contribution and direction activities, the only (to the best of our knowledge) theoretical study of a contributing leader is Hermalin (1998), who considers a setting where the role of the leader is to lead by example. We complement his study by considering a team leader who is not only an active contributor to the project, but who has also been endowed with the authority to manage the other team members' contributions as often happens in software and product development (Bogue 2005, Edmondson 2012, Kua 2014). Our results therefore generate insights into how team leaders should combine their roles of contribution and direction to enhance the team's performance and, if given the authority, how they should set the team size and team members' rewards.

2.2. Organizational Behavior and Leadership

Team leadership has naturally been central to the field of research on organizational behavior, which is generally descriptive and based on field and lab experiments. We complement the organizational behavior studies by adopting a prescriptive approach and focusing on rational decision processes rather than individual psychological traits. Although our stylized model does not capture all the subtleties of leadership styles documented by the organizational behavior literature (there are over 70 definitions of leadership; see House and Baetz 1979), we borrow the terminologies of "directive" and "participatory" team leadership approaches from that literature.[3] We next review some representative papers in the field of research on organizational behavior that have adopted similar definitions of leadership types.

In a seminal piece of work on leadership, Lewin et al. (1939) classify leadership styles along democratic and autocratic dimensions. They contrast an authoritarian leader, who dictates particular work tasks to the group, with a democratic leader, who lets the group freely choose their tasks while getting assistance from the leader. Similarly, Baumgartel (1957) assesses the participatory and directive leadership styles in a laboratory research environment. Focusing on the attitude of the team members toward their leader, both studies report that team members who work in a directive leadership climate hold less favorable attitudes toward their leader.

Moving beyond the team members' attitudes toward their leader, more recent studies have assessed the effect of leadership style on team performance. In particular, Kahai et al. (2004) consider a group of undergraduate students working on a creative task who are led either by a directive leader, who guides their participation and problem solving, or by a participatory leader, who equalizes power and shares and consults with them on problem solving. They find that participative leadership is more effective for unstructured problems, but directive leadership is more effective for structured problems. Similarly, Yun et al. (2005) consider a group of trauma specialists who are led either by an autocratic lead surgeon, who develops and finalizes the patient care plan with little consultation with other team members, or by an empowering lead surgeon, who encourages them to actively participate in the decision making and task management. They find that empowering leadership is more effective when the team is more experienced but that autocratic leadership is more effective otherwise.

In contrast to this stream of research, which studies the psychological traits of leaders and team members, we consider the choice of leadership style as the outcome of a rational decision process, focusing on one aspect of leadership, namely, the team leader's degree of direction on the other team members' efforts. We show that two team leadership approaches arise in equilibrium, which are analogous to the traditional dichotomous classification posed by the organizational behavior literature reviewed in this subsection. Specifically, we identify a team leadership approach as being directive when, in equilibrium, the team leader demands that team members exert effort beyond what they individually desire and as being participatory when, in equilibrium, the team members voluntarily choose their contribution effort. Moreover, we offer prescriptions as to how the team leader should adjust her team leadership approach with respect to the team and project characteristics.

3. Model

We consider a team consisting of n symmetric (i.e., identical) workers and a team leader who jointly undertake a stochastic coproductive project. We denote the set of team members by $\mathcal{N} = \{1, \ldots, n\}$ and the team leader by 0. The project has an uncertain binary outcome; without loss of generality, we set the reward to V if the project is successful and zero otherwise. We furthermore assume that the project's success probability depends on the combined efforts of the team leader and members.

3.1. Team Leader's Efforts

The team leader can engage in two types of efforts, namely "contributing effort" and "directing effort." The two types of effort differ in terms of their effect on the project's success rate and their costs. Specifically, the team leader's contributing effort may involve working independently on the project's activities, collaborating and brainstorming with team members, and helping in resolving technical issues. In contrast, the team leader's directing effort may involve setting meetings, requesting and reviewing reports of progress, and monitoring presence. We denote by $E_0 \in [0, 1]$ the team leader's contributing effort and by $\theta \in [0, 1]$ the team leader's directing effort.[4]

The costs to the team leader for exerting contributing and directing efforts are $c(E_0)$ and $g(\theta)$, respectively. To simplify the exposition, we model these costs as linear although the same insights hold for any increasing-convex cost functions. In addition, given that it is often more costly to manage larger teams (Garen 1985), we model the team leader's cost of directing effort as an increasing function of the team size n. In particular, we consider the following cost functions: $c(E_0) = c \cdot E_0$ with $c > 0$, and $g(\theta) = n \cdot g \cdot \theta$ with $g > 0$. The asymmetry in cost functions (i.e., when $c \neq g$) may reflect the team leader's efficiency in each role. For instance, $c > g$ implies that the team leader is more efficient at directing than at contributing.

3.2. Team Members' Efforts

Each team member exerts a contributing effort to increase the project success rate. We assume that the team members have no control over the team leader's and each other's contributing efforts but that the team leader can control the team members' efforts as a part of her directing activity θ. Thus, the team members' contributing efforts are functions of the team leader's directing effort.

To model the dependency between the team leader's directing effort and the team members' contributing efforts, we divide the team members' contributing efforts into two parts, namely, "demanded" effort (i.e., θ proportion of their effort that is determined by the team leader) and "voluntary" effort (i.e., $(1-\theta)$ proportion of their efforts that is determined by the team members themselves). In particular, we denote the team members' contributing efforts by $\mathbf{E}(\theta, \mathbf{e}) = (E_1(\theta, e_1), E_2(\theta, e_2), \ldots, E_n(\theta, e_n))$ such that

$$E_i(\theta, e_i) \doteq \underbrace{\theta \cdot 1}_{\text{Demanded}} + \underbrace{(1-\theta) \cdot e_i}_{\text{Voluntary}} \quad \forall\, i \in \mathcal{N}, \tag{1}$$

in which $\theta \cdot 1$ denotes the demanded proportion of team member i's effort that is controlled by the team leader, and $(1-\theta) \cdot e_i$ denotes the voluntary proportion of team member i's effort that is not controlled by the team leader. Although this model assumes that the team leader's directing effort perfectly increases the team members' contributing efforts from e_i to 1, similar insights would hold if the team leader's directing effort could only partially increase the team members' efforts.

According to (1), if the team leader does not exert directing effort (i.e., $\theta = 0$), the team members' efforts will be equal to their voluntary efforts (i.e., $E_i(0, e_i) = e_i$). On the other hand, if the team members choose not to exert voluntary efforts (i.e., $e_i = 0$), their efforts will be equal to the effort demanded by the team leader (i.e., $E_i(\theta, 0) = \theta$). In addition, for any $\theta \in [0, 1]$ and $e_i \in [0, 1]$, each team member's contributing effort lies in the unit interval (i.e., $E_i(\theta, e_i) \in [0, 1]\ \forall\, i \in \mathcal{N}$).[5]

Similar to the team leader's cost of contributing effort, we assume that the team members' cost of contributing effort is linear. In addition, to simplify the notation, we assume that the team members and the team leader have the same cost of contributing effort. That is, we assume that the team leader and members are equally efficient in their contributing roles, which is often the case in software development projects (Kua 2014). In particular, we define the team members' cost function as $c(E_i(\theta, e_i)) = c \cdot (\theta + (1-\theta) \cdot e_i)$ for all $i \in \mathcal{N}$.

