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Encouraging Help Across Projects

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Abstract. Companies struggle with timely project execution despite employing sophisticated management methods. Although help across projects is critical for time performance, it has not been explicitly incorporated into project management (PM) systems. We model a PM system, based on an innovative real-life practice, that both incorporates and shapes project managers' helping behavior. A help process is at the core of this system, in which project managers may ask for and provide help while top management facilitates such exchanges. We find that companies should take a nuanced approach when designing help exchange and time-based incentives in tandem. A company that faces high project rewards after delays and highly effective help can benefit from inducing help because doing so enables the pursuit of projects it might abandon if delayed or even at the outset. The formal help process delivers value by creating and exploiting interdependencies between projects. These interdependencies allow project prioritization by inducing different effort levels in otherwise identical projects. A help process also allows the company to "tune" the timing of efforts by front-loading or back-loading project work. The benefits of a help system accrue through cost efficiencies, increased probability of success under help, and intertemporal incentive effects that encourage early efforts. However, because the help process creates the opportunity for free riding, a help system is not always recommended and a no-help system may perform better, especially when there are low project rewards after delay and low opportunity costs for project work.

Keywords: project management • new product development • cooperative behavior

1. Introduction

Timely project completion is crucial for firms in competitive markets (Eisenhardt and Tabrizi 1995, Cohen et al. 1996, Loch and Kavadias 2011). Across industries, however, firms are plagued by project delays. Mitchell (2006) reports that 49% of all information technology projects are late, overrunning their intended duration by 63% on average; according to Assaf and Al-Hejji (2006), 70% of large construction projects exhibit an average time overrun of 30%. Even the tightly controlled OEM (original equipment manufacturer) automotive suppliers surveyed by Hartley et al. (1997) complete 17% of their projects late and with an average delay of 12%. Cooperative behavior across projects is one success factor in timely project completion that has been suggested by project practitioners (PMI 2013) and also by empirical innovation researchers (Sivadas and Dwyer 2000, Hoegl et al. 2004). Yet current approaches remain vague (if not altogether silent) about just how to incorporate cooperative behavior into a project management (PM) system. Most notably, the widely used *A Guide to the Project Management Body of Knowledge* relegates the encouragement of help to the realm of leadership (PMI 2013, chap. 9.3) but fails to describe any PM *processes* for attaining and harnessing help.

In this paper we explicitly study when, how, and why cross-project help should be embedded into the formal building blocks of a project management system. Our parsimonious model is inspired by and grounded in a cooperative PM system implemented at Roto Frank AG (hereafter Roto), a window and solar technology manufacturer based in Germany. In December 2009, this company implemented a system designed to create and exploit cross-project help by launching an innovative PM practice that formalized mutual help at the project execution level. In particular, project engineers at Roto are encouraged to publicize emerging problems that threaten on-time completion of their task by "raising a red card"—which means that troubled project engineers actually put a small red flag on top of their work desks. This change reflects the lean management principle of *visualization*: the idea of signaling work progress and making problems observable to everyone on the work floor.

To encourage engineers' use of the red cards, Roto's top management promised to facilitate support for the troubled project engineer by enlisting the help of colleagues working on other projects, who would form a *red-card team* in charge of resolving the issue. (We shall ease the exposition by using masculine and feminine pronouns for agents who, respectively, request and provide help.) Members of a red-card team are selected for their technical expertise and availability—that is, they are recruited only from projects that are on schedule and can afford to provide some engineering help. Other than this modification of project execution processes, Roto's PM system remained unchanged. In particular, the project *planning* that annually assigns projects to project managers was not altered; neither was the principle changed that project managers and engineers work on secondary (nonproject) tasks when not busy with their main projects.

After implementing the red-card system, Roto demonstrated three consecutive years of increased project performance as measured by improved deadline reliability and reduced expenditures on late tool changes. The average number of milestone delays per project fell from 60 in 2009 to 30 in 2012 (out of 120 milestones per project on average), and expenses for late tool changes declined 55% over that time period—during which project portfolios remained comparable in terms of both quantity (20 projects per year) and quality (high-end roof windows requiring six worker years of labor input). For more details, see Sting et al. (2015).

The model developed here allows us to analyze and generalize the central new concept of Roto's PM system, the *formal help process*, in order to explore when and how it can be used to achieve success in different project environments. We adopt Roto's definition of the operative term: *help* is exchanged when a manager of one project deploys effort and resources to cooperate on another manager's project. A formal help process—as implemented by Roto—establishes clear guidelines for project managers who seek problem-solving support and also gives the company a way to monitor and reward the provision of such help.

Our paper is the first to model help in a multiproject setting where timely completion matters. In doing so, it makes contributions by answering three critical questions, namely, *when*, *how*, and *why* a company should encourage help across projects. First, we build a comprehensive framework that characterizes *when* the firm should incorporate help into its PM system—and when it might be preferable to rely on a no-help system. Using this framework, we develop insights on the relative gains possible from a help system contingent not only on strategic factors (project and recovery values) but also on operational factors (effectiveness of efforts and opportunity costs). Contrary to intuition, a help system becomes *more* advisable as the project managers' opportunity cost increases. Also, since a help system can transform loss-making projects into viable ones, it can be more advantageous to projects of low than of high value.

Second, we prescribe *how* to use a formalized help process to manage multiple projects. The key lies in the combination of creating interdependencies between projects and designing help-based and time-based incentives accordingly. In implementing the help system, the firm should exploit the flexibility of pooling resources from multiple projects toward a troubled one, and reward project managers for time performance and help exchange. A formal help process works by purposely creating interdependencies and then exploiting these. It gives the firm options to prioritize ex ante identical projects one over another, and back-load resources in projects. As a consequence, encouraging help expands the portfolio of projects that can be profitably undertaken with high levels of engagement. This approach is in contrast with that in the no-help system where project engagement and incentives are purely based on the success of one's own project.

Finally, we demonstrate, from a cost-benefit perspective, *why* firms should choose to optimally influence help exchange. The costs of help are incurred because the firm needs to pay both managers for help exchange and meanwhile overcome free-riding concerns. The benefits of help are generated by the following mechanisms. Cost efficiencies can arise when the effectiveness of help is very high, which lowers the risk of failure and hence the incentives to both project managers under help. Even if the cost burden were to increase, the higher probability of success under help may yet raise the expected value to the company if the cost is not overly high. Finally, intertemporal incentive effects lower the incentives in the first stage as the project managers anticipate the possibility to provide help and earn the rent to overcome free riding. Implementation of the help system may not be optimal when the benefits of help are small and unable to compensate for the cost of free riding. Thus, the formal help system is intended to channel the helping behavior rather than encourage altruistic helping, after fully accounting for all costs and benefits of helping.

Our findings echo recent research (Hutchison-Krupat and Kavadias 2016) addressing optimal incentives for cross-functional teams. We also show how a firm can use help to optimize the timing of high engagement in projects. In doing so, firms may benefit from earlier project engagement and thereby reap the well-known benefits of front-loading (Thomke and Fujimoto 2000). We augment those results by showing that back-loading of project engagement (i.e., delaying project efforts) can also be optimal when a help process is in place.

2. Related Literature

This paper speaks and contributes primarily to the literature on incentives in project management.

The practitioner-oriented bodies of PM knowledge (Kerzner 2013, PMI 2013) emphasize the importance of help across projects. However, this literature does not offer any systematic advice on when, how, and why to encourage such help. The innovation management literature similarly indicates that cooperative behavior across projects improves their performance (Sivadas and Dwyer 2000, Hoegl et al. 2004) while offering no theoretical analysis of the benefits and drawbacks of a formal help process. To inform our inductively motivated research problem, we can nevertheless (i) conceptually draw from the organizational design literature on interdependencies and coordination between subunits, and also (ii) methodologically build on the principal-agent literature that addresses incentives for cooperation.

2.1. Interdependencies Between Projects

When managing multiproject environments (e.g., in R&D organizations), it is crucial to recognize that—although completing any project contributes value to the company—there are interdependencies between projects and their managers (Adler et al. 1995, 1996). These interdependencies entail that specific actions taken in one project will affect the other project (Krishnan and Ulrich 2001). So that we can better characterize these interdependencies, in this paper we adopt a framework from the field of organizational design (Puranam et al. 2012) that distinguishes between project interdependence and agent interdependence.[1] Consider the case of two projects, 1 and 2, that are assigned (respectively) to project managers A and B.

Project interdependence exists when the value of executing one project differs as a function of whether or not the other project is also executed. Project interdependence could arise from interdependent inputs, as when joint dependence on a common input factor offers economies of scale and pooling benefits or when projects compete for resource allocation (Kavadias and Loch 2003, Girotra et al. 2007). It could also arise from interdependent outputs, as when knowledge is developed over time in domains that span several projects (Chao and Kavadias 2008, Gaimon et al. 2011) or when the projects aim to develop compatible solutions that yield a consistent overall result (Mihm et al. 2003, Sosa et al. 2004, Gokpinar et al. 2010).

Agent interdependence exists when the reward for project manager A depends on project manager B's actions (and vice versa). Thus project agents are interdependent when they face "broad" incentives linked to the output of all agents' units; they are independent when they face "narrow" incentives linked only to their own units' outputs (Kretschmer and Puranam 2008). Puranam et al. (2012) argue that task interdependence is neither necessary nor sufficient for agent interdependence, so the two concepts are orthogonal and can be decoupled.

Kretschmer and Puranam (2008) explore incentives for collaboration between differentiated subunits with interdependent production functions. These authors find that the benefits of increased agent interdependence (via broad incentives for both subunits' outputs) do increase collaborative efforts but may come at the cost of each subunit neglecting its own production tasks. Hutchison-Krupat and Kavadias (2016) study the optimal breadth of incentives for cross-functional teams under different value-generating project interdependencies. They find that functional interdependencies can act as substitutes for agent interdependencies; in other words, the breadth of incentives becomes less important as functional interactions become more important for value creation.

From a conceptual standpoint, the helping mechanism we introduce creates *agent interdependence* via broad incentives that account for helping. Thus the reward for project manager A depends in part on the actions of help provided by project manager B. In the absence of help, projects are assumed to be independent. Yet if help is provided then, because agents also represent the (key) input factor required to execute projects that are made available across tasks, *project interdependence* is also created. To see this, consider the value of executing project 1. Under a system with help, the value contributed by project 1 depends also on whether and when project 2 is executed; the reason is that early execution of project 2 can free up input factor capacity (in the form of help from manager B) for project 1. Our study first contributes to the research on project and agent interdependencies by adding the time dimension of project execution: the company reorganizes project work dynamically by means of a help process. Second, our study complements this research by demonstrating how the firm chooses an optimal level of agent interdependence (ranging from a narrow agent focus to broader, help-based incentives) and also an optimal level of project interdependence (no, unilateral, or mutual help exchange between projects). It is worth noting how our results reveal that "shirking" can be beneficial in certain situations (Hutchison-Krupat and Kavadias 2016)—here, as a result of asymmetric engagement deliberately induced by the firm. However, since help in our system is exchanged dynamically (red-card help is contingent on the helping agent's own project being on schedule), it follows that help never has priority over own-project work.

2.2. Cooperation and Moral Hazard in Projects

Principal-agent models are naturally relevant to PM settings in which project managers are better informed than is the company about (a) their uncertain tasks and (b) the costly efforts they exert (Mihm 2010). The result is a moral hazard problem between agents and the principal, who cannot observe agent effort levels. Hence the principal seeks to design contracts that incentivize each agent to exert the desired effort level (Laffont and Martimort 2001). In the context of multiple agents, Itoh (1991) introduces the possibility of cooperation in a two-agent, two-task model where each agent decides on own-task effort levels and also on effort levels for helping the other agent. Neither type of effort is observable by the principal. The principal maximizes company profits by setting a compensation scheme that induces either strict division of labor or teamwork with mutual help; the latter outcome is optimal when help and own-task effort are complements. A similar situation is studied by Drago and Turnbull (1991), who predict that companies will implement noncompetitive promotion schemes when help is efficient and there is imperfect information regarding worker effort. Building upon Itoh's model, Siemsen et al. (2007) derive optimal individual and group incentives in the presence of different linkages pertaining to outcome, help, and knowledge. When help linkages exist—that is, when agents can effectively provide help—optimal group-level incentives should be positive. In contrast with Kretschmer and Puranam (2008) and Hutchison-Krupat and Kavadias (2016), this literature suggests that group and individual incentives must be carefully balanced in order to discourage agents from shirking.

The moral hazard problem in our project environment bears similarities to the principal-agent models just cited. However, the time dimension—which is key for value creation in our multiproject setting—has been neglected by classical principal-agent models with cooperation (Holmstrom and Milgrom 1990, Itoh 1992). Rather than relying on help, for instance, project managers may simply choose to spend more effort in a later period (Zhang 2016, Rahmani et al. 2017). Crucial to the problem we study is that an agent can help a colleague only if her own project is on schedule, so that she has "freed up time" to provide help. Moreover, the provision of help is visible to top management; this visibility allows the company to facilitate the help process by tailoring new incentives in addition to those already in place.

In project environments where completion time plays a leading role, Bayiz and Corbett (2005) and Kwon et al. (2010) study payment schemes for multiproject subcontractors who work on complementary tasks. Wu et al. (2014) incorporate present-biased agents who exhibit a behavioral tendency to postpone work for later completion. In such environments, milestones and deadlines are crucial determinants of individual (Zhang 2016) or coproduction efforts (Rahmani et al. 2017). These models highlight the intricate interplay of payment and effort timing. However, none of the cited papers accounts for help across projects.

In multiproject settings under uncertainty and centralized decision making, the flexible rearrangement of project work has been shown to reduce the completion times of projects. Adler et al. (1995, 1996) show how multiple cross-trained engineers working on the same task can reduce average project completion times. For environments characterized by task-time uncertainty, Goh and Hall (2013) advocate risk pooling via flexible commitment of resources (e.g., personnel, equipment, budget) to individual project tasks. However, this literature has ignored how help across projects can unlock the benefits of risk pooling—let alone when and how it should be encouraged. In this paper we do characterize when and how resource flexibility can be profitably created, by means of a help process, in decentralized project environments.

3. Model and Analysis

3.1. Model Grounding

Our model is grounded in the three most salient components of Roto's PM system: its project portfolio planning, (2) the implemented help process, and (3) performance measurement and rewards. Table 1 lists the detailed components of Roto's formal help system and our translation into a formal model.

First, the model should represent Roto's annual project portfolio planning cycle. Under this cycle, projects are defined and released for common delivery dates with exogenously given deadlines—most of which are imposed by annually recurring trade-fair presentation dates. When not busy with their main project(s), employees are supposed to work on secondary projects or nonproject work.

Second, the help process should be modeled closely after Roto's practice. Here, the help request is visualized by help seekers literally affixing a red card on top of their desk. This action makes the help request observable to all project employees and to top management. Crucial to the help process is that a request triggers help, which means that the help-seeking and help-providing project managers will try to solve the problem by teamwork—rather than merely reassigning project work to another project manager. Roto instructs its project managers to request help during project execution when their project is at risk to miss the project deadline. A raised red card triggers the head of new product development as well as the project coordinator to approach the help-seeking project manager or engineer about assembling a *red-card team*. Help can be requested by project managers (typically for help across projects) or by project engineers (typically for help within the project across tasks). In line with our focus on the strategic and tactical features of a help system and its interaction with project portfolio planning, we model cross-project help triggered by the project managers. Roto chooses potential helpers who are both available (i.e., at no risk of delaying their own project) and have the technical competence to help (i.e., they

Table 1. Translating Roto's Project Management System of Formal Help Into a Model

System component	Roto's formal help system	Model of a formal help system	Modeling rationale
Project portfolio planning	*Planning cycle* with common project releases and deadlines.	Idem	Equivalence
	Project deadlines that are exogenous (annual trade fair).	Idem	Equivalence
	Project portfolio fixed during planning cycle with about 20 main projects of similar scope.	Portfolio is fixed during planning cycle with two equivalent projects.	Minimal representation
	Residual time used for secondary projects and nonproject backup work.	Residual time is used for secondary nonproject work.	Focus on project vs. nonproject work
Help process	*Help request* is formal and observable to all; visualized by a *red card.*	Idem	Equivalence
	Cooperation of help-seeking and help-providing employees on *red-card teams.*	Idem	Equivalence
	When? If troubled task jeopardizes a project deadline.	If project is unfinished at scheduled completion time.	Minimal representation
	Response: Top management assigns helping employees from different projects or from different tasks of the same project.	Top management induces the other project manager to help.	Focus on tactical cross-project help
	Who requests? Project managers and project engineers.	Project managers request help.	Focus on tactical cross-project help
	Who helps? Available project employees (i.e., own project is not endangered) with complementary technical capability.	The other project manager if her project is completed.	Focus on availability with variable complementarity
Performance measurement and rewards	Individual *time-based KPIs* for timely project delivery, both for project and task deadlines.	Individual financial rewards for timely project delivery.	Generalized representation of explicit objectives
	Individual *help-based KPIs* for help seeking and help provision recorded in *red-card database.*	Individual financial rewards for timely project delivery with help.	Generalized representation of explicit objectives

have complementary capabilities for tackling the troubled project).

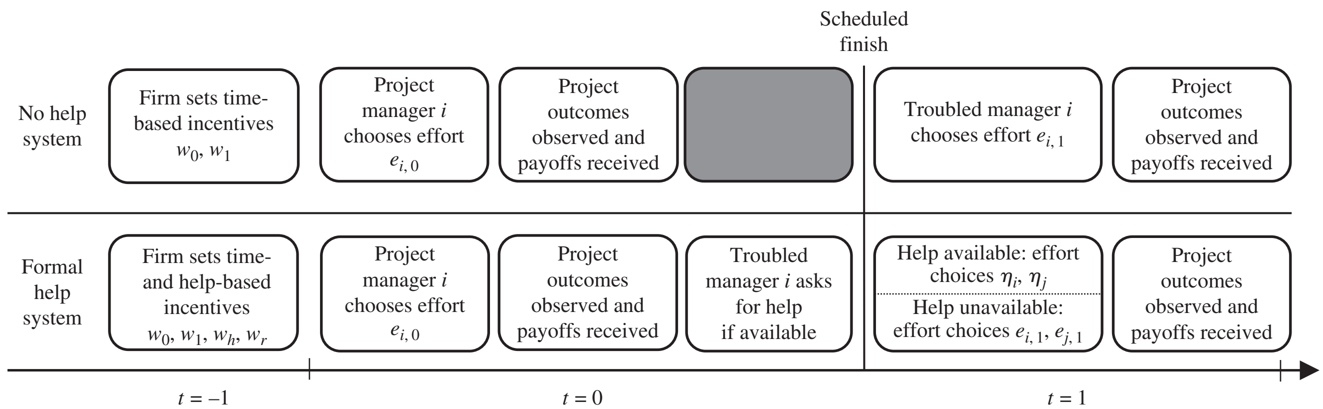
Third, our model must incorporate the system components of performance measurement and rewards. We remark that the help system in steady state is inherently formal in that it relies on explicit measurements (although they are not directly related to financial rewards). For instance, Roto's system involves no direct financial reward for on-schedule project completion yet project managers are explicitly evaluated based on completion-time key performance indicators (KPIs). And even though there is no direct financial reward linked to helping, Roto's top management keeps track of all help transactions via its *red-card database*. These data, too, are used as explicit help-based KPIs; for example, the company evaluates how successful is the help provided by each project manager. In sum, Roto's project management system encourages early project completion and formal help exchange by relying on explicit measures that are *contractible*. The model captures these measures in the form of financial rewards so that Roto's system can be easily adapted to project environments in which financial rewards can be directly linked to KPIs.

3.2. Model of a Formal Help System

For a minimal representation of a project environment with help, we consider a company that assigns two symmetric projects to two equally capable project managers. The project's payoff for the firm depends on its completion time. A project completed on schedule (in $t=0$) yields the company a total payoff of V; an initially troubled yet recovered project with delayed completion (in $t=1$) yields the company αV; and the payoff for an unfinished and therefore abandoned project is normalized to 0. The parameter $\alpha \in (0,1]$ denotes a project's *recovery value* that the firm can recoup under delayed completion. It is intuitive that the company will benefit from faster (ideally, on-schedule) delivery of its projects. Within a given time period, a project manager who is not induced to work on a project is tasked with secondary, nonproject work that yields a constant revenue o to the firm. So for the firm, o represents the opportunity cost of the project managers' capacity.

The firm's objective is to maximize its expected profit—namely, the expected payoff from the two projects (net of their costs) and from secondary work. Because the projects are delegated to two autonomous project managers, the company seeks to design incentives

Figure 1. Sequence of Events in a No-Help System and with an Additional Formal Help Process



that induce actions capable of realizing that objective. Figure 1 presents the sequence of events in the standard project management (no-help) system and in the red-card (formal help) system.

In the base case of a no-help system, the firm first chooses a set of time-based incentives in $t = -1$—that is, payments to a project manager based on completion time, which is verified when the project is finished. The firm pays project manager i ($i = 1, 2$) either $w_{i,0}$ or $w_{i,1}$ according to whether the project is completed on schedule (by the end of $t = 0$) or behind schedule (by the end of $t = 1$). In $t = 0$, project manager i chooses whether to exert effort ($e_{i,0} = 1$) or not ($e_{i,0} = 0$).[2] This engagement comes at a cost of $ce_{i,0}$ ($c > 0$), though the actual value $e_{i,0}$ is not observable to the company. The project can be completed on schedule (i.e., by the end of $t = 0$) with *success probability* $p \in (0, 1)$ if the project manager exerts effort, but it cannot be finished on schedule if the project manager chooses to exert no effort. Whether because of uncertainty or no previous effort, a project manager may find himself unable to deliver by the end of $t = 0$. Then, in $t = 1$, he can again choose a level of effort $e_{i,1} \in \{0, 1\}$ while facing the same success probabilities p and cost c encountered in $t = 0$. Once again, owing to uncertainty or lack of effort, a troubled project may not recover and so may not be completed by the end of $t = 1$. In that case, the project will be abandoned and thus will not generate value for the company.

As an add-on to standard project management, the company can implement the red-card help process described in Section 3.1. Then the firm chooses and commits to an additional set of help-based incentives in $t = -1$ to encourage efforts in the help scenario: it offers $w_{j,h}$ to the helping manager j ($j = 1, 2$ with $j \neq i$) and offers $w_{i,r}$ to the help-receiving manager i. These help-based incentives are paid only if a troubled project is recovered with help and finishes in $t = 1$. For a recovered project the firm pays no time-based incentives. Note, however, that project manager j will have earned $w_{j,0}$ for finishing her project on schedule and can earn $w_{j,h}$ if successfully helping a colleague to recover his project. Thus the help system's compensation package for project manager i is $\mathbf{w}_i = \{w_{i,0}, w_{i,1}, w_{i,h}, w_{i,r}\}$. (Since project managers are symmetric, we suppress the i and j subscripts when there is no difference in their respective incentives.) Upon learning about project outcomes by the end of $t = 0$, the manager of a troubled project (manager i) can raise a red card to seek help from project manager j in $t = 1$—provided that j's project is completed on schedule. A raised red card is visible to senior management, which ensures that a helping manager will be assigned if one is available.

The probability of recovering a focal project that is behind schedule in $t = 1$ depends on the effort choices of both the helped ($\eta_i \in \{0, 1\}$) and the helping ($\eta_j \in \{0, 1\}$) project managers, but neither choice is observable to the firm; as described in Section 3.1, the project managers cooperate without top management interference. If neither project manager exerts effort during their red-card teamwork, the project cannot be recovered. If either one of the project managers exerts effort (thus incurring cost c), then the project is recovered with probability p. These values are equivalent to the probability and cost under the no-help system. If both project managers exert efforts under help ($\eta_i = \eta_j = 1$) and each incurs cost c for doing so, then the probability of recovering the troubled project is $p + hp(1 - p)$. Here $h \in [0, 1/p]$ signifies the *complementarity of help* when project managers work jointly to recover the project (cf. Siemsen et al. 2007).[3] As help complementarity exceeds a threshold—that is, when $h > 1$—the two cooperating project managers together have a greater likelihood of success than one project manager exerting effort twice (i.e., in sequence). The opposite outcome obtains under low complementarity of help. We assume that a troubled project's chance of being recovered and completed in $t = 1$ is *memoryless*—that is, it depends on the efforts expended in $t = 1$ but not on efforts expended in $t = 0$.[4]

In sum, our PM model of formal help relies on a minimal set of assumptions that allow us to balance parsimony with grounding in the Roto case. We have translated Roto's project portfolio planning, its help process, and its performance measurement and rewards into corresponding formal components (see Table 1). Beyond the Roto-specific components, we have incorporated features common to many new product development settings: effort is costly to exert but is not observable; the effect of effort on project completion is uncertain and memoryless; and the firm's value from project completion decays over time.

We shall analyze and compare the system of *no help* (in Section 3.3) with that of *help* (in Section 4). As is the case for Roto, we assume that the company credibly commits to the help system; thus the firm sustains help-based incentives, initially fixed in $t=-1$, throughout all periods of a project.

3.3. Base Model: Project Management in a No-Help System

We start by analyzing the no-help system in which the two projects are executed independently and without help. Toward that end, we work backward through the project managers' objectives and effort decisions. Recall that the compensation package for manager i specifies a reward for completion on schedule or behind schedule $\mathbf{w}=\{w_0, w_1\}$. Project manager i's payoff in $t=1$ can be written as $\pi_{i,1}(e_{i,1})=w_1 p e_{i,1}-c e_{i,1}$. If the firm wants project manager i to exert effort in $t=1$, then the offered incentive w_1 should satisfy the following condition:

$$\pi_{i,1}(e_{i,1}=1)\ge \pi_{i,1}(e_{i,1}=0) \iff p w_1 - c \ge 0.$$

Thus the optimal incentive for effort in $t=1$ is $w_1^*=c/p$. To induce effort for on-schedule project completion (in $t=0$), the firm must consider the overall payoff a project manager expects to receive. That payoff can be expressed as follows:

$$\pi_{i,0}(e_{i,0}, e_{i,1}) = p w_0 e_{i,0} - c e_{i,0} + (1-p)(p w_1 e_{i,1} - c e_{i,1}).$$

The incentive wage w_0 must satisfy $\pi_{i,0}(e_{i,0}=1, e_{i,1}) \ge \pi_{i,0}(e_{i,0}=0, e_{i,1}) \Leftrightarrow p w_0 \ge c$, so the optimal incentive to induce effort in $t=0$ is $w_0^*=c/p$.