3.3. Success Rate

We assume that the project is successful with probability $p(E_0, \mathbf{E})$ and fails with probability $1 - p(E_0, \mathbf{E})$ and that the success probability is increasing in the mean effort of the team leader and members. In particular, we employ a generalized mean function (Hardy et al. 1952) as is commonly used in the literature on joint production (see, e.g., Bhattacharyya and Lafontaine 1995, Roels 2014):

$$p(E_0, \mathbf{E}) = k \cdot \left(\frac{(E_0)^r + \sum_{i=1}^{n} (E_i)^r}{n+1} \right)^{b/r}, \tag{2}$$

in which E_i is a function of (θ, e_i) as defined in (1) with $0 < k < 1$, $0 < b < 1$, and $r < 1$ (with $r \neq 0$). This generalized mean function reduces to the arithmetic mean (when $r \to 1$) as in Carpenter et al. (2009), the geometric mean (when $r \to 0$) as in Roels et al. (2010), the harmonic mean (when $r = -1$), and the minimum function (when $r \to -\infty$) as in Buzacott (2004).

The production function (2) fits well in situations where the task's degree of effort interdependency is conjunctive or compensatory (Steiner 1972), which is in contrast to Bonatti and Hörner (2011) and Fu et al. (2016), who consider situations where efforts are additive. Such tight coupling is characteristic of coproductive settings.[6] For instance, in software development, complex programming projects cannot be perfectly partitioned into discrete tasks that can be worked on without communication between the workers and without establishing a set of complex interrelationships between tasks and the workers performing them (Brooks 1995). Although a team's performance could potentially exceed its members' (generalized) mean performance, the mean performance is often used as a baseline for comparison.[7]

Although the success probability (2) increases in efforts, adding a member to the team may not necessarily result in an increase in the success rate unless that additional team member exerts a higher effort than the (generalized) mean effort of the existing team members. Teamwork is indeed often associated with "coordination losses" (Ringelmann 1913, p. 9), such as production blocking or difficulty of sharing individual contributions through meetings and extensive coordination. Consequently, adding team members is not always beneficial. For instance, in software development, adding more members to the team can be destructive as a result of "disruption of repartitioning work, training, and added intercommunication" (Brooks 1995, p. 232). In particular, Van De Ven et al. (1976) report that the more interconnected the workflows, the higher the use of coordination mechanisms and, among them, there is a greater use of less efficient coordination mechanisms (Kraut and Streeter 1995), such as personal discussions or group meetings, and less use of policies and procedures, such as work plans and schedules.[8]

Parameter r measures the degree of complementarity in the team leader's and team members' efforts with

$r \in (-\infty, 1)$. In particular, because the elasticity of substitution is equal to $1/(1-r)$, the smaller the r the more complementary the efforts. Efforts are strategic complements if $r < b$ and strategic substitutes otherwise. The degree of complementarity of efforts captures the degree of interaction involved in the project (Roels 2014). Specifically, routine projects tend to be associated with substitutable efforts (i.e., large r) whereas innovative projects tend to be associated with complementary efforts (i.e., small r). For instance, consider a team of developers working on a software development project. When the project is routine, developers can work on separate modules and conduct the project with limited interaction. In contrast, when the project is innovative, developers may require to work collaboratively on all modules with high interaction (Eppinger and Browning 2012).

Finally, by combining (1) and (2), we obtain

$$p(E_0, \mathbf{E}) = p(E_0, \mathbf{e}, \theta) = k \cdot \left(\frac{(E_0)^r + \sum_{i=1}^{n} (\theta + (1-\theta) e_i)^r}{n+1} \right)^{b/r}. \quad (3)$$

3.4. Rewards

We assume that if the project is successful, the team leader receives V and shares $R < V$ with the team members. Because the team members are symmetric, we assume that they each receive R/n. This type of reward-sharing contract is second best (Bhattacharyya and Lafontaine 1995) and is commonly used to motivate engineers in high technology, software, or biotechnology companies in the form of stock options or cash bonuses; see, for example, Mihm (2010). Similarly, co-ownership of research grants and patents in R&D projects effectively act as linear sharing rules. In addition, rewards R and V can capture nonfinancial incentives, such as opportunities for career growth, which are often effective in motivating individuals in knowledge-intensive projects (Dewhurst et al. 2009).

As is common in practice, we also assume that team members are paid a fixed wage irrespective of their effort levels, which guarantees their participation. Since such fixed wage payments do not affect the team leader's and members' choice of efforts, we normalize them to zero to simplify the exposition.

Accordingly, for a given set of directing and contributing efforts $(E_0, \mathbf{e}, \theta)$, we define the team leader's and members' expected rewards as follows:

$$V_0(E_0, \mathbf{e}, \theta) \doteq \overbrace{p(E_0, \mathbf{e}, \theta)}^{\text{Success rate}} \cdot \overbrace{(V-R)}^{\text{Reward upon success}} + \overbrace{(1 - p(E_0, \mathbf{e}, \theta))}^{\text{Failure rate}} \cdot \overbrace{\bar{U}_0}^{\text{Payoff upon failure}}, \quad (4)$$

$$V_i(E_0, \mathbf{e}, \theta) \doteq \overbrace{p(E_0, \mathbf{e}, \theta)}^{\text{Success rate}} \cdot \overbrace{(R/n)}^{\text{Reward upon success}} + \overbrace{(1 - p(E_0, \mathbf{e}, \theta))}^{\text{Failure rate}} \cdot \overbrace{\bar{U}_i}^{\text{Payoff upon failure}}, \quad \forall i \in \mathcal{N}, \quad (5)$$

with $p(E_0, \mathbf{e}, \theta)$ defined in (3) and where $\bar{U}_0$ and $\bar{U}_i$, for $i \in \mathcal{N}$, respectively, represent the team leader's and members' payoffs upon the project's failure. Although these payoffs can be normalized to zero in a one-shot project, we consider them here as being nonzero so as to extend our analysis to a setting with sequential trials in Section 5. In addition, to avoid trivial cases, we assume $\bar{U}_0 < V - R$ and $\bar{U}_i < R/n$, $\forall i \in \mathcal{N}$.

Finally, we define the ratio of the team leader's marginal gain relative to each team member's marginal gain as

$$\rho \doteq \frac{V - R - \bar{U}_0}{R/n - \bar{U}_i}. \quad (6)$$

We use this ratio in characterizing our results in Section 4. Table 1 summarizes the key notations of this paper.

3.5. Stochastic Game Formulation

We next present the choice of efforts as a noncooperative game between the team leader and team members.

Table 1. Summary of Notations

Notation	Definition
Parameters	
n	Team size
$V-R$	Team leader's reward
R/n	Team member's individual reward
c	Unit cost of contributing effort
g	Team leader's unit cost of directing effort
r	Degree of complementarity of efforts (inverted scale)
k	Maximum probability of success if $E_i = 1$ for all $i = 0, \ldots, n$
b	Returns to scale parameter
$\bar{U}_0$	Team leader's payoff upon failure
$\bar{U}_i$	Team member i's individual payoff upon failure for $i \in \mathcal{N}$
ρ	Ratio of the team leader's marginal gain to each member's marginal gain
Variables and functions	
θ	Team leader's directing effort
E_0	Team leader's contributing effort
e_i	Team member i's voluntary contributing effort for $i \in \mathcal{N}$
$E_i(\theta, e_i)$	Team member i's total contributing effort for $i \in \mathcal{N}$
$g(E_0)$	Team leader's cost of directing effort
$c(E_0)$	Team leader's cost of contributing effort
$c(E_i(\theta, e_i))$	Team member i's cost of contributing effort for $i \in \mathcal{N}$
$p(E_0, \mathbf{e}, \theta)$	Project's success rate, equivalent to $p(E_0, \mathbf{E})$
$V_0(E_0, \mathbf{e}, \theta)$	Team leader's expected reward
$V_i(E_0, \mathbf{e}, \theta)$	Team member i's expected reward for $i \in \mathcal{N}$

The sequence of decisions is as follows: First, the team leader chooses her directing effort θ. Then, the team leader and members choose their corresponding contributing efforts, that is, the team leader chooses E_0, and each team member chooses e_i for $i \in \mathcal{N}$.