The firm chooses the combination of project efforts or secondary work (in the two consecutive periods) that maximizes its expected profit Π. Proposition 1 summarizes the incentives and induced efforts that are optimal from the firm's perspective.

Proposition 1. *As a function of (α, V), the following firm choices are optimal in a no-help system.*

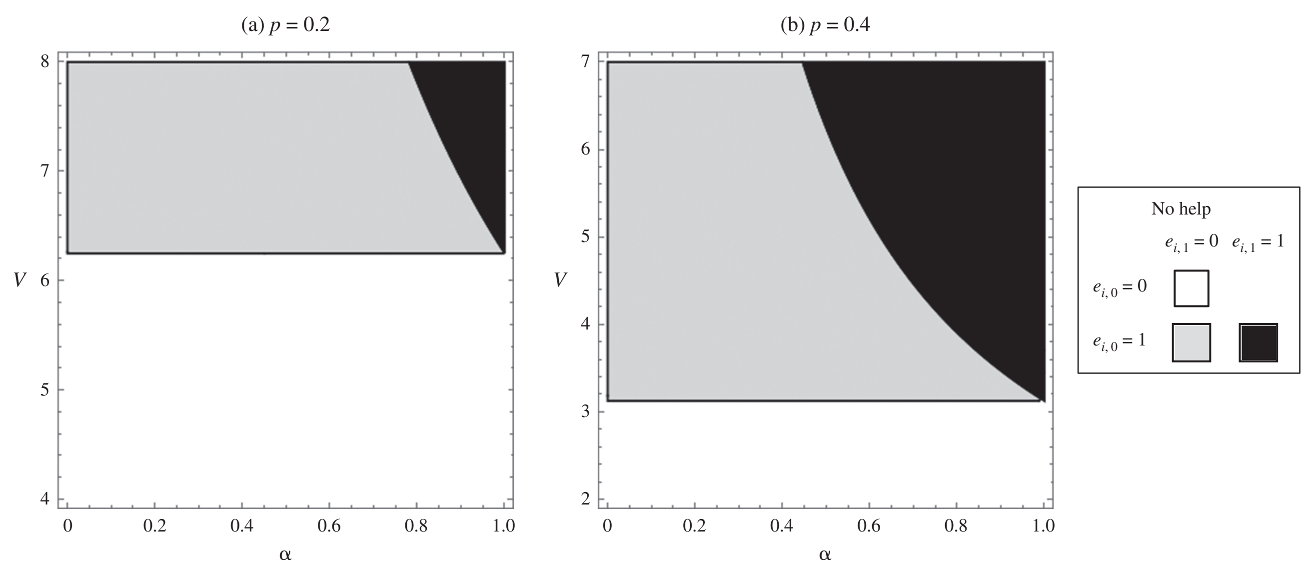
(i) *The firm induces effort throughout all periods by setting $w_0^*=w_1^*=c/p$ when $p\alpha V \ge c+o$, in which case it earns a profit of $\Pi = 2(p(V+o)-c+(1-p)(p\alpha V - c))$.*

(ii) *The firm induces only early effort by setting $w_0^*=c/p$ and $w_1^*=0$ when $p\alpha V < c+o \le pV$, thereby earning a profit of $\Pi=2(pV-c)+2o$.*

(iii) *The firm precludes effort by setting $w_0^*=w_1^*=0$ when $pV<c+o$; in this case, the firm earns a profit from only the secondary work ($\Pi=4o$) and abandons the projects.*

Figure 2 illustrates the optimal firm choices in a no-help system contingent on the project recovery value α (x-axis) and the project payoff V (y-axis) for a lower success probability (left-hand panel, $p=0.2$) and a greater success probability (right-hand panel, $p=0.4$).[5] The firm always induces effort ($e_0=e_1=1$) in the black region of the graphs. It is intuitive that, if the firm can generate high payoffs from on-schedule completion *or*

Figure 2. Optimal Firm Choices and Effort Levels in a No-Help System



from behind-schedule completion, then it is optimal to induce effort in all project periods. In each graphs gray region, the firm optimally induces only early efforts ($e_0 = 1$, $e_1 = 0$) because the lower recovery value α no longer warrants inducing costly project recovery efforts. In the graphs' white regions, the firm abandons projects at the outset. Here the low payoff V is not expected to cover the firm's cost of inducing the early efforts required to deliver a project, so the firm collects only the payoff from secondary work.

Therefore, and in line with the front-loading argument of Thomke and Fujimoto (2000), it is never optimal in a no-help system for the firm to induce only late effort (i.e., to incentivize $e_0 = 0$, $e_1 = 1$). The reason is that, in our model, the payoff from project completion decays over time, whereas the project managers' effort costs (and the corresponding success probabilities) persist.

4. Project Management with Help

In this section we study the optimal design of incentives in a PM system with help; the company commits to its choice of help system and sustains incentives throughout stages. Working backward, in Section 4.1 we first analyze how the firm sets help-based incentives to encourage help for a troubled project in period $t = 1$ (stage 2). Note that if both managers are troubled in $t = 1$, then help is not available and so efforts will be induced by the time-based incentive w_1 (as in Section 3). Thus we focus on the help game in $t = 1$ when one project manager (i) is troubled *and* the other manager (j) is available for help. Then, in Section 4.2, we analyze how the firm optimizes time-based incentives for early effort in $t = 0$ (stage 1), which will enable us to determine optimality conditions for the different PM system configurations (Section 4.3). We conclude in Section 4.4 with a discussion on the value-creating and value-reducing mechanisms of the help system.

4.1. Second Stage: How the Company Encourages Help

Both the helped and helping managers can choose whether or not to exert effort; hence there are four possible equilibria depending on the incentive structure. Consider an equilibrium in which one of the project managers exerts no effort ($\eta_i = 0$, $\eta_j = 1$ or $\eta_i = 1$, $\eta_j = 0$). In either one of these equilibria, the chance of project recovery is no greater than what the troubled manager could achieve on his own. As a consequence, those partial help equilibria do not improve company profits and so are dominated from the firm's perspective. Yet if the firm can induce effort from both project managers, then its profit may increase because the likelihood of completion increases. The rate of increase is determined by the help complementarity h between the helping and the troubled manager. In the model presented here, the value of h is known to the project managers and also to the firm. (In Section 5.1 we relax that assumption and show that our qualitative results still hold when h is private information learned by the project managers.)

We can therefore analyze help-based incentives by concentrating on the equilibrium in which effort is exerted by both the helping and the troubled manager. In this case, the firm should set incentives that satisfy the following three constraints:

$$w_r p(1 + h(1-p)) - c \geq \max\{w_1 p - c, 0\};$$
$$w_r p(1 + h(1-p)) - c \geq w_r p;$$
$$w_h p(1 + h(1-p)) - c \geq w_h p.$$

The first two constraints ensure (respectively) that the troubled manager calls for help and that he exerts effort while being helped. The third constraint ensures that the helping manager actually exerts effort during the help process. The incentives that optimize company profits for this equilibrium are given in Lemma 1.

Lemma 1. *The optimal incentives for help in $t = 1$ are*

$$w_r^* = w_h^* = \frac{c}{p(1-p)h}.$$

This lemma states that the optimal incentives are the same for the troubled and the helping manager. That outcome follows because, for each manager, the binding constraint is the incentive compatibility constraint for each manager to exert effort under help. Observe that both of the optimal help-based incentives are decreasing in the complementarity parameter h. As complementarity h increases, lesser incentives are needed to encourage the project managers' efforts. Thus the company may benefit not only from higher expected payoffs (because of the increased likelihood of project recovery) but also from cost reductions (because of lower incentives).

4.2. First Stage: How the Company Encourages Early Efforts

The incentive w_0 for on-time completion is the only remaining item in the firm's incentive package. The project managers' early efforts are a pivotal aspect of the help system's configuration, because only those project managers who exert early effort in $t = 0$ are able to complete their respective projects by the end of $t = 0$ and thus be in a position to help a troubled colleague in $t = 1$. The company can set w_0 to induce one of the following three scenarios: the *high engagement* scenario (indexed by superscript $\mathcal{H}$), where both project managers exert effort for on-schedule completion; the *asymmetric engagement* scenario (superscript $\mathcal{A}$), where one manager exerts effort while the other does not; and the *no engagement* scenario, where neither manager exerts early effort.

A project manager's expected payoff at the start of a project consists of revenues from completion on or behind schedule, with or without help, and as either a receiver or a giver of help. Project managers choose effort levels that maximize their respective utilities over the two time periods. Our next proposition characterizes the optimal incentives for on-schedule completion with help.

Proposition 2. *If the company chooses to encourage help in $t = 1$, then the following statements hold.*

(i) *To induce the scenario with high engagement ($e_{i,0} = e_{j,0} = 1$), the firm's optimal incentive for on-time completion is $w_0^{\mathscr{H}} = \max\{0, c/p - c/h + pc/((1-p)h)\}$.*

(ii) *To induce the scenario with asymmetric engagement ($e_{i,0} + e_{j,0} = 1$), the firm's optimal on-time completion incentive for one project manager is zero and for the other manager is $w_0^{\mathscr{A}} = \max\{0, c/p - c/((1-p)h)\}$.*

Comparing the incentives in the two cases of Proposition 2, we observe that high engagement costs the firm more than asymmetric engagement: the compensation offered to each manager in the high-engagement scenario is higher than the compensation offered to the high-effort manager in the asymmetric scenario (i.e., $w_0^{\mathscr{H}} \geq w_0^{\mathscr{A}}$). In the asymmetric scenario, the high-effort project manager's expectation of earning a future help-based incentive w_h allows the company to reduce the incentive to a level that is below that needed to induce high engagement. In the high-engagement scenario, managers' expectations of a future help-based incentive w_h are lower because each project manager exerts effort and so opportunities to earn that incentive are less likely to arise. This expectation of a future profit from help allows the company to set the incentive for asymmetric engagement lower than that in the no-help system (i.e., $w_0^{\mathscr{A}} < w_0^* = c/p$). However, it is interesting that the same is not generally true for the high-engagement incentive: when $p > 0.5$, we find that $w_0^{\mathscr{H}} > w_0^*$. If the probability of on-schedule completion is high, then the project managers are reluctant to exert effort simultaneously because in that case neither one is likely to gain from providing help. So to prevent project managers from shirking in $t = 0$, the firm should incentivize them with a higher reward—one that leads to surplus utility when the project is completed on schedule.

4.3. Optimal Project Management Configurations

The company chooses its PM configuration so as to generate the maximum profit by selecting time-based and help-based incentives that optimally induce or discourage individual and cooperative efforts. The following proposition characterizes the firm's optimal equilibrium choice as a function of project parameters.

Proposition 3. *Whenever $h(1-p) \geq p(2-p)$, the company's optimal engagement strategies can be characterized as follows.*

1. *When $p\alpha V < c + o$, the company induces no effort in $t = 1$ from the troubled manager when help is not available. Furthermore, the company chooses*

(a) *high engagement by offering both managers a common payment $w_0^{\mathscr{H}}$ if $V \geq \max\{V_1, V_2\}$; or*

(b) *asymmetric engagement by offering one manager $w_0^{\mathscr{A}}$ and the other manager zero if $\min\{V_2, V_3\} > V \geq V_4$.*

2. *When $p\alpha V \geq c + o$, the company induces effort in $t = 1$ from the troubled manager when help is not available. Furthermore, the company chooses*

(a) *high engagement in both periods by offering both managers a common payment $w_0^{\mathscr{H}}$ if $V \geq \max\{V_5, V_6\}$; or*

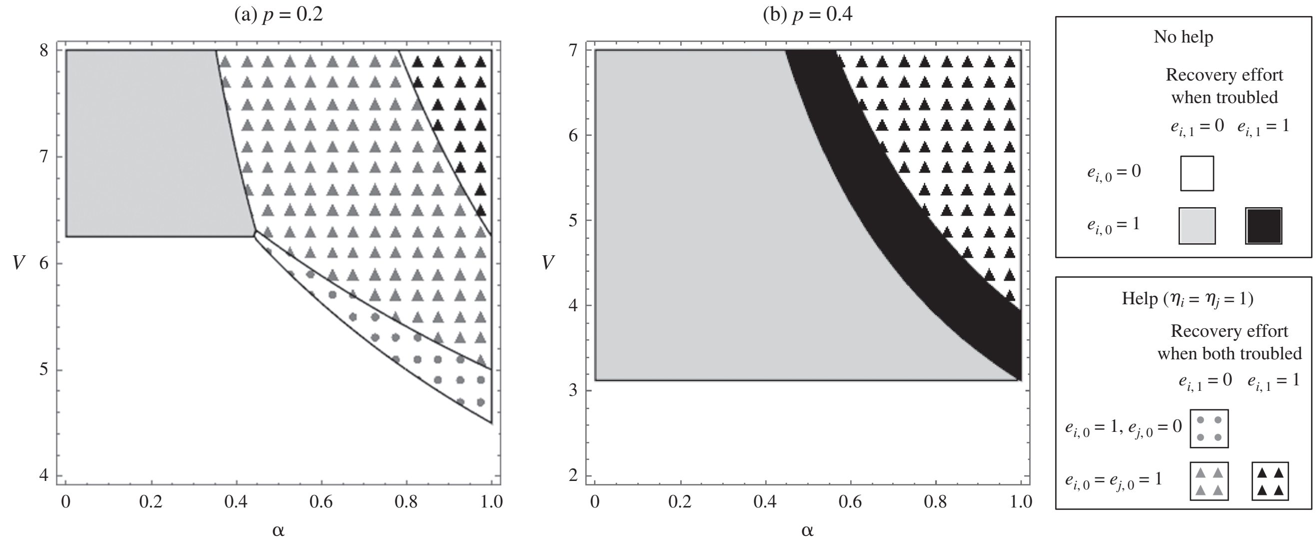
(b) *asymmetric engagement by offering one manager $w_0^{\mathscr{A}}$ and the other manager zero if $\min\{V_3, V_5\} > V$.*

In all cases not specified here, the company chooses not to induce help and sets the optimal time-based incentives for the no-help system as given in Proposition 1.