Using backward induction, we first characterize the team leader's and members' equilibrium contributing efforts for a given directing effort θ. We then replace those equilibrium contributing efforts in the team leader's objective to find the team leader's optimal choice of directing effort. We therefore first present in Section 3.5.1 the stochastic game between the team leader and members for choosing their contributing efforts. We then present in Section 3.5.2 the team leader's optimization problem for choosing her directing effort.

3.5.1. The Team Leader's and Members' Contributing Efforts. For any given directing effort θ, the team leader and members choose their contributing efforts, independently and simultaneously, by maximizing their individual expected payoffs while anticipating the strategies of other members. We denote by $(E_0^*(\theta), \mathbf{e}^*(\theta))$ the team leader's and members' equilibrium voluntary contributing efforts for a given directing effort θ. Accordingly, the stochastic game model of contributing efforts is as follows:

Contribution Game:

$$\begin{cases} E_0^*(\theta) = \underset{E_0 \in [0,1]}{\arg\max} -c(E_0) + V_0(E_0, \mathbf{e}^*(\theta), \theta), \\ e_i^*(\theta) = \underset{e_i \in [0,1]}{\arg\max} -c(\theta + (1-\theta)\cdot e_i) \\ \qquad + V_i(E_0^*(\theta), (e_i, \mathbf{e}_{-i}^*(\theta)), \theta), \quad \forall\, i \in \mathcal{N}, \end{cases} \tag{7}$$

in which $\mathbf{e}_{-i}^*(\theta) = (e_1^*(\theta), \ldots, e_{i-1}^*(\theta), e_{i+1}^*(\theta), \ldots, e_n^*(\theta))$, and $V_0(E_0, \mathbf{e}, \theta)$ and $V_i(E_0, \mathbf{e}, \theta)$ are presented in (4)–(5).

3.5.2. The Team Leader's Directing Effort. We denote by θ^* the team leader's optimal directing effort. The team leader chooses her directing effort to maximize her expected payoff while anticipating its effect on the team equilibrium contributing efforts. That is, she chooses her directing effort as follows:

$$\begin{aligned} \theta^* = \underset{\theta \in [0,1]}{\arg\max} & -g(\theta) - c(E_0^*(\theta)) + V_0(E_0^*(\theta), \mathbf{e}^*(\theta), \theta), \\ \text{s.t.} \quad & (E_0^*(\theta), \mathbf{e}^*(\theta)) \text{ being solutions to the} \\ & \text{contribution game (7).} \end{aligned} \tag{8}$$

If the team leader's role were only to direct the team (i.e., she were not contributing to the project, $E_0 = 0$), her choice of directing effort would have been based simply on the trade-off between an increase in the project's success rate (via an increase in the team members' efforts) and an increase in her cost of directing. However, because the team leader is combining the roles of direction and contribution, her choice of directing effort is more intricate because she also needs to consider how an increase in her directing effort affects her own contribution, which we characterize in the next section.

4. Results

We first characterize, in Section 4.1, the team leader's and members' equilibrium contributing efforts $(E_0^*(\theta), \mathbf{e}^*(\theta))$, for any given directing effort θ, by solving the contribution game (7). We then characterize, in Section 4.2, the team leader's optimal directing effort θ^* by solving (8) and identify the equilibrium team leadership approaches. In Section 4.3, we study how the team leader's equilibrium directing and contributing efforts depend on the team and project characteristics. Finally, in Section 4.4, we study how the team leader, if given the authority, should set the team size and team members' rewards. In order to simplify the exposition, we assume throughout the paper that the cost of effort c is high enough that the team leader's and members' equilibrium contributing efforts never reach their upper bound (i.e., $E_0^*(\theta) < 1$ and $E_i^*(\theta) < 1$ $\forall\, i \in \mathcal{N}$).[9]

4.1. Equilibrium Contributing Efforts

In this section, we characterize the team leader's and members' contributing efforts for a given directing effort θ. We establish the existence and uniqueness of the team leader's and members' equilibrium contributing efforts in Lemma EC.6 in the online appendix. Our results show that when $r > 0$ or $\theta > 0$, the contribution game has a unique and strictly positive equilibrium solution, $(E_0^*(\theta), \mathbf{e}^*(\theta)) > (0, \mathbf{0})$. For the case in which $r \le 0$ and $\theta = 0$, in addition to a strictly positive equilibrium, there might be an equilibrium with which no effort is exerted. However, we show in Lemma EC.6 that the strictly positive equilibrium is Pareto-dominant. Thus, in order to avoid trivial cases, we focus our analysis on the Pareto-dominant equilibrium (Harsanyi and Selten 1992).

We next characterize the team leader's and members' equilibrium efforts as a function of a given directing effort by solving the contribution game. Before presenting the result, let us define the following threshold:

$$\bar{\theta} \doteq \min\left\{1, (\rho)^{-1/(1-r)}\left(\frac{kb(V - R - \bar{U}_0)}{c(n+1)}\right)^{1/(1-b)} \cdot \left(\frac{n(\rho)^{-r/(1-r)} + 1}{n+1}\right)^{(b-r)/(r(1-b))}\right\}. \tag{9}$$

We show in the next lemma that the characterization of equilibrium contributing efforts depends on whether the directing effort is above or below the threshold $\bar{\theta}$.

Lemma 1 (Contributing Efforts). *There exists a threshold $\bar{\theta}$, defined in (9), for which the following statements hold true:*

(i) *When the directing effort is low (i.e., $\theta \le \bar{\theta}$), the team members choose to voluntarily contribute to the project beyond what is demanded from them; specifically, $e_i^*(\theta) = (\bar{\theta} - \theta)/(1-\theta) \ge 0$ (i.e., $E_i^*(\theta) = \bar{\theta}$), and the team leader's contributing effort is $E_0^*(\theta) = \bar{\theta} \cdot (\rho)^{1/(1-r)}$.*

(ii) *When the directing effort is high (i.e., $\theta > \bar{\theta}$), the team members choose to not contribute to the project beyond what is demanded from them; specifically, $e_i^*(\theta) = 0$ (i.e., $E_i^*(\theta) = \theta$), and the team leader's contributing effort is $E_0^*(\theta) = \bar{E}_0(\theta)$, in which $\bar{E}_0(\theta)$ is the unique solution of*

$$\left(\frac{kb(V-R-\bar{U}_0)(E_0)^r}{E_0(n(\theta)^r+(E_0)^r)}\right)\cdot\left(\frac{n(\theta)^r+(E_0)^r}{n+1}\right)^{b/r} - c = 0. \qquad (10)$$

Lemma 1 shows that depending on the degree of directing effort, the team members may choose to exert voluntary effort beyond their demanded effort or not. Because the team members' payoffs are tied to project success (through their rewards R/n), when low effort is demanded from them (i.e., $\theta \le \bar{\theta}$), it is optimal for the team members to voluntarily exert more effort on the project so that their total contribution reaches $\bar{\theta}$. On the contrary, when their demanded effort is above their desired voluntary effort (i.e., $\theta > \bar{\theta}$), it is prohibitive for them to exert any effort beyond what is demanded from them.

We next study the interaction between the team leader's and team members' choices of contributing efforts for a given directing effort. We restrict our attention to the case in which $\theta > \bar{\theta}$ because by Lemma 1 that is where contributing efforts are sensitive to the degree of directing effort.

Proposition 1 (Relative Contributions). *For any $\theta > \bar{\theta}$, the following statements hold true:*

(i) *The team leader's equilibrium contributing effort is decreasing in the team members' contributing efforts (i.e., $dE_0^*(\theta)/dE_i^*(\theta) < 0$) if and only if $r > b$.*

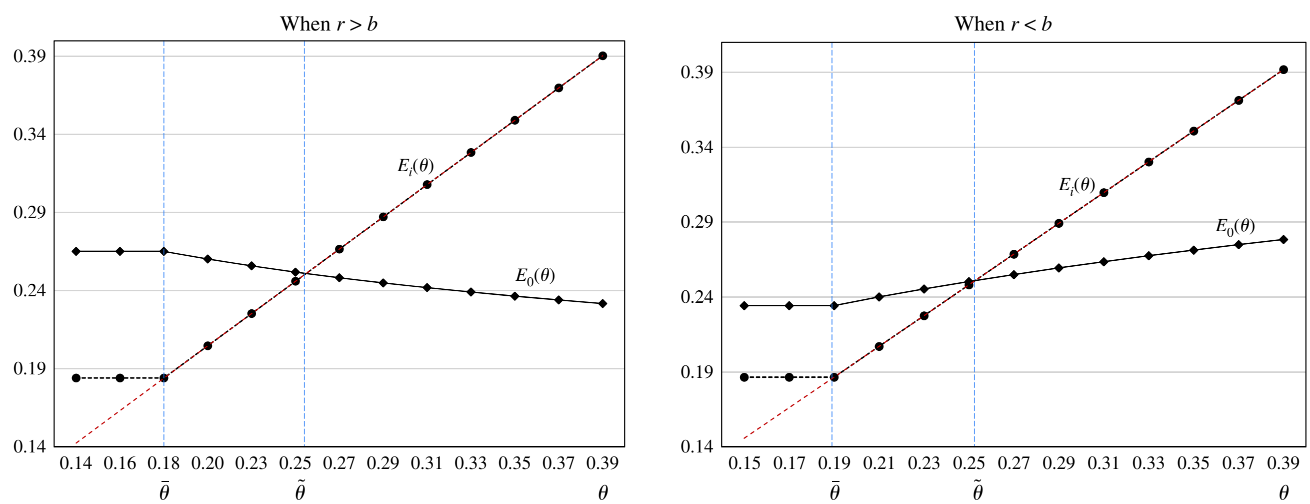
(ii) *The team leader's equilibrium contributing effort is higher than the team members' contributing effort if and only if $\rho > 1$ and $\theta < \tilde{\theta} \doteq (kb(V-R-\bar{U}_0)/((n+1)c))^{1/(1-b)}$.*

Figure 1 illustrates the results in Proposition 1 (when $\rho > 1$). Proposition 1(i) shows that the team leader's contribution can increase or decrease as the team members' contribution increases, depending on whether efforts are strategic complements ($r < b$) or strategic substitutes ($r > b$). Specifically, when the team's contributing efforts are strategic complements (e.g., the project is innovative and requires high interaction), it is beneficial for the team leader to align her contributing effort with the other team members' efforts whereas when they are strategic substitutes (e.g., the project is routine and requires limited interaction), it is beneficial for the team leader to counterbalance the other team members' efforts.

In addition, Proposition 1(ii) shows that the team leader's contribution can be higher or lower than the team members' contributions. Specifically, as a contributor, the team leader chooses to be less involved than the team members when they exert high efforts, which happens when the team members either have high incentives (i.e., $\rho \le 1$) or are demanded to exert high efforts (i.e., $\theta \ge \tilde{\theta}$); otherwise, when both $\rho > 1$ and $\theta < \tilde{\theta}$, the team leader contributes more than the team members.

In the next section, we endogenize the team leader's choice of directing effort and characterize the team leadership approaches that arise in equilibrium.

Figure 1. (Color online) Equilibrium Contributing Efforts with Respect to θ



Note. Parameters: $V = 5{,}600$, $R = 5{,}000$, $k = 0.1$, $n = 10$, $c = 5$, $b = 0.4$, $\bar{U}_0 = \bar{U}_r = 0$, $\rho = 1.2$, $r = 0.2$ (left) and $r = 0.5$ (right).

4.2. Equilibrium Team Leadership

In this section, we first characterize the team leader's optimal directing effort by solving (8) while anticipating the team leader's and members' equilibrium contributing efforts characterized in Lemma 1. We then characterize the team leader's and members' equilibrium contributing efforts and relate them to different team leadership approaches in Proposition 2. Finally, in Proposition 3, we study how the team leader's optimal choice of team leadership approach depends on the team and project characteristics. The next lemma characterizes the team leader's optimal directing effort.

Lemma 2 (Directing Effort). *The team leader's optimal directing effort is either equal to zero or equal to*

$$\hat{\theta} = \min\left\{1, \left(\frac{c}{g}\right)^{1/(1-r)} \left(\frac{kb(V - R - \bar{U}_0)}{c(n+1)} \cdot \left(\frac{n(c/g)^{r/(1-r)} + 1}{n+1}\right)^{(b-r)/r}\right)^{1/(1-b)}\right\}. \tag{11}$$

Using the result in Lemma 2, we next characterize the equilibrium team leadership approaches, which result from the team leader's choice of directing effort and the team leader's and members' choices of contributing efforts.

Proposition 2 (Team Leadership). *Consider $\bar{\theta}$ and $\hat{\theta}$ defined in (9) and (11), and suppose they are strictly less than one. One of the following two team leadership approaches emerges in equilibrium*:

(i) *If $\rho > g/c$, a directive team leadership approach is optimal*: *The team leader demands $\hat{\theta}$ effort from the team members, and they exert no voluntary effort; specifically, $\theta^* = \hat{\theta}$ and $e_i^*(\theta^*) = 0\ \forall i$. Moreover, the team leader contributes $E_0^*(\theta^*) = \hat{\theta} \cdot (g/c)^{1/(1-r)}$.*

(ii) *If $\rho \le g/c$, a participatory team leadership approach is optimal*: *The team leader does not demand effort from the team members, and they voluntarily exert positive efforts; specifically $\theta^* = 0$ and $e_i^*(\theta^*) = \bar{\theta} > 0\ \forall i$. Moreover, the team leader contributes $E_0^*(\theta^*) = \bar{\theta} \cdot (\rho)^{1/(1-r)}$.*

Proposition 2 identifies two types of equilibrium team leadership approaches: (i) Under *directive* team leadership, the team leader exerts both directing and contributing efforts and demands that team members exert more effort than what they would choose to exert voluntarily. (ii) Under *participatory* team leadership, the team leader only exerts contributing effort and gives the team members full discretion on their choice of efforts, and the team members choose to voluntarily exert positive effort toward the completion of the project.

More specifically, Proposition 2 indicates that the choice of team leadership approach depends on the team leader's directing efficiency relative to contributing (g/c) and the ratio of marginal gains (ρ). Specifically, for fixed marginal gains, directive team leadership arises when the team leader's directing efficiency, relative to contributing, is high, and participatory team leadership arises otherwise. On the other hand, for fixed efficiency levels, the choice of team leadership approach depends on the ratio of marginal gains, which is a function of both the team size and team members' rewards. The next proposition characterizes the effect of these two factors on the equilibrium choice of team leadership approach.