The first striking result from Proposition 3 is that both the help system and the no-help system can be optimal. Moreover, unlike in the no-help system—which, as stated in Proposition 1, chooses identical engagement levels for symmetric projects—the formal help system may induce different engagement levels across otherwise identical projects. As a result, adding a help process to a standard PM system gives rise to more varied engagement strategies in the first stage. The left- and right-hand panels of Figure 3 illustrate these optimal strategies for (respectively) low and high probabilities of success. We remark that Figure 3 also enables identification of areas ripe for increased engagement (as compared with the no-help system) because it is parameterized identically to Figure 2.

We begin by looking at what remains the same as in the no-help system—namely, the areas shaded in black or gray, where the no-help system dominates. Although the help system is generally optimal when the project payoff and recovery value are both high, there are significant differences between the cases of high versus low probabilities of success. When comparing the left and the right panels of Figure 3, one can see that the no-help system becomes more advantageous as the probability of project success increases. In such cases, the firm prefers to rely on time-based incentives without help exchange, even for larger recovery values. The firm thereby precludes free riding, whose costs are a downside of the help system that we shall further elucidate in Section 4.4. When the probability of project success is high, inducing help is suboptimal *unless* the project payoff and recovery value are both extremely high—or $p\alpha V \geq c + o$. Then the formal help process is simply a means by which the company can intensify its push to recover projects that are of such high value that any inefficiencies because of free riding can be justified. In contrast, if the probability of project success

Figure 3. Optimal PM System Configurations Under *High* Complementarity of Help ($h = 1/p$)



is low then a help process is optimal (a) whenever the firm would induce effort under the no-help system *and* (b) for payoff and recovery values that would not warrant a recovery effort under the no-help system. Thus we see that a formal help process (provided it is feasible) allows the firm not only to increase the intensity of its project recovery efforts but also to recover troubled projects that, under the no-help system, would be abandoned in $t = 1$.

If success probabilities are low, then, provided complementarity h is high enough, we can see that the help system may facilitate *portfolio expansion* and *project prioritization*; in fact, it may even lead to *project back-loading*. These results are shown in the left panel of Figure 3. First, we observe portfolio expansion—whereby the firm profitably undertakes one or both projects that the no-help system would reject—in the left-hand panel of Figure 3 when $V < (c + o)/p$. Portfolio expansion is enabled by the reduction in the firm's first-period incentives because of the possibility of subsequent benefits from help, as detailed in Proposition 2. Second, when portfolio expansion exists and the project payoff reduces further, a help system with asymmetric engagement becomes optimal. This finding is noteworthy because, despite the two projects' initial symmetry, the firm endogenously prioritizes one of them. Since only one project manager exerts initial effort, it follows that the transfer of help is unidirectional: from the effort project to the no-effort project. Thus prioritization assures the successful project manager the opportunity to help and gain value, which allows to further reduce the incentive to induce high engagement from that project manager. The conditions under which project portfolio expansion is a significant implication of the help system are established by Lemma 2.

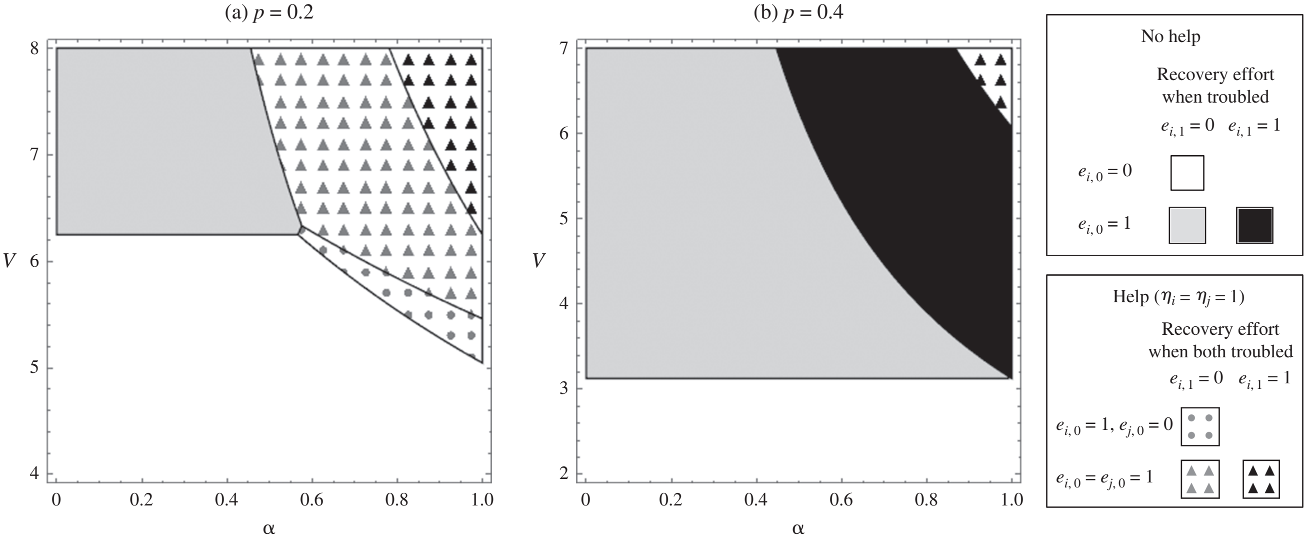
Lemma 2. *Project portfolio expansion and back-loading exist if and only if* $h(1 - p) > \frac{1}{2}(1 + \sqrt{(5c + o)/(c + o)})$.

Finally, Lemma 2 also establishes the conditions for back-loading—that is, for the firm delaying efforts as compared with the case under no help—to be another important consequence of the help system. It is remarkable that, under these conditions, because of prioritization we observe that a no-help system encourages high initial effort for both projects, whereas a help system induces late efforts on one of the projects. This unexpected result is driven by the project interdependency created by the help system; when considering a project *portfolio* that features help linkages among projects, it can be more efficient initially to incentivize engagement for just one project—thus reaping the cost benefits of prioritization—and later to rely on the helping process to recover the other project.

Figure 4 illustrates the company's optimal PM system configurations for lower levels of complementarity (namely, $h = 0.75/p$). Less help complementarity reduces the areas in which the help system is optimal when compared with the high-complementarity case shown in Figure 3. The condition $h(1 - p) \geq \frac{1}{2}(1 + \sqrt{(5c + o)/(c + o)})$ in Proposition 3 implies that if the complementarity of help $h < 1$ then portfolio expansion will not occur, but the help system may still be beneficial nonetheless. Such benefits arise in settings characterized by high project payoff V, a high recovery parameter α, and a relatively low probability of success. So despite offering no efficiency advantages—when $h < 1$, two cooperating managers are actually *less* likely to succeed than is a single manager exerting effort in consecutive periods—help contributes value.

To summarize, we observe asymmetric engagement, project portfolio expansion, and project back-loading

Figure 4. Optimal PM System Configurations Under *Low* Complementarity of Help ($h = 0.75/p$)



as significant and robust effects of the help system. These effects—and, more generally, the situational advantages of the help system over the no-help system—result from several connected mechanisms. Next, we shed more light on these mechanisms and how they operate.

4.4. Mechanisms: How Help Creates or Reduces Value

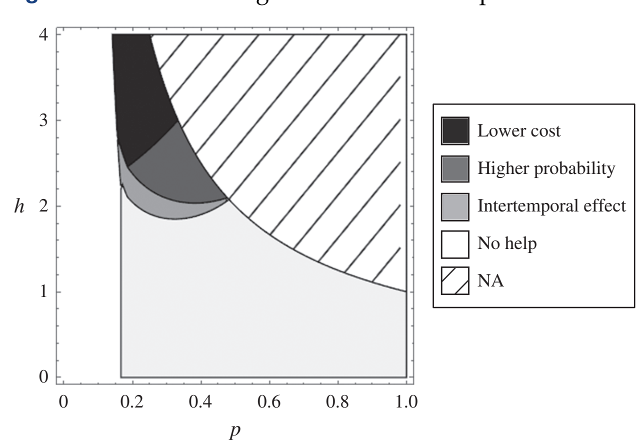
In this section we disentangle the mechanisms of the help system while explaining how they operate to add to or subtract from firm value.

Value-Creating Mechanisms. We start by illuminating the mechanisms by which the help system creates value. The contingencies of the project environment that favor a help system are relatively straightforward: project portfolios with high complementarity, low success probability, and jointly high recovery and payoff values are more likely to benefit from introducing a help system. There are three separate yet nested mechanisms through which a help system benefits the firm in decreasing order: cost efficiency, higher success probability, and intertemporal incentive effects. These mechanisms are nested in the sense that, when the help system engenders cost efficiency benefits, the benefits from higher success probability and intertemporal incentive effects are also observed; in addition, when there are no cost efficiency benefits but help still increases the likelihood of success, intertemporal incentive effects are also present. Finally, intertemporal incentive benefits can also occur on their own without the two other effects. For all values of success probability p and help complementarity h under which a help system is the company's optimal strategy, Figure 5 shows the highest-order mechanism attained (the other parameter values are $V = 6$, $\alpha = 0.9$, and $o = 0.25$).

For extremely high complementarity and low success probability, the total reward paid out for help falls short of the reward for working alone (formally, $w_h + w_r \leq w_1$). Since help also reduces the reward paid out in the first stage, these conditions make help strictly advantageous in both the first and the second stage. Thus help creates value by improving the firm's *cost efficiency*.

For slightly lower levels of complementarity, the total reward for help exceeds the reward for working alone ($w_h + w_r > w_1$) and so the company's profit—contingent on success—is lower under help than under no help. Yet help remains attractive because the firm expects that the *greater success probability* enabled by bundled efforts will compensate for the lower profit when successful. Hence we still observe a net expected benefit of help in the second stage, in addition to a cost reduction in the first stage, and again the help system still proves beneficial.

Figure 5. Value-Creating Mechanisms of Help



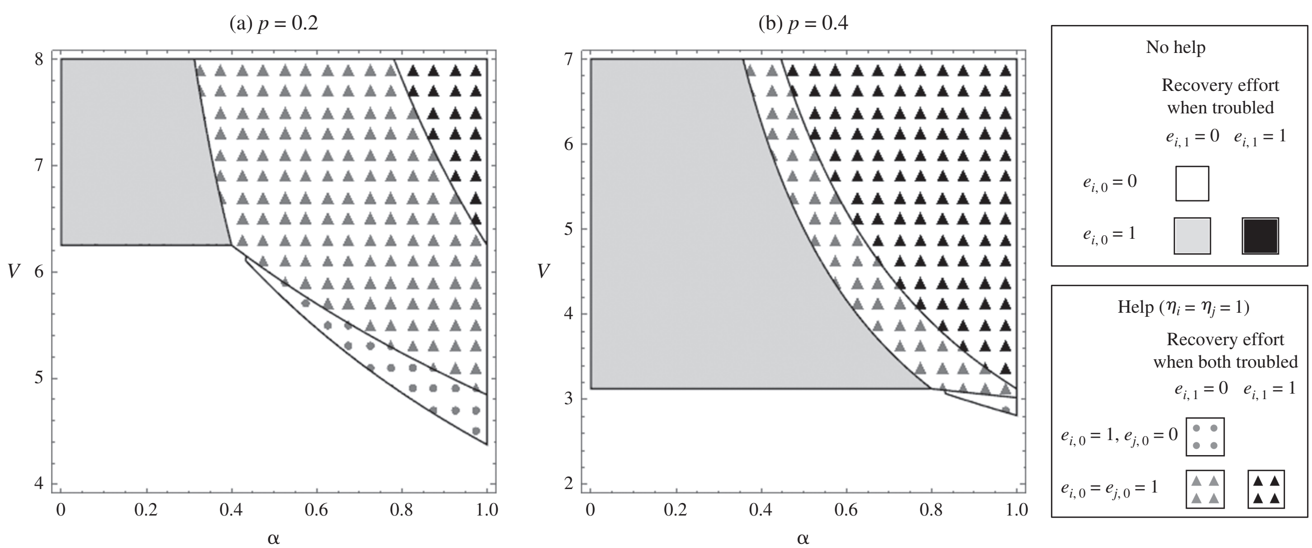
Finally, for even lower complementarity and low probability of success, there exists a region in which the help system is actually detrimental in the second stage; in other words, the increased probability of success does not compensate for the higher cost of help. However, project managers expect a positive payoff in $t = 1$ in the case of help, from which it follows that the firm can reduce the time-based incentive w_0 offered for on-time completion. As a result, the help system can increase company profit in $t = 0$ even if it does not do so in the second stage. Thus the *intertemporal effect* of help leads to a reduced first-stage reward, and the net impact of help on company profit becomes positive.