Proposition 3 (Sensitivity of Team Leadership). (i) *For a given team size, there exists a threshold $\hat{R}$ such that the directive team leadership approach is optimal if and only if $R < \hat{R}$, and the team leader's directing effort is decreasing in R.*

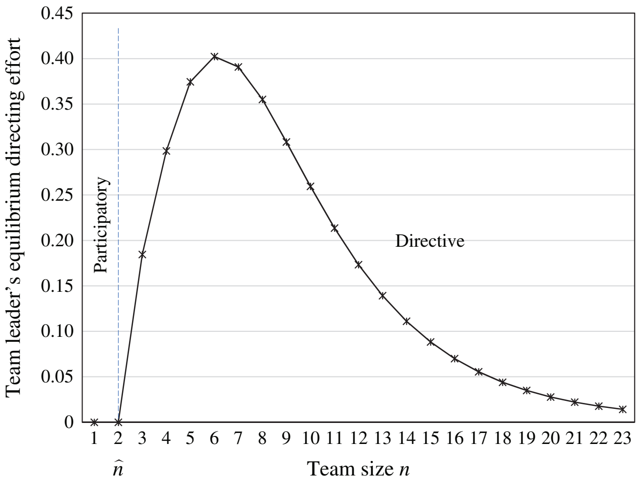
(ii) *For a given team members' reward, there exists a threshold $\hat{n}$ such that the directive team leadership approach is optimal if and only if $n > \hat{n}$, and the team leader's directing effort is quasi-concave in n.*

Proposition 3(i) shows that, when the team members' rewards are low, it is optimal for the team leader to adopt a directive team leadership approach and demand high efforts from the team members. In contrast, when the team members' rewards are high, the team leader should avoid engaging herself in (costly) directing activities because the team members have high incentives to voluntarily contribute to the project. Hence, in projects where team members have high stakes, either financial or nonfinancial (e.g., career opportunities), the team leader should adopt a participatory team leadership approach.

In addition, Proposition 3(ii) shows that it is optimal for the team leader to be directive when the size of the team is large. Because each team member receives a fraction of the reward (i.e., R/n), team members are more prone to free-riding in large teams than in small teams (Kandel and Lazear 1992), similar to the "motivation loss" documented by Ringelmann (1913). As the team size increases, the effect of free-riding increases, and the team leader must switch from a participatory to a directive type of leadership approach to ensure the team members provide enough efforts. The intensity of the team leader's directing effort initially increases in team size, but beyond a certain team size, directing becomes so prohibitive that the team leader decreases her directing effort as the team size increases. Figure 2 illustrates the result.[10]

In summary, our analysis in this section shows that the choice of team leadership approach depends on the team leader's directing efficiency relative to contributing and the team characteristics (i.e., team size and team members' rewards) but that it does not depend on the degree of effort complementarity. That is, irrespective of whether the contributing efforts are complementary or substitutable, the team leader should

Figure 2. (Color online) Team Leader's Equilibrium Directing Effort as a Function of the Team Size n



Note. Parameters: $V = 4{,}000$, $R = 3{,}980$, $k = 0.3$, $c = 16$, $g = 0.2$ $b = 0.9$, $r = -1$, and $\hat{n} = 2$.

switch from a directive team leadership to a participatory team leadership when the team members' rewards are high, the size of the team is small, or her relative efficiency at directing to contributing is high. However, the degree of effort complementarity affects the team leader's optimal combination of directing and contributing efforts, which we study in the next section.

4.3. Optimal Combination of Directing and Contributing Efforts

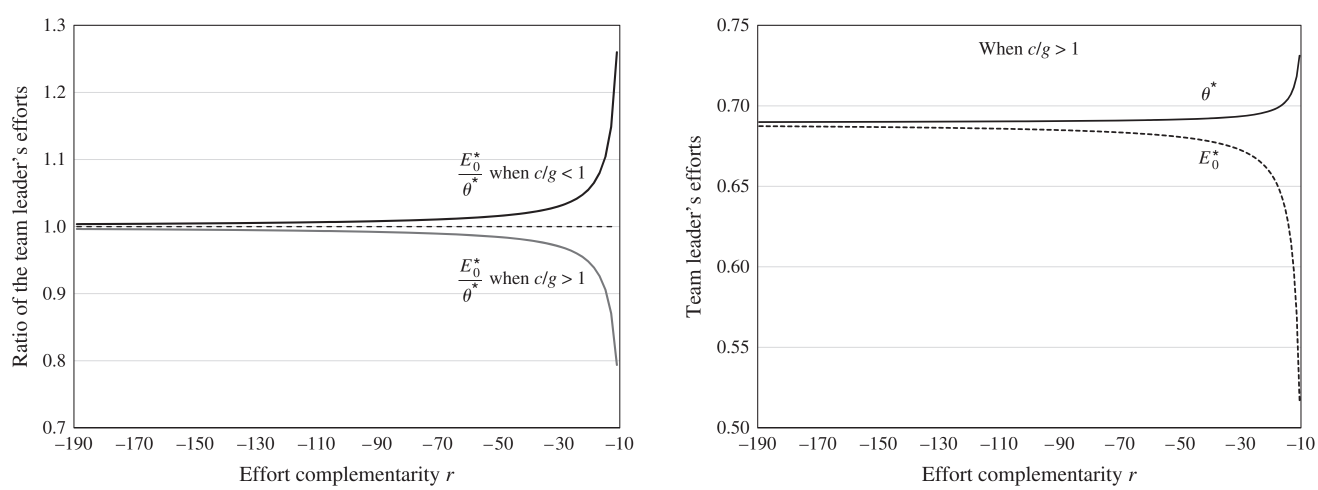
Recall that the team leader exerts both directing and contributing efforts under directive team leadership and only contributing effort under participatory team leadership. In this section, we first analyze the sensitivity of the team leader's optimal combination of efforts under directive team leadership and then analyze the sensitivity of the team leader's contribution relative to the team members' voluntary contributions under participatory team leadership. Overall, we find that greater effort complementarity leads to greater alignment of the team leader's and the team members' contributing efforts, which, under the directive team leadership, also leads to greater alignment between the team leader's directing and contributing efforts.

Proposition 4. *Under directive team leadership, the ratio of the team leader's contributing effort to her directing effort (i.e., E_0^*/θ^*) is increasing in (g/c), and it is decreasing in the degree of effort complementarity (r) if and only if $c \geq g$ with $E_0^*/\theta^* \to 1$ when $r \to -\infty$.*

Proposition 4 shows that, under directive team leadership, the team leader substitutes, in relative terms, her contributing effort with her directing effort as she becomes relatively more efficient at directing than at contributing, irrespective of whether the team's contributing efforts are substitutes or complements (Proposition 1(i)).

Proposition 4 also shows that the team leader's optimal combination of efforts depends on the degree of effort complementarity, and Figure 3 (left) illustrates the results. Specifically, in situations where the team's contributing efforts are complementary, which happens in more innovative projects, it is optimal for the team leader to align her directing and contributing efforts (i.e., when $r \to -\infty$, $E_0^*/\theta^* \to 1$) so that they all contribute at the same level. In contrast, when the team's contributing efforts are more substitutable, which happens in more routine projects, the team leader's directing and contributing efforts should be imbalanced, that is, the team leader should put greater weight on the role in which she is the most efficient (i.e., when $r \to 1$, $E_0^* \ll \theta^*$ if and only if $c > g$). Hence, when the team leader is more (less) efficient at directing than at contributing, that is, $c > g$ ($c < g$), she should direct

Figure 3. E_0^*/θ^* with Respect to r (Left) and (E_0^*, θ^*) with Respect to r When $c > g$ (Right)



Notes. Same parameters as in Figure 1 with c/g equal to 0.5 and 2. Note that the degree of effort complementarity increases as r decreases.

less (more) and contribute more (less) when efforts are complementary than when they are substitutable as illustrated in Figure 3 (right).

Under participatory team leadership, the team leader only uses her lever of contributing effort, which we next compare with the team members' voluntary contributions in terms of the team and project characteristics.

Proposition 5. *Under participatory team leadership, the ratio of the team leader's contributing effort to the team members' voluntary contributions (i.e., E_0^*/E_i^*) is increasing in team size n, it is decreasing in the team members' rewards R, and it is decreasing in the degree of effort complementarity (r) if and only if $\rho \le 1$ with $E_0^*/E_i^* \to 1$ when $r \to -\infty$.*

Proposition 5 shows that, under participatory team leadership, the team leader increases her contribution relative to the team members' voluntary contributions when the team members have lower incentives to contribute to the project either collectively (low R) or individually (high n) because of the higher degree of free-riding (Kandel and Lazear 1992) and motivation losses (Ringelmann 1913).

In addition, similar to the case of directive team leadership (Proposition 4), the team leader's and the team members' contributing efforts should be aligned when the team's contributing efforts are more complementary (i.e., when $r \to -\infty$, $E_0^*/E_i^* \to 1$) and imbalanced otherwise; in the latter case, the direction of imbalance depends on the relative magnitude of rewards ρ, and not on the team leader's relative efficiency g/c (i.e., when $r \to 1$, $E_0^* \gg E_i^*$ if and only if $\rho > 1$).

In summary, our analysis in this section shows how the team leader's optimal combination of directing and contributing efforts depends on the team and project characteristics. In particular, when the team members' rewards are low or the size of the team is large, directive team leadership arises in equilibrium, where the team leader exerts both directing and contributing efforts. In that situation, the team leader should align her directing and contributing efforts when the team's contributing efforts are complementary and have them imbalanced otherwise, and the direction and intensity of imbalance depend on the team leader's relative efficiency in each role. On the contrary, when the team members' rewards are high or the size of the team is small, participatory team leadership arises in equilibrium, where the team leader exerts contributing effort but no directing effort. In that situation, the team leader and the team members should align their efforts when contributing efforts are complementary and have them imbalanced otherwise, and the direction and intensity of imbalance depend on their relative rewards.

In the next section, we study situations in which, in addition to the levers of contributing and directing, the team leader has also been given the decision right to choose the team size and team members' rewards.

4.4. Setting Team Size and Team Members' Reward

In order to study how team leaders (if given the decision rights)[11] should choose the team size and team members' rewards, we assume that the team leader chooses the team size and team members' reward so as to maximize her payoff and before choosing her directing and contributing efforts. Thus, using backward induction and by replacing the equilibrium efforts $(E_0^*, \mathbf{e}^*, \theta^*)$ from Proposition 2 in (8), the team leader chooses the team size and team members' reward to maximize the following payoff:

$$U_0(n,R) \doteq -g(\theta^*(n,R)) - c(E_0^*(n,R)) + V_0\big(E_0^*(n,R), \mathbf{e}^*(n,R), \theta^*(n,R)\big), \qquad (12)$$

in which $\theta^*(n,R)$, $E_0^*(n,R)$ and $\mathbf{e}^*(n,R)$ are defined in Proposition 2, and $V_0(E_0, \mathbf{e}, \theta)$ is defined in (4). In addition, we require $n \ge n_{\min}$ and $R_{\min} \le R < V$, in which $n_{\min} \ge 1$ and $R_{\min} > 0$ denote the smallest team size and reward, respectively, that the team leader is allowed to set.[12] We first characterize the optimal team size and team members' reward under directive team leadership and then under participatory team leadership.

Proposition 6. *Under directive team leadership, the optimal team size is $n^* = \max\{\lceil ((c/g)^{r/(1-r)} - 1)/r(c/g)^{r/(1-r)} \rceil, n_{\min}\}$, and the optimal team members' reward is $R^* = R_{\min}$. In addition, n^* is decreasing in (g/c) and is quasi-concave in r.*

Proposition 6 shows that, under directive team leadership, it is optimal for the team leader to offer the team members the lowest reward possible (i.e., $R^* = R_{\min}$) and set the team size based on her costs of efforts and the degree of effort complementarity, which is typically larger than the minimum team size (i.e., $n^* \ge n_{\min}$). Specifically, the more efficient the team leader is at directing relative to contributing, the larger the team size.

To get intuition into this result, recall that, under directive team leadership, the team leader directs the team members' efforts to the extent that they exert no voluntary effort. Therefore, it is optimal for the team leader to set low rewards for them. On the other hand, the team leader's choice of team size affects the relative effectiveness of her directing and contributing efforts in the probability of success (i.e., her directing effort is weighted by $n/(n+1)$, and her contributing effort is weighted by $1/(n+1)$). Accordingly, the team leader should choose a larger team size the more efficient she is at directing than at contributing.

In the next proposition, we characterize the team size and team members' rewards that maximize the team leader's payoff under participatory team leadership. In order to simplify the analysis, we assume that $\bar{U}_0 = \bar{U}_i = 0\,\forall\, i$. In addition, we consider the case in which $r < 0$, but we numerically observed similar results for when $r > 0$.

Proposition 7. *Under participatory team leadership and when $\bar{U}_0 = \bar{U}_i = 0\ \forall\, i$ and $r < 0$, the optimal team size is $n^* = n_{\min}$, and the optimal team members' reward is $R^* = \max\{\bar{\alpha}\cdot V, R_{\min}\}$, where $\bar{\alpha}$ is unique and satisfies $0 < \bar{\alpha} < b$.*

Proposition 7 shows that under participatory team leadership and when $r < 0$, the team leader should assemble the smallest team possible (i.e., $n^* = n_{\min}$) and provide a reward to the team members that is typically above the minimum reward (i.e., $R^* \geq R_{\min}$). Consistent with the team size result, Brooks (1995) proposes that complex development projects are better run with smaller teams, and Hackman and Vidmar (1970) observe that dyadic teams tend to outperform larger teams.

It turns out that the optimal team members' reward R^* increases when efforts are more complementary (i.e., r is small). The reason is as follows: because when efforts are complementary, the team leader's and team members' efforts should be aligned (Proposition 5), and the team leader should therefore offer higher rewards to the team members. In contrast, when efforts are substitutable, efforts are typically imbalanced, and the team leader may offer low rewards to the team members and increase her own contribution instead.

To get intuition into this result, recall that, under participatory team leadership, the team leader's contribution relative to the team members' voluntary contributions (i.e., E_0^*/E_i^*) is smaller when the team members have lower incentives to provide effort, that is, when they receive a smaller reward R or when the size of the team n is larger (Proposition 5). Therefore, if the team leader assembles a large team, she needs to contribute more proportionally, which may be costly; in addition, she needs to allocate a large proportion of the project reward to the team members to increase their voluntary contributions (because they each receive R/n), which then reduces her own share of the project reward in case of success. For these two reasons, it is optimal for the team leader to choose a small team size and provide high rewards to the team members to motivate them.[13]

In practice, there may be additional factors not modeled here that would make the team leader want to operate with a larger team, such as requiring various kinds of expertise (e.g., when the team members are not symmetric), adopting technology to mitigate coordination losses in large teams (e.g., when the scaling parameter k in (2) is an increasing function of n, cf. Endnote 8), or managing project tasks that are not coproductive (e.g., when the degree of effort interdependency is additive or disjunctive). We leave it for future research to explore the effect of these factors on the team leader's choice of team size and whether they could lead the team leader to choose a larger team size under participatory rather than directive team leadership.