Value-Reducing Mechanism: Free Riding. Motivated by the grounding case of Roto, our model assumes that help requests are triggered in a decentralized way by project managers; hence there is the potential for free riding. To isolate the cost of the free-riding inherent to a decentralized help process, we now compare the base model with a centralized system in which the firm controls help exchange as well as all efforts, individual and under help. The optimal centralized PM system configuration is illustrated in Figure 6, which is based on parameter values identical to those for the decentralized PM system shown in Figure 3. We observe that help is even more attractive in the centralized than in the decentralized system. This effect can therefore be attributed to the elimination of the free-riding characteristic of a decentralized help system. Free riding is detrimental to a help system and is evidenced when a help system is optimal under centralized but not under decentralized decision making. This is especially true of environments associated with greater probabilities of success, as seen in the right panel of Figure 6.

Interacting Mechanism: Secondary Work. Next we focus on the effect that a secondary work opportunity has on the value of help. Straightforward intuition suggests that the more valuable the secondary work, the less attractive the projects and the higher the threshold that V must exceed for a project to be undertaken. This is certainly the case when there is no help, and analogous reasoning applies in the presence of help: whenever help occurs in the second stage, at least one of the project managers is prevented from performing the secondary work; hence, secondary work of greater value reduces the attractiveness of help. Yet a more careful analysis reveals that, for intermediate values of h with $1 < h(1-p) < (1+\sqrt{5})/2$, the portfolio expansion effect of help occurs when the value of the secondary work is sufficiently large—in other words, the relative benefit of help may increase with the value of secondary work. This dynamic is driven mainly by the asymmetric engagement strategy, which becomes relatively more attractive with increasing secondary work value. Indeed, with asymmetric engagement, the idle manager engages in the (valuable) secondary work in the first stage; in the second stage, either both project managers perform secondary work (if the nonidle project manager failed) or the company reaps the benefit of help (if the nonidle project manager was successful). Therefore, the relative attractiveness of projects in both systems decreases as the value of secondary work increases, but not at the same rate. Secondary work is less likely to detract from project work in the presence of help than in the no-help system.

Bounds on the Value Created by Help. Finally, we provide bounds on the percentage increase in the company's profit that the help system delivers above the no-help system. In the absence of portfolio expansion, we can show that the percentage profit increase from

Figure 6. Optimal Centralized PM System Configurations



help is jointly increasing in the project payoff (V) and the recovery value (α) and is bounded from above by $hp(1-p)^2/(2-p)$, which does not exceed 50%.

In the presence of project portfolio expansion, however, the percentage profit increase over the no-help system could become arbitrarily large if the value of secondary work becomes arbitrarily small. In the extreme case without secondary work ($o = 0$), portfolio expansion would represent an infinite percentage increase in profit. Yet even in the case with project portfolio expansion, if the value of secondary work is high enough then the profit increase is similarly bounded from above by $hp(1-p)^2/(2-p)$. The threshold value of secondary work such that this bound holds is given in Lemma 3.

Lemma 3. *The percentage profit increase from help is bounded from above by $hp(1-p)^2/(2-p) \le 0.5$ if and only if*

$$o \ge \max\left\{\frac{c(h(1-p)(h(1-p)-1)-1)(2-p)}{h(1-p)(2-p+h(1-p))(2-3p)}, \frac{c(h(1-p)^2(h(1-p)-1)-1)(2-p)}{h(1-p)^2(2+p(h(1-p)-1))}\right\}.$$

5. Extensions

In this section we introduce several model extensions that verify the robustness of our qualitative insights on the benefits and costs of the PM system with formal help. For this purpose, we augment the model by accounting for private information on the value of help complementarity and by increasing the set of possible effort choices. The first extension allows us to deal with the more realistic case in which project managers, but not the firm, are able to assess the value of complementarity h. This situation is likely to occur because project managers are typically better informed about project problems and about the effectiveness of joint problem solving under help. In that case, it may be inefficient for the company to impose help for all troubled projects, since the level of complementarity may be too low for help to be of any benefit; hence it may be better for the firm to offer screening incentives such that troubled managers ask (and receive) help only when the complementarity h is high. Our second extension allows for a more fine-grained representation of effort choices—in particular, by allowing the troubled project manager to work harder on his own project. This approach will enable us to determine whether help is beneficial owing to the complementarity effect or rather to an increased work rate. These extensions yield optimal PM configurations that are more nuanced than described previously, but we find that our main results are robust to both of them.

5.1. Asymmetric Information on the Complementarity of Help

We first analyze the game under help in $t = 0$ when one project manager is troubled and the other is available for help. The exact value of help complementarity h is observed by the project managers in $t = 0$; however, the firm knows only that this parameter can take either a high value $h = \bar{h}$ or a low value $h = \underline{h}$ (with equal probability). Since the company does not know the true value of h, it will likely refrain from triggering help in a centralized fashion even though it can observe on-schedule project completion. The reason is that help may be suboptimal for the firm when $\underline{h}$ is low.

We therefore focus on two help policies, both of which ensure that effort is exerted by each project manager ($\eta_i = 1$ and $\eta_j = 1$) and so have the potential to improve the company's payoff: (i) a *pooling* policy, whereby the troubled project manager requests help irrespective of whether complementarity is high or low; and (ii) a *shutdown* policy, under which project managers call for help only after establishing that complementarity is high. In the shutdown policy, help for a troubled project can be triggered only by the project managers' problem-specific decisions based on their private information about the complementarity h. In our setup, the firm commits not only to the help system but also to a particular policy—that is, to a pooling policy or a shutdown policy.

For the pooling policy, the firm must satisfy the incentive compatibility constraint of both project managers as well as the individual rationality constraint of the troubled project manager. These constraints must hold for both high and low complementarity, but clearly they can be binding only when complementarity is low. For the shutdown policy, in contrast, the firm must satisfy the same constraints but only when complementarity is high. However, in this case the company faces an additional constraint: ensuring that a troubled project manager will *not* request help when complementarity is low.

The optimal incentives for both policies are stated in our next result. Superscript $\mathcal{P}$ and $\mathcal{S}$ are used to index (respectively) the pooling and shutdown policy.

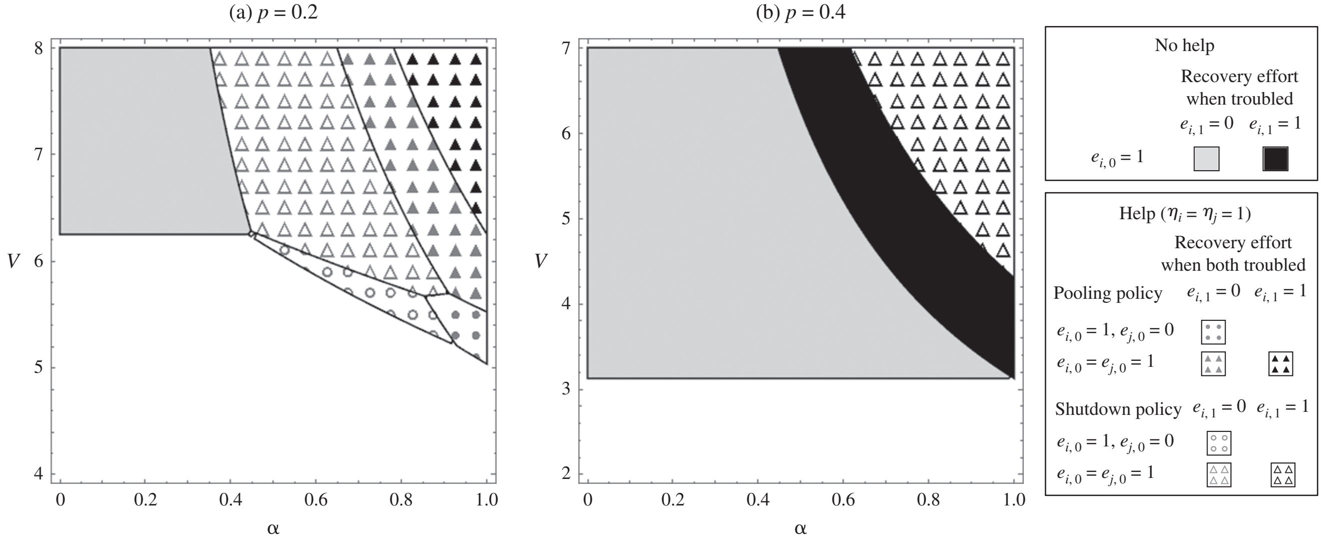
Proposition 4. *The optimal incentives for help in $t = 0$ are as follows.*

(i) *For the pooling policy, $w_h^{\mathcal{P}} = c/(p(1-p)\underline{h})$ and $w_r^{\mathcal{P}} = c/(p(1-p)\underline{h})$.*

(ii) *For the shutdown policy, $w_h^{\mathcal{S}} = c/(p(1-p)\bar{h})$ and $w_r^{\mathcal{S}} = c/(p(1-p)\bar{h})$; this policy is feasible only when $(\bar{h}-\underline{h})\cdot(1-p) \ge 1$.*

Moreover, the optimal incentives for the pooling policy are higher than those for the shutdown policy: $(w_h^{\mathcal{P}}, w_r^{\mathcal{P}}) > (w_h^{\mathcal{S}}, w_r^{\mathcal{S}})$.

Figure 7. Optimal PM System Configurations with Asymmetric Information on Help Complementarity ($\bar{h} = 1/p$, $\underline{h} = \bar{h} - 1.7$, $o = 0.25$)



Optimal Project Management System. Our findings are illustrated by the graphs in Figure 7. We observe that the main qualitative effects—namely, the expansion of the portfolio and the prioritization of projects—persist when information is asymmetric. The selected problem parameters are such that we observe both pooling- and shutdown-type help, but other parameter choices could exclude the shutdown policy (e.g., if $(\bar{h} - \underline{h})(1-p) \le 1$) or the pooling policy (e.g., if $\underline{h} = 0$).

We remark that the shutdown policy (if it can be implemented) is preferable to the pooling policy for lower payoffs and recovery values, whereas the pooling policy requires a higher payoff and recovery value to be optimal. Thus the company may often be unwilling to induce help for all troubled projects; it may instead prefer to set incentives that encourage help requests contingent on the project managers' observing a high level of complementarity h. This result is intuitive given that (a) the reward under the pooling policy is larger to induce project managers with low complementarity to request help and (b) the benefits of help may turn out to be low when complementarity is low.

5.2. Model with Three Levels of Effort

So far the exertion of effort has been characterized as a binary (effort–no effort) variable, yet in reality it could take several values. Here we show that our key results hold for a model in which the level of effort can take one of three values—high ($e = 2$), normal ($e = 1$), or none ($e = 0$)—and briefly argue that they would continue to hold with increasing numbers of effort levels. We assume that a project manager's cost increases linearly with effort and that each unit increase in effort corresponds to an additional draw from the same probability distribution for project completion. Suppose, for example, that a project manager chooses high effort ($e = 2$); then her cost is $2c$ and her probability of completing the project by the end of the current period is $p(2-p)$.

5.2.1. No Help.

In the no-help system, we observe the intuitive result that higher effort levels are warranted only for high payoffs and high recovery values. Since cost increases linearly in effort whereas the likelihood of success (project completion) is concave in effort, a greater effort is justified only for high payoffs in the first stage or for high payoffs *and* a high recovery value in the second stage. These claims are illustrated in Figure 8 and are formalized in our next proposition.