In summary, our analysis in this section shows that directive and participatory team leadership approaches have opposite effects on the choice of reward and team size: Whereas the reward should be small under directive team leadership, it should be sufficiently high under participatory team leadership to provide incentives to the team members to voluntarily contribute to the project. And whereas the team size should be small under participatory team leadership, it can be much larger under directive team leadership as it may be more efficient for the team leader to increase the chances of success of the project through direction than through contribution. Hence, our analysis suggests that the team leader's strategic decisions on team size and reward design and her operational decision on combining directing and contributing roles are more effective when they are aligned.

5. Project with Multiple Sequential Trials

In this section, we generalize the model in Section 3 to a setting where the project consists of a finite number of sequential trials. We denote by T the maximum number of trials before the project gets terminated and by $t \in \{T, T-1, \ldots, 0\}$ the remaining number of trials. Hence, the project is stopped in two situations: (i) if it succeeds in any trial before reaching T, upon which the team leader and members receive their corresponding rewards, or (ii) if the final trial T is reached and the project is still not successful, upon which the project is terminated and the team leader and members receive no reward. This implies that the overall chances of success become smaller as the project gets closer to its final trial T, and this is reflected on continuation payoffs (i.e., payoffs upon failure $\bar{U}_0$ and $\bar{U}_i\ \forall\, i \in \mathcal{N}$).

We assume that for each trial t, the team leader and members choose their effort levels. Specifically, in each trial, the team leader first chooses her directing effort θ_t, and then, the team leader and members choose their corresponding contributing efforts; that is, the team leader chooses $E_{0,t}$, and each team member chooses $e_{i,t}$ for all $i \in \mathcal{N}$ and $t \leq T$. Thus, because of this dynamic choice of efforts, the success probability of the project changes in each trial. For simplicity, we assume that trials are independent of each other (similar to Kwon et al. 2010 and Terwiesch and Loch 2004, and consistent with empirical evidence in Adler et al. 1995, 1996). That is, we assume that the functional form of the success probability and costs are identical across trials.[14]

Accordingly, for each trial t, we rewrite the contribution game in (7) as follows:

Contribution Game in Trial t:

$$\begin{cases} E_{0,t}^*(\theta_t) = \underset{E_{0,t}\in[0,1]}{\arg\max}\, U_{0,t}(E_{0,t}, \mathbf{e}_t^*(\theta_t), \theta_t), \\ e_{i,t}^*(\theta_t) = \underset{e_{i,t}\in[0,1]}{\arg\max}\, U_{i,t}(E_{0,t}^*(\theta_t), (e_{i,t}, \mathbf{e}_{-i,t}^*(\theta_t)), \theta_t), \end{cases} \quad \forall\, i \in \mathcal{N} \quad (13)$$

in which

$$U_{0,t}(E_{0,t},\mathbf{e}_t,\theta_t) \doteq -g(\theta_t)-c(E_{0,t})+p(E_{0,t},\mathbf{e}_t,\theta_t)\cdot(V-R) \\ +(1-p(E_{0,t},\mathbf{e}_t,\theta))\cdot U^*_{0,t-1}, \tag{14}$$

$$U_{i,t}(E_{0,t},\mathbf{e}_t,\theta_t) \doteq -c(E_{i,t}(\theta,e_i))+p(E_{0,t},\mathbf{e}_t,\theta_t)\cdot(R/n) \\ +(1-p(E_{0,t},\mathbf{e}_t,\theta))\cdot U^*_{i,t-1}, \tag{15}$$

with $U_{0,0}=0$ and $U_{i,0}=0$. We focus on pure strategy Markov equilibrium of the contribution game in (13), which is the most common type of equilibrium used in the analysis of dynamic games with simultaneous moves (Fudenberg and Tirole 1991, Cachon and Netessine 2003) and is also consistent with existing literature (e.g., Bonatti and Hörner 2011, Keller et al. 2005, Keller and Rady 2010, Hörner and Skrzypacz 2017).

Similar to (8), in each trial t, the team leader chooses her directing effort as follows:

$$\theta^*_t = \underset{\theta_t\in[0,1]}{\arg\max}\, U_{0,t}(E^*_{0,t}(\theta_t),\mathbf{e}^*_t(\theta_t),\theta_t). \tag{16}$$

Finally, the optimal continuation payoffs to go for the team leader and members can be obtained by $U^*_{0,t}=U_{0,t}(E^*_{0,t}(\theta^*_t),\mathbf{e}^*_t(\theta^*_t),\theta^*_t)$ and $U^*_{i,t}=U_{i,t}(E^*_{0,t}(\theta^*_t),\mathbf{e}^*_t(\theta^*_t),\theta^*_t)$, respectively.

The results derived in Section 4 generalize to this setting of multiple trials by replacing payoffs upon failure $\bar{U}_0$ and $\bar{U}_i$ with continuation payoffs $U^*_{0,t-1}$ and $U^*_{i,t-1}$ (see Lemma EC.13). In particular, according to Proposition 2, directive team leadership is optimal in trial t if and only if $\rho_t \ge g/c$, in which

$$\rho_t \doteq \frac{V-R-U^*_{0,t-1}}{R/n-U^*_{i,t-1}}. \tag{17}$$

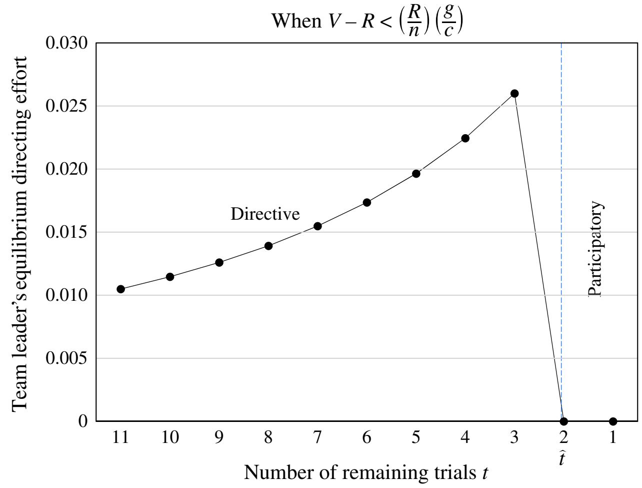
Hence, the choice of team leadership approach over multiple trials depends on the continuation payoffs $U^*_{0,t-1}$ and $U^*_{i,t-1}$.

As the number of remaining trials t decreases, the team leader's and members' continuation payoffs decrease because the chances of success get smaller; as a result, both the numerator and denominator of ρ_t increase as t decreases. In the next proposition, we study how the team leader should adapt her team leadership approach as a function of the number of remaining trials.