Proposition 5. *As a function of (α, V), the following firm choices are optimal in a no-help system.*

1. *In the second stage, the firm induces high effort with $w_1^* = c/(p(1-p))$ when*

$$\alpha V \ge \max\left\{\frac{c}{p(1-p)^2}, \frac{c+(c+o)(1-p)}{(2-p)(1-p)p}\right\};$$

in the first stage, it induces high effort with $w_0^* = c(1+p^2)/(p(1-p))$ if

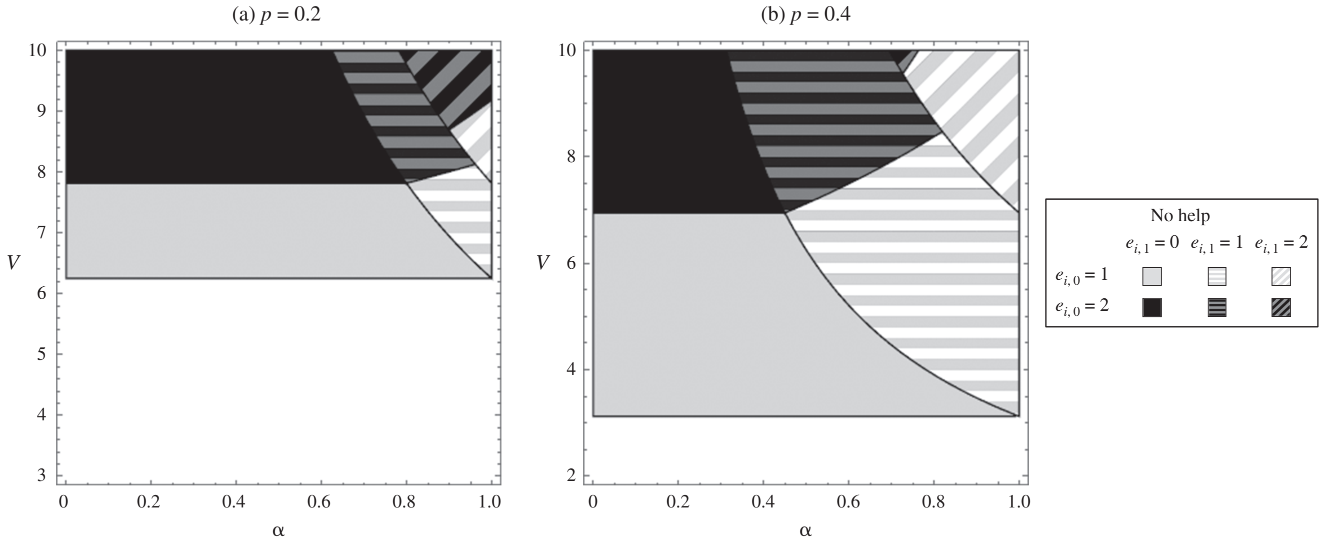
$$V \ge \max\left\{\frac{c(1-2p(1-p)^2)-o(1-p)^2 p}{p(1-p)^2(1-\alpha p(2-p))}, \frac{c(2-p(5-2p(3-p)))+o(1-p)^3}{p(1-p)(2-p)(1-\alpha p(2-p))}\right\},$$

induces normal effort with $w_0^* = c/p + pc/(1-p)$ if

$$\frac{c(1-2p(1-p)^2)-o(1-p)^2 p}{p(1-p)^2(1-\alpha p(2-p))} \ge V \ge \frac{(c+o)(1-p)-cp}{p(1-\alpha p(2-p))},$$

and otherwise induces no effort.

Figure 8. Optimal Firm Choices and Effort Levels in a No-Help System Under Three Effort Levels



2. *In the second stage, the firm induces normal effort with* $w_1^* = c/p$ *when* $(c+o)/p \leq \alpha V \leq c/(p(1-p)^2)$*; in the first stage, it induces high effort* $w_0^* = c/(p(1-p))$ *if*

$$V \geq \max\left\{\frac{c(1-p(1-p)^2) - o(1-p)^2 p}{p(1-p)^2(1-\alpha p)}, \frac{c(2-p)(1-p(1-p)) + o(1-p)^3}{p(1-p)(2-p)(1-\alpha p)}\right\},$$

induces normal effort with $w_0^* = c/p$ *if*

$$\frac{c(1-p(1-p)^2) - o(1-p)^2 p}{p(1-p)^2(1-\alpha p)} \geq V \geq \frac{(c+o)(1-p)}{p(1-\alpha p)},$$

and otherwise induces no effort.

3. *In the second stage, the firm does not induce any effort if*

$$\alpha V \leq \min\left\{\frac{c + (c+o)(1-p)}{p(1-p)(2-p)}, \frac{c+o}{p}\right\};$$

in the first stage, it induces high effort with $w_0^* = c/(p(1-p))$ *if*

$$V \geq \max\left\{\frac{c}{p(1-p)^2}, \frac{c+(c+o)(1-p)}{p(1-p)(2-p)}\right\},$$

induces normal effort with $w_0^* = c/p$ *if* $c/(p(1-p)^2) \geq V \geq (c+o)/p$*, and otherwise induces no effort.*

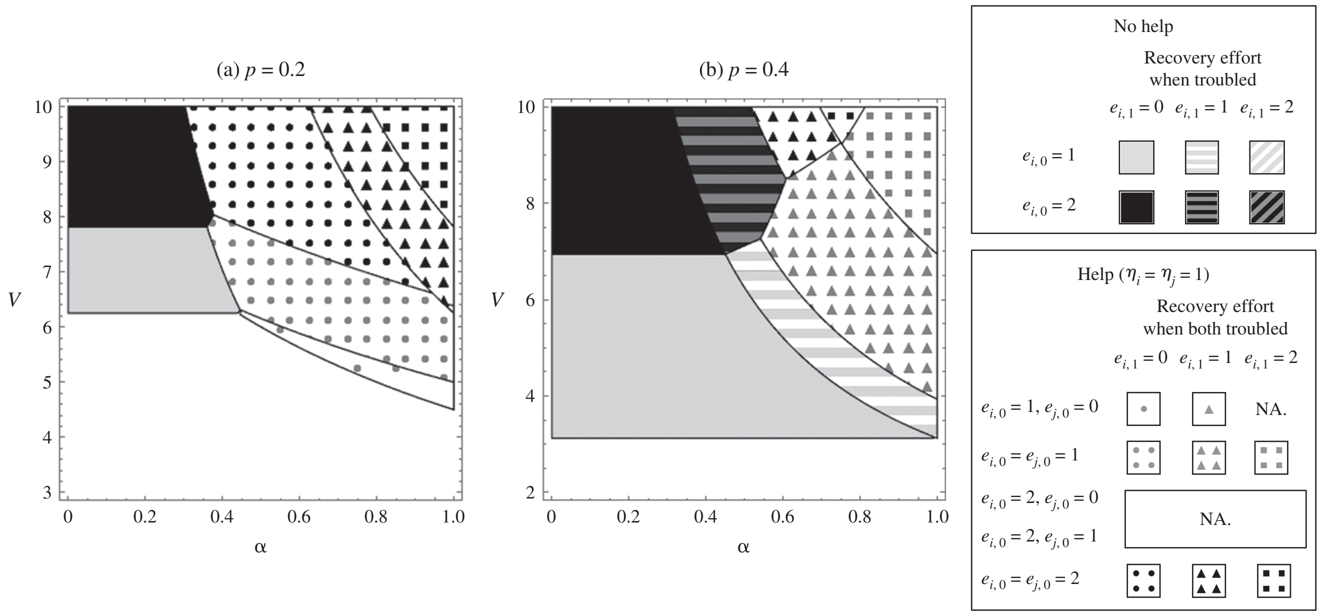
First, a comparison with the no-help base case yields the interesting observation that there are project parameter values for which the effort in the second stage exceeds that of the first stage: $e_2 = 2 > e_1 = 1$. This never occurred in the binary effort case, where a project would receive effort in the second stage only if it had also received effort in the first stage. In the multiple effort model, however, the postponed high effort is due to a negative intertemporal effect: when the company incentivizes a high effort in the second stage, the project manager anticipates an expected profit in that stage; and in the first stage, the project manager prefers to work less in order to increase the probability of failure and then of reaping that expected second-stage profit. For this reason, the firm must pay an additional incentive to induce high or even normal effort in the first stage.

It is instructive also to contrast this manifestation of intertemporal influence with the *positive* intertemporal effect of help discussed in Section 4.4. Help creates a positive intertemporal effect because the expected profit of helping cannot be reaped unless one's own project is completed. With multiple effort levels and in the absence of help, however, we observe a negative intertemporal effect of help because the profit in the second period can be obtained only if the project manager fails his own project in the first stage.

Second, note that there exists an $\bar{o}$ such that, when $o > \bar{o} = cp(2-p)/(1-p)^2$, it is never optimal to exert normal effort ($e_{i,t} = 1$) but exerting either no effort or high effort is optimal. This situation arises because the choice between normal or high effort in the project does not depend on the value of secondary work: once the project manager works on the project, regardless of her effort level, she is assumed not to perform secondary work. Nonetheless, the value of secondary work does affect the manager's decision about whether to work on the project at all. To become profitable, project payoffs need to surpass increasing thresholds as the value of secondary work increases. Yet under such high project payoffs, the company is better off inducing high effort outright.

5.2.2. Help. Figure 9 illustrates that the key results pertaining to the help system continue to hold also under

Figure 9. Optimal PM System Configurations with Help Under Three Effort Levels



the extension to more than two effort levels. We argue further that a formal help process can lead to portfolio expansion regardless of how many effort levels are stipulated. In other words, this result would persist even if there were an infinite number of (countable) effort levels. More specifically, since increasingly higher effort levels will be optimal only at ever-increasing payoffs and recovery values, it follows that the portion of the graph where $pV < c + o$ will *not* be affected by increasing the number of effort levels. As a result, portfolio expansion—and also the deliberate creation of asymmetry in the project portfolio—will persist no matter how many effort levels are allowed.

Introducing several effort levels has the additional benefit of allowing us to focus on the different ways in which help creates value at the project execution stage. The first such advantage is created and also moderated by the complementarity factor h. Help is valuable if the problem encountered straddles the problem-solving domains of both the troubled and helping project manager. If the complementarity level h is low, then help becomes correspondingly less attractive. Nevertheless, help may still be beneficial when the project manager's work rate is constrained (as in the binary effort model, where a project manager's effort cannot exceed $e = 1$ in one period). As mentioned previously, this dynamic arises because help increases the work rate on a troubled project. Yet that relation does not hold when the same total capacity of effort levels can be achieved by working alone as by working with help: in this event, help (with $\eta_i = \eta_j = 1$) is valuable only if the complementarity h exceeds a certain threshold. Lemma 4 formulates this claim; note that this threshold is strictly greater than 1.

Lemma 4. *The firm will prefer cooperation over high effort if and only if*

$$h \geq \tfrac{1}{2} + \left[\sqrt{8cp\alpha V(1-p)^2 + (cp - p\alpha V(1-p)^2 - o(1-p))^2} + o(1-p) - cp\right] \cdot \left[2p\alpha V(1-p)^2\right]^{-1}.$$

Figure 9 also illustrates that a help process can lead to either front- or back-loading. Back-loading occurs when the gray-dotted area rises above the horizontal line dividing the gray and black area; front-loading occurs when the black-dotted area extends below that same line. Front-loading occurs because the intertemporal incentive effect of help decreases the incentive needed for engagement in the first period, thus making higher engagement levels profitable for the firm.

6. Conclusion

Cooperative behavior is known to play a crucial role in project environments, and innovation research has identified cooperation across projects as a major determinant of project success. State-of-the-art PM education emphasizes the importance of a cooperative atmosphere and advocates for leadership that establishes such environments. Yet to the best of our knowledge, no prior work has analyzed the effectiveness of using a help process as a building block in a project environment. The case of Roto, a manufacturer of roof and solar technologies, demonstrates that a help process *can* be effectively incorporated into a formal PM system. Rather than relying on altruism or emotions often associated with help, this formal process of help sets incentives for rational help seeking and provision. Inspired by this company, we have built a model to shape a comprehensive answer to the question of when, and if so, how and why a help process should be used across projects. We derive our insights by comparing two relevant organizational alternatives: a PM system with formal help and a standard PM system.

Our paper's first contribution is to shed light on the contingency factors that determine *when* a help system should be used (or not). In fact, we find that both the help system and the no-help system can be optimal. A no-help system may be preferred when the benefits of a help system do not offset its major drawback of free riding. We also analyze the value that a help system can create relative to a no-help system. Intuitively, a help system is most valuable when payoff and recovery values are high, help is complementary, and project success is more uncertain. Less intuitive, however, is that the help system may become more advantageous as project managers' opportunity costs increase—because then the firm can reap the expected benefits from both types of work under asymmetric engagement.

Second, our paper contributes by characterizing *how* the company should use a help system. The company should create project interdependencies in combination with time- and help-based incentives. Regarding these combinations we identify three subtle yet significant effects. First, a surprising result is that the help system can facilitate project prioritization; that is, it may be optimal for the company to induce asymmetric engagement (effort levels) for otherwise symmetric projects. In such an asymmetric engagement configuration, help is provided in one direction: from the high-engagement to the low-engagement project. This result broadens the perspective obtained from the single case of Roto; there, the system is operated in accordance with our configuration of symmetric engagement and bidirectional help. Second, the firm can—often by relying on asymmetric engagement—encourage help in such a way that its project portfolio is profitably expanded; the implication is that a company can deliver projects that would be abandoned under a no-help system. Third, the firm may exemplify the accelerating effects on project timing observed at Roto (Sting et al. 2015) and thus reap the well-known benefits of front-loading projects (Thomke and Fujimoto 2000). Yet we also identify other situations in which, contrary to extant PM knowledge and to Roto's situation, a help process should optimally induce project back-loading. The benefit of back-loading project efforts has not been discussed in the literature because its value derives (as we demonstrate) from help *between* projects that allow the firm to make portfolio-wide timing adjustments, a phenomenon not previously acknowledged.

Finally, we analyze *why* companies may benefit from using a formal help process. Toward that end, we identify mechanisms that shape the costs and benefits of a help system. We show that although help itself may be expensive—compensation will be owed to two project managers instead of just one, and free riding must be overcome—help also creates an *intertemporal incentive*: because project managers anticipate potential benefits from offering help, the firm can reduce the incentives it offers for timely completion. Furthermore, the *greater likelihood of success* resulting from bundled efforts during help may outweigh the higher cost for rewarding such cooperation. Finally, when help is complementary enough, the firm incurs a lower cost for rewarding cooperative versus individual efforts and so benefits from the *efficiency gains* of help. These findings contribute to explaining Roto's enhanced project completion performance at lower execution costs (Sting et al. 2015).

We generalize the representation of effort to multiple effort levels and address the effect of private information on the complementarity of help to show that our main results remain robust. That said, our analysis is subject to several limitations. The most telling of these is that we analyze a two-project setting in which each project can be completed at one of two possible completion times (or be abandoned), so we do not address the effects of repeated interactions on the behavior of those involved with the projects. Moreover, our analysis focuses on managers at the project level; hence, the model presented here does not incorporate individual project tasks and their task owners. We must also mention that our insights are limited to project interactions within a single "strategic bucket" (Chao and Kavadias 2008, Hutchison-Krupat and Kavadias 2014), a model assumption grounded in Roto's rather homogeneous project portfolio. In other words, the results we derive ignore any effects that might arise because of different project scopes, risks, or learning orientations across such buckets. These important aspects of potential help settings merit further investigation, and we hope that future field or model-based work will extend our findings along these promising avenues.

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Appendix

Proof of Proposition 1

Part (i) can be shown as follows. Project manager i exerts effort in $t=1$ if $w_1 p - c \geq 0$, so at this point we have $w_1^* = c/p$. He exerts effort in $t=0$ if $w_0 p - c + (1-p)(w_0 p - c) \geq 0$ and so $w_0^* = c/p$ at this stage. The firm induces effort in $t=1$ if $\Pi = p(\alpha V - w_1^*) \geq o$, in which case $p\alpha V \geq c + o$. The firm's expected payoff from a project is thus

$$\Pi = 2p(V - w_0^* + o) + 2(1-p)p(\alpha V - w_1^*) = 2(p(V+o) - c + (1-p)(p\alpha V - c)).$$

The rest of the proposition is proved similarly.

Proof of Lemma 1

Clearly, the optimal incentives are the *minimum* values that satisfy the incentive constraints.

Proof of Proposition 2

In $t=-1$, the company can choose to incentivize either high engagement ($e_{i,1} = e_{j,1} = 1$) or asymmetric engagement ($e_{i,1} = 0, e_{j,1} = 1$) for $j = 1, 2,\ j \neq i$. Then project managers earn the respective payoffs $W^{\mathscr{H}}$ and $W^{\mathscr{A}}$. Formally,

$$W^{\mathscr{H}} = pw_0^{\mathscr{H}} - c + 2p(1-p)\left(p(1+(1-p)h)\frac{c}{p(1-p)h} - c\right),$$

$$W^{\mathscr{A}}(e_{i,1}=1) = pw_0^{\mathscr{A}} - c + p\left(p(1+(1-p)h)\frac{c}{p(1-p)h} - c\right),$$

$$W^{\mathscr{A}}(e_{i,1}=0) = p\left(p(1+(1-p)h)\frac{c}{p(1-p)h} - c\right).$$

To induce high engagement, the company must ensure that $W^{\mathscr{H}} \geq W^{\mathscr{A}}(e_{i,1}=0)$, from which we obtain $w_e^{\mathscr{H}} \geq c/p - c/h + pc/((1-p)h)$. Therefore, the optimal wage is $w_0^{\mathscr{H}} \geq \max\{c/p - c/h + pc/((1-p)h), 0\}$. To induce high effort under asymmetric engagement, the company must ensure that $W^{\mathscr{A}}(e_{i,1}=1) \geq 0$; therefore, $w_e^{\mathscr{A}} \geq c/p - c/((1-p)h)$. Hence the optimal wage is $w_0^{\mathscr{A}} = \max\{c/p - c/((1-p)h), 0\}$.

Proof of Proposition 3

The following equations express the firm's payoff under the optimal incentives for *high* engagement and help with and without individual effort (respectively, $\mathscr{HH}$ and $\mathscr{HL}$) when help is unavailable as well as for *asymmetric* engagement with and without individual effort (respectively, $\mathscr{AH}$ and $\mathscr{AL}$) when help is unavailable:

$$\Pi^{\mathscr{HH}} = 2p\left(V - \max\left\{\frac{c}{p} - \frac{c}{h} + \frac{pc}{(1-p)h}, 0\right\}\right) + 2p(1-p)p(1+(1-p)h)\left(\alpha V - \frac{2c}{p(1-p)h}\right) + 2(1-p)^2(p\alpha V - c) + 2p^2 o;$$

$$\Pi^{\mathscr{HL}} = 2p\left(V - \max\left\{\frac{c}{p} - \frac{c}{h} + \frac{pc}{(1-p)h}, 0\right\}\right) + 2p(1-p) \cdot p(1+(1-p)h)\left(\alpha V - \frac{2c}{p(1-p)h}\right) + 2(1-p)^2 o + 2p^2 o;$$

$$\Pi^{\mathscr{AH}} = p\left(V - \max\left\{\frac{c}{p} - \frac{c}{(1-p)h}, 0\right\}\right) + o + pp(1+(1-p)h) \cdot \left(\alpha V - \frac{2c}{p(1-p)h}\right) + 2(1-p)(p\alpha V - c);$$

$$\Pi^{\mathscr{AL}} = p\left(V - \max\left\{\frac{c}{p} - \frac{c}{(1-p)h}, 0\right\}\right) + o + pp(1+(1-p)h)\left(\alpha V - \frac{2c}{p(1-p)h}\right) + 2(1-p)o.$$

Under the no-help system (subscript $\mathscr{N}$), the firm's payoffs for the three scenarios—$\Pi_{\mathscr{N}}^{\mathscr{HH}}$ for high effort in both stages, $\Pi_{\mathscr{N}}^{\mathscr{HL}}$ for high effort in the first stage only, and $\Pi_{\mathscr{N}}^{\mathscr{LL}}$ for no effort in either stage—are as stipulated in Proposition 1.

The conditions for each scenario can be derived via comparisons made among these payoffs under the condition $h(1-p) \geq p(2-p)$, which ensures that $c/p - c/h + pc/((1-p)h) \geq 0$ and $c/p - c/((1-p)h) \geq 0$.

In part 1, the company induces no individual effort in the second stage when help is not available. Hence we have $(c+o)/(\alpha p) > V$ (this condition is given in Proposition 1). Furthermore, the thresholds for engagement strategies can be derived as follows.

(a) High engagement is preferred when $\Pi^{\mathscr{HL}} \geq \Pi_{\mathscr{N}}^{\mathscr{HL}}$ and $\Pi^{\mathscr{HL}} \geq \Pi^{\mathscr{AL}}$, which yield the respective thresholds

$$V_1 = \frac{c + 2h(c+o)(1-p)^2}{\alpha hp(1-p)^2(1+h(1-p))} \quad \text{and}$$

$$V_2 = \frac{pc + h(c+o)(1+p-6p^2+4p^3)}{hp(1-p)(1+\alpha(1+h(1-p))p(1-2p))}.$$

(b) Asymmetric engagement is preferred when $\Pi^{\mathscr{AL}} \geq \Pi^{\mathscr{HL}}$, $\Pi^{\mathscr{AL}} \geq \Pi_{\mathscr{N}}^{\mathscr{HL}}$, and $\Pi^{\mathscr{AL}} \geq \Pi_{\mathscr{N}}^{\mathscr{LL}}$. The first inequality gives V_2 as in (a). The second and third inequalities yield thresholds

$$V_3 = \frac{h(c+o)(1-3p+2p^2) - cp}{hp(1-p)(1-\alpha(1+h(1-p))p)} \quad \text{and}$$

$$V_4 = \frac{pc + h(c+o)(1+p-2p^2)}{hp(1-p)(1+\alpha p(1+h(1-p)))},$$

respectively.

In part 2 of the proposition, the company induces individual effort in the second stage when help is not available. Under these circumstances, $V > (c+o)/(\alpha p)$ for all the cases and the thresholds for engagement strategies are as listed next.

(a) High engagement is preferred when $\Pi^{\mathscr{HH}} \geq \Pi^{\mathscr{AH}}$ and $\Pi^{\mathscr{HH}} \geq \Pi_{\mathscr{N}}^{\mathscr{HH}}$, which give the thresholds

$$V_5 = \frac{cp + h(c+o)(1-p)(1-2p^2)}{h(1-p)p(1-\alpha p(1-h(1-p)(1-2p)))} \quad \text{and}$$

$$V_6 = \frac{c + h(c+o)(1-p)^2}{\alpha h^2(1-p)^3 p},$$

respectively.

(b) Asymmetric engagement is preferred when $\Pi^{\mathscr{AH}} \geq \Pi^{\mathscr{HH}}$ and $\Pi^{\mathscr{AH}} \geq \Pi_{\mathscr{N}}^{\mathscr{HH}}$, from which follow the respective thresholds V_5 and V_3.

Proof of Lemma 2

Under commitment, the company expands its portfolio if its expected profit in $t=0$ under the most favorable conditions (i.e., $\alpha = 1$ and $V = (o+c)/p$) is larger than in the no-help system. In the former case, the firms earns

$$\Pi^{\mathscr{AL}}|_{\alpha=1, V=(o+c)/p} = 3o + (1+hp)(1-p)o + cp\left(h(1-p) - \frac{1}{h(1-p)} - 1\right);$$

in the latter case, it earns $4o$. Therefore, the conditions for portfolio expansion can be found by solving

$$3o + (1+hp)(1-p)o + cp\left(h(1-p) - \frac{1}{h(1-p)} - 1\right) \geq 4o,$$

which gives $h(1-p) \geq \frac{1}{2}(1+\sqrt{(5c+o)/(c+o)})$ or $h(1-p) \leq \frac{1}{2}(1-\sqrt{(5+o)/(c+o)})$, where $\frac{1}{2}(1-\sqrt{(5c+o)/(c+o)}) < 0$ for $o \geq 0$. Hence the only condition we need is $h(1-p) \geq \frac{1}{2}(1+\sqrt{(5c+o)/(c+o)})$.

Back-loading occurs if and only if $\Pi^{\mathcal{AL}} > \Pi^{\mathcal{HL}}$ and $\Pi^{\mathcal{AL}} > \Pi^{\mathcal{HL}}_{\mathcal{N}}$. The condition $h(1-p) < \frac{1}{2}(1+\sqrt{(5c+o)/(c+o)})$ implies that $\Pi^{\mathcal{AL}}|_{V=(c+o)/p} < \Pi^{\mathcal{HL}}_{\mathcal{N}}|_{V=(c+o)/p} = 4o$ and so there is no back-loading. For $h(1-p) \geq \frac{1}{2}(1+\sqrt{(5c+o)/(c+o)})$, we look at two scenarios:

1. $\Pi^{\mathcal{HL}}|_{\alpha=1,\,V=(c+o)/p} < 4o$. In that case, the existence of project portfolio expansion implies that $\Pi^{\mathcal{AL}}|_{\alpha=1,\,V=(c+o)/p} \geq \Pi^{\mathcal{HL}}_{\mathcal{N}}|_{V=(c+o)/p} = 4o$ and thus back-loading exists.

2. $\Pi^{\mathcal{HL}}|_{\alpha=1,\,V=(c+o)p} \geq 4o$. In this case, Since $\Pi^{\mathcal{HL}}$ decreases in α, we can find $\alpha^* = (c+2h(c+o)(1-p)^2)/(h(c+o)(1+h(1-p))(1-p)^2)$ such that $\Pi^{\mathcal{HL}}|_{\alpha=\alpha^*,\,V=(c+o)/p} = 4o$. Then we can show that $\Pi^{\mathcal{AL}}|_{\alpha=\alpha^*,\,V=(c+o)/p} > \Pi^{\mathcal{HL}}|_{\alpha=\alpha^*,\,V=(c+o)/p} = 4o$ and back-loading exists.

Proof of Lemma 3

We first define the percentage increase as $\rho = (\Pi^{\mathcal{H}} - \Pi^{\mathcal{N}})/\Pi^{\mathcal{N}}$, where $\Pi^{\mathcal{H}}$ and $\Pi^{\mathcal{N}}$ are profits under (respectively) the help system and the no-help system. The specific values of these profits depend on which engagement strategy is adopted by the company.

1. Assume that $V \leq (c+o)/p$.

In this case there are two possible engagement strategies, which lead to $\rho_1 = (\Pi^{\mathcal{HL}} - \Pi^{\mathcal{LL}}_{\mathcal{N}})/\Pi^{\mathcal{LL}}_{\mathcal{N}}$ and $\rho_2 = (\Pi^{\mathcal{AL}} - \Pi^{\mathcal{LL}}_{\mathcal{N}})/\Pi^{\mathcal{LL}}_{\mathcal{N}}$; here the specific values of these profits are as described in the proof of Proposition 3.