Proposition 8 (Multiple Trials)**.** *There exists a threshold $\hat{t}$ such that directive team leadership is optimal in period t if and only if $t\ge\hat{t}$. In addition, $\hat{t}>0$ if and only if $V-R\le(R/n)(g/c)$.*

Proposition 8 shows that a directive team leadership approach is optimal in the early trials and a participatory team leadership approach is optimal in the late trials. Figure 4 illustrates the result in Proposition 8. As

Figure 4. (Color online) Team Leader's Equilibrium Directing Effort θ_t with Respect to Remaining Trials t



Notes. Parameters: $V=250$, $R=185$, $k=1$, $n=8$, $c=4$, $g=12$, $b=0.6$, $r=0.5$. Threshold: $\hat{t}=2$.

with our analysis of the single-shot project, the intuition behind this result is related to the team members' incentives. In the early trials, the team members' incentives are low because, should they fail, they still have many opportunities to succeed. As a result, the team leader should be more directive to increase the chances of early success. In the late trials, the deadline provides enough incentive for the team members to contribute to the project, and the team leader can switch to a more participatory mode. Hence, the insights from the single-shot project generalize to a dynamic setting with independent trials.

6. Conclusions

In knowledge-intensive and coproductive projects (e.g., software development, new product development), one of the biggest challenges project team leaders often face is how to combine their roles of contribution and direction (Hill and Lineback 2011, Kua 2014). In this paper, we introduce an analytical model of team leadership as an organizational mechanism to improve team performance by considering how team leaders should combine their directing and contributing efforts and, if given the authority, how they should set the team size and team members' rewards. We consider both a single-shot project and a project that consists of multiple independent trials with a finite deadline.

We identify two equilibrium team leadership approaches. Under "directive" team leadership, the team leader demands team members exert more effort than what they would choose to exert voluntarily. To the contrary, under "participatory" team leadership, the team leader gives the team members full discretion over their choice of effort levels. We show that the directive team leadership approach is optimal when

Table 2. Summary of Results

	Large team, low reward	Small team, high reward
Substitutable efforts (routine projects)	Directive team leadership (imbalanced direction and contribution)	Participatory team leadership (contribution, but no direction)
Complementary efforts (innovative projects)	Directive team leadership (aligned direction and contribution)	

the team members' incentives are low, which happens when their rewards are low, the size of the team is large, or failure is not too costly (e.g., continuation is possible in a multi-trial setting). Otherwise, the participatory team leadership approach is optimal.

Under both team leadership approaches, we show that the team leader's and members' contributions to the project should be aligned when contributing efforts are complementary (as in innovative projects) and imbalanced otherwise (as in routine projects). This leads, under directive team leadership, to greater alignment (imbalance) between the team leader's directing and contributing efforts when efforts are complementary (substitutable). Also, in case of imbalance, the team leader should put greater weight on the role in which she is the most efficient. Similarly, under participatory team leadership, the contributions are aligned under complementary efforts and imbalanced otherwise, and in the latter case, the direction of imbalance depends on the relative rewards. Table 2 summarizes how team leaders should combine their roles of direction and contribution, depending on the project and team characteristics.

When the team leader has the decision right to choose the team size and team members' rewards, we show that the team leader should set the team size and team members' rewards in a way that accentuates the difference between the two equilibrium team leadership approaches. Particularly under directive team leadership, she should offer the team members low rewards and set the team size so as to balance the effectiveness of her directing and contributing roles. In contrast, under participatory team leadership, she should set a small team size and offer the team members sufficiently high rewards to exert voluntary efforts, especially when efforts are complementary and need to be aligned.

Our model can be extended in several directions. First, we could consider heterogeneity of team members in terms of costs and skills. Although our model of effort complementarity captures some notion of skill complementarity, it may be worth studying how the heterogeneity in the team members' costs and success rates affects the results. Second, in our generalization to a multi-trial setting, we could consider effort-dependent trials with learning effects. Although our preliminary analysis shows that the same insights would hold, it may be worth exploring how such effects impact the team leader's choices. As another extension, we could consider a different performance objective; for example, the leader could maximize a weighted average of her payoff and the other team members' payoffs, similar to the altruistic leader of Rotemberg (1994).

Despite the evidence that team leaders are critical for project success and firm performance (Krishnan and Ulrich 2001, Hill and Lineback 2011, Mollick 2012), the operational role of leaders as team managers has received limited attention in management science. We hope that this study will open up a new avenue for future research on the operational role of leaders.

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Endnotes

[1] Throughout the paper, we refer to the team leader as "she" and each of the team members as "he."

[2] We use the term "team leadership" to emphasize the impact of a leader on team management and to distinguish its nature from "strategic leadership."

[3] We use the term "approach" to distinguish our leadership type from "style" so as to reflect that it is the outcome of a rational decision process as opposed to psychological traits.

[4] In practice, any team leadership position may involve some unavoidable bureaucratic tasks (e.g., completing paperwork and enforcing the firm's procedure and policies), which may not be under the team leader's control. Because such bureaucratic tasks have no impact on our analysis and results, we ignore them for simplicity.

[5] This assumption guarantees that the project's success rate, introduced in (2), lies in the unit interval (Keller et al. 2005, Bonatti and Hörner 2011).

[6] In the economics literature, Alchian and Demsetz (1972, p. 779) propose that "the output [of team production] is not a *sum* of separable outputs of each of its members . . . [making it] difficult, solely by observing total output, to either define or determine *each* individual's contribution to this output." In the sociology literature, Van De Ven et al. (1976, p. 325) propose that team workflows are the most interconnected among the various kinds of "operations technologies" identified by Thompson (1967) when "the work is undertaken

jointly by unit personnel who diagnose, problem-solve and collaborate in order to complete the work."

[7] For instance, Forsyth reports that "groups often outperform the most incompetent group member (the "better than the worst" effect), and they may outperform as well as the most competent member (the "equal to the best" effect), but the "better than the best" effect occurs only rarely" (Forsyth 2009, p. 300).

[8] The success probability (2) can be extended to the case in which the scaling parameter k is a function of n as in Kremer (1993) and Heywood and Jirjahn (2009) to capture situations in which the coordination losses take a different form than what is specified here. Unless noted otherwise, our results about the team leader's optimal combination of directing and contributing efforts (i.e., Propositions 1–5) extend to a (general) functional form of $k(n)$.

[9] Accounting for those boundary cases leads to similar insights at the expense of a more complicated exposition. See Bonatti and Hörner (2011) for a similar assumption on agents' efforts.

[10] When the scaling parameter k in (2) is a function of team size n (cf. Endnote 8), the first half of Proposition 3 (ii) still holds, but the team leader's directing effort may not necessarily be quasi-concave in n, depending on the functional specification of $k(n)$.

[11] In certain situations, such as in academic research and startups, team leaders (e.g., principal investigators or founders) have the authority to determine the size of the team and the team member's rewards. However, this may not be the case in situations in which these decisions are made by the firm (e.g., in large semiconductor or pharmaceutical companies) or when rewards are nonfinancial (e.g., career opportunities).

[12] When $n = 1$, the team is a dyad consisting of the team leader and a team member.

[13] When $r > 0$, the team leader's payoff in (12) may not be monotone in n for a given R or quasi-concave in R for a given n. However, we numerically observed that the results in Proposition 7, which consider the joint optimization over (n, R), were in general robust; that is, in our extensive numerical simulation, we always found that n^* and R^* were as given in Proposition 7.

[14] In projects with multiple trials, the maximum probability of success (k) could be trial-dependent. For instance, k_t could be increasing in t in projects in which, upon each failure, the team leader and members become more pessimistic about the viability of the project (Bonatti and Hörner 2011, Zhang 2016). In contrast, k_t could be decreasing in t in projects in which, upon each trial, the team leader and members learn new things about the project (e.g., customer feedback) or get better at working together, which makes them more optimistic about the chance of success. It turns out that our results in this section hold for any functional form of k_t (whether increasing or decreasing in t) provided that it is effort-independent, and we leave the study of its effort dependency for future research.

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