It is easy to verify that both ρ_1 and ρ_2 are strictly increasing in V and α. Therefore, $\rho_1 \leq (p(h(c+o)(h(1-p)-1)\cdot(1-p)^2 - c))/(2ho(1-p))$ and $\rho_2 \leq (p(h(o+c)(h(1-p)-1)\cdot(1-p)-c))/(4ho(1-p))$, which are the values at $\alpha = 1$ and $V = (c+o)/p$. As a consequence,

$$\rho \leq \max\left\{\frac{p(h(c+o)(h(1-p)-1)(1-p)^2-c)}{2ho(1-p)}, \frac{p(h(o+c)(h(1-p)-1)(1-p)-c)}{4ho(1-p)}\right\}.$$

2. Assume that $V \geq (c+o)/(\alpha p)$.

In this case there are two possible increases: $\rho_3 = (\Pi^{\mathcal{HH}} - \Pi^{\mathcal{HH}}_{\mathcal{N}})/\Pi^{\mathcal{HH}}_{\mathcal{N}}$ and $\rho_4 = (\Pi^{\mathcal{AH}} - \Pi^{\mathcal{HH}}_{\mathcal{N}})/\Pi^{\mathcal{HH}}_{\mathcal{N}}$. We start with ρ_3. The first-order derivative of ρ_3 with respect to V is

$$\begin{aligned}\frac{\partial \rho_3}{\partial V} &= [p^2(c(1+\alpha(1+h(1-h(2-p))(1-p)^2)(1-p)+h(1-p)^2)\\ &\quad +ho(1-p)^2(1+\alpha(1-p)(1+hp)))]\\ &\quad \cdot[h(1-p)(p(o+(1+\alpha(1-p))V)-c(2-p))^2]^{-1}.\end{aligned}$$

Note that $\partial\rho_3/\partial V$ goes to zero only if V goes to infinity. In other words, there is no interior value of V such that $\partial\rho_3/\partial V = 0$. Hence the maximum value of ρ_3 occurs either as $V \to \infty$ for a given α or when $V = (c+o)/(\alpha p)$.

When $V \to \infty$, we have $\rho_3 = \alpha hp(1-p)^2/(1+\alpha(1-p))$. This quantity is greatest when $\alpha = 1$, from which it follows that $\rho_3 \leq (hp(1-p)^2)/(2-p)$.

If instead ρ_3 is greatest along the curve $V = (c+o)/(\alpha p)$, then we substitute $V = (c+o)/(\alpha p)$ into the definition of ρ_3 and take the first-order derivative over α. Now

$$\frac{\partial\rho_3}{\partial\alpha} = \frac{-(c+o)(c+h(c+o)(1-h(1-p))(1-p)^2)p}{h(1-p)(c+o-\alpha(c-o))^2}.$$

If $c + h(c+o)(1-h(1-p))(1-p)^2 < 0$, then the maximum ρ_3 can be found at $\alpha = 1$ and $V = (c+o)/p$; it is the same as the upper bound of ρ_1 found in part 1. If $c + h(c+o)(1-h\cdot(1-p))(1-p)^2 > 0$, then $\rho_3 < 0$ for all values of α and so help would never be beneficial at $V = (c+o)/(\alpha p)$.

We follow the exact same procedure for ρ_4. Again we observe that ρ_4 as a function of V is maximized either as $V \to \infty$ or when $V = (c+o)/(\alpha p)$. In the former instance, $\rho_4 \leq (\alpha p(1+h(1-p))-1)/(2(1-\alpha(1-p))$ and this value is smaller than $(hp(1-p)^2)/(2-p)$, the upper bound of ρ_3 as $V \to \infty$. In the latter instance, the maximum ρ_4 can be found at $\alpha = 1$ and $V = (c+o)/p$, which is the same as the bound of ρ_2 found in part 1.

3. Assume that $(c+o)/p \leq V < (c+o)/(\alpha p)$.

In this case, the two possible increases are $\rho_5 = (\Pi^{\mathcal{HL}} - \Pi^{\mathcal{HL}}_{\mathcal{N}})/\Pi^{\mathcal{HL}}_{\mathcal{N}}$ and $\rho_6 = (\Pi^{\mathcal{AL}} - \Pi^{\mathcal{HL}}_{\mathcal{N}})/\Pi^{\mathcal{HL}}_{\mathcal{N}}$. The proof follows the same procedure in part 2. Similarly, we observe that the first-order derivatives of ρ_5 and ρ_6 with respect to V go to zero only if V goes to infinity and therefore there are no interior values of V that maximize ρ_5 and ρ_6, respectively. Then, ρ_5 and ρ_6 are maximized either at $V = (c+o)/p$ or $V = (c+o)/(\alpha p)$. In the latter instance, the maximums of ρ_5 and ρ_6 can be found at $\alpha = 1$ and $V = (c+o)/p$, which are the same in the former instance and also coincide with the bounds of ρ_3 and ρ_4 found in part 2.

The bounds themselves are capped at $(hp(1-p)^2)/(2-p) \leq 0.5$, at $(p(h(c+o)(h(1-p)-1)(1-p)^2-c))/(2ho(1-p)) \leq \infty$, and at $p((h(o+c)(h(1-p)-1)(2-p)-c))/(4ho(1-p)) \leq \infty$. Solving $(p(h(c+o)(h(1-p)-1)(1-p)^2-c))/(2ho(1-p)) \leq (hp(1-p)^2)/(2-p)$ now yields the condition $o > (c(h(1-p)^2\cdot(h(1-p)-1)-1)(2-p))/(h(1-p)^2(2+p(h(1-p)-1)))$. Solving $(p(h(o+c)(h(1-p)-1)(2-p)-c))/(4ho(1-p)) \leq (hp(1-p)^2)/(2-p)$, we have the condition $o > (c(h(1-p)\cdot(h(1-p)-1)-1)(2-p))/(h(1-p)(2-p+h(1-p))(2-3p))$. So when

$$o > \max\left\{\frac{c(h(1-p)^2(h(1-p)-1)-1)(2-p)}{h(1-p)^2(2+p(h(1-p)-1))}, \frac{c(h(1-p)(h(1-p)-1)-1)(2-p)}{h(1-p)(2-p+h(1-p))(2-3p)}\right\},$$

we have $\rho \leq (hp(1-p)^2)/(2-p)$.

Proof of Proposition 4

For the *pooling* policy, the company must satisfy the following constraints:

$$\begin{aligned}&w_r(p+(1-p)p\underline{h}) - c \geq \max\{w_1 p - c, 0\},\\ &w_r(p+(1-p)p\underline{h}) - c \geq w_r p,\\ &w_h(p+(1-p)p\underline{h}) - c \geq w_h p.\end{aligned}$$

The first two constraints are for the troubled manager to call for help and exert effort; the third is for the helping manager to exert effort. Here the optimal $w_1 = c/p$. The optimal incentives can be found in the binding constraints and are given as

$$w_r^{\mathscr{P}} = \frac{c}{p(1-p)\underline{h}} \quad \text{and} \quad w_h^{\mathscr{P}} = \frac{c}{p(1-p)\underline{h}}.$$

For the *shutdown* policy, the firm must satisfy the following constraints:

$$\begin{aligned} w_r(p+(1-p)p\bar{h}) - c &\geq \max\{w_1 p - c, 0\}, \\ w_r(p+(1-p)p\bar{h}) - c &\geq w_r p, \\ w_h(p+(1-p)p\bar{h}) - c &\geq w_h p, \\ w_r(p+(1-p)p\underline{h}) - c &\leq \max\{w_1 p - c, 0\}. \end{aligned}$$

The new constraint ensures that the troubled manager does not call for help when the *complementarity* of help is low. The optimal incentives in this case are

$$w_r^{\mathscr{S}} = \frac{c}{p(1-p)\bar{h}} \quad \text{and} \quad w_h^{\mathscr{S}} = \frac{c}{p(1-p)\bar{h}}.$$

The last of these constraints requires that $w_r^{\mathscr{S}} = c/(p(1-p)\bar{h}) \leq c/(p+(1-p)p\underline{h})$, which holds only when $(\bar{h}-\underline{h})(1-p) \geq 1$.

Proof of Proposition 5

We first find the optimal incentives for high and normal efforts at $t=1$. Project manager i exerts *high* effort at $t=1$ if $w_1 p(2-p) - 2c \geq w_1 p - c$, which gives the optimal wage $w_1^h = c/(p(1-p))$. Project manager i exerts *normal* effort at $t=1$ if $w_1 p - c \geq 0$, which gives the optimal wage $w_1^n = c/p$. These optimal wages will be used to determine the optimal effort levels to induce, and also the optimal wages, in $t=0$.

1. In $t=1$, the company induces *high* effort if its expected profit is then greater than under normal effort or no effort, respectively,

$$\begin{aligned} p(2-p)(\alpha V - w_1^h) &\geq p(\alpha V - w_1^n); \\ p(2-p)(\alpha V - w_1^h) &\geq o. \end{aligned}$$

Hence $\alpha V \geq c/(p(1-p)^2)$ and $\alpha V \geq (c+(c+o)(1-p))/(p(1-p)\cdot(2-p))$ or, equivalently, $\alpha V \geq \max\{c/(p(1-p)^2), (c+(c+o)\cdot(1-p))/(p(1-p)(2-p))\}$.

Given high effort in $t=1$, project manager i exerts high effort in $t=0$ if

$$\begin{aligned} & w_0 p(2-p) - 2c + (1-p(2-p))(w_1^h p(2-p) - 2c) \\ & \quad \geq w_0 p - c + (1-p)(w_1^h p(2-p) - 2c), \end{aligned}$$

and the optimal wage is $w_0^h = c(1+p^2)/(p(1-p))$. Project manager i exerts normal effort at $t=0$ if

$$w_0 p - c + (1-p)(w_1^h p(2-p) - 2c) \geq w_1^h p(2-p) - 2c,$$

and the optimal wage is $w_0^n = c/p + cp/(1-p)$.

In $t=0$, the company induces high effort if its expected profit is then greater than under normal effort or no effort, respectively,

$$\begin{aligned} & p(2-p)(V+o-w_0^h) + (1-p(2-p))p(2-p)(\alpha V - w_1^h) \\ & \quad \geq p(V+o-w_0^n) + (1-p)p(2-p)(\alpha V - w_1^h); \\ & p(2-p)(V+o-w_0^h) + (1-p(2-p))p(2-p)(\alpha V - w_1^h) \\ & \quad \geq o + p(2-p)(\alpha V - w_1^h). \end{aligned}$$

From these expressions it follows that $V \geq (c(1-2p(1-p)^2) - o(1-p)^2 p)/(p(1-p)^2(1-\alpha p(2-p)))$ and $V \geq (c(2-p(5-2p\cdot(3-p)) + o(1-p)^3)/(p(1-p)(2-p)(1-\alpha p(2-p)))$ or, equivalently,

$$V \geq \max\left\{\frac{c(1-2p(1-p)^2) - o(1-p)^2 p}{p(1-p)^2(1-\alpha p(2-p))}, \frac{c(2-p(5-2p(3-p)) + o(1-p)^3}{p(1-p)(2-p)(1-\alpha p(2-p))}\right\}.$$

The company induces normal effort if its expected profit is then greater than under high effort or no effort, respectively,

$$\begin{aligned} & p(V+o-w_0^n) + (1-p)p(2-p)(\alpha V - w_1^h) \\ & \quad \geq p(2-p)(V+o-w_0^h) + (1-p(2-p))p(2-p)(\alpha V - w_1^h); \\ & p(V+o-w_0^n) + (1-p)p(2-p)(\alpha V - w_1^h) \\ & \quad \geq o + p(2-p)(\alpha V - w_1^h). \end{aligned}$$

Thus we have $(c(1-2p(1-p)^2) - o(1-p)^2 p)/(p(1-p)^2(1-\alpha p(2-p))) \geq V \geq ((c+o)(1-p) - cp)/(p(1-\alpha p(2-p)))$.

2. In $t=1$, the company induces *normal* effort if its profit is then greater than under high effort or no effort, respectively,

$$\begin{aligned} p(\alpha V - w_1^n) &\geq p(2-p)(\alpha V - w_1^h); \\ p(\alpha V - w_1^n) &\geq o. \end{aligned}$$

Therefore, $c/(p(1-p)^2) \geq \alpha V \geq (c+o)/p$. Note that this inequality does not hold when $o > (cp(2-p))/(1-p)^2$, and in this case it is not optimal to induce normal effort in $t=1$.

Given normal effort at $t=1$, project manager i exerts high effort at $t=0$ if

$$\begin{aligned} & w_0 p(2-p) - 2c + (1-p(2-p))(w_1^n p - c) \\ & \quad \geq w_0 p - c + (1-p)(w_1^n p - c), \end{aligned}$$

in which case the optimal wage is $w_0^h = c/(p(1-p))$. Project manager i exerts normal effort at $t=0$ if

$$w_0 p - c + (1-p)(w_1^n p - c) \geq w_1^n p - c,$$

and the optimal wage is $w_0^n = c/p$.

The company induces high effort at $t=0$ if its expected profit is then greater than under normal effort or no effort, respectively,

$$\begin{aligned} & p(2-p)(V+o-w_0^h) + (1-p(2-p))p(\alpha V - w_1^n) \\ & \quad \geq p(V+o-w_0^n) + (1-p)p(\alpha V - w_1^n); \\ & p(2-p)(V+o-w_0^h) + (1-p(2-p))p(\alpha V - w_1^n) \\ & \quad \geq o + p(\alpha V - w_1^n). \end{aligned}$$

These expressions imply that $V \geq (c(1-p(1-p)^2) - o(1-p)^2 p)/(p(1-p)^2(1-\alpha p))$ and $V \geq (c(2-p)(1-p(1-p)) + o(1-p)^3)/(p(1-p)(2-p)(1-\alpha p))$ or, equivalently,

$$V \geq \max\left\{\frac{c(1-p(1-p)^2) - o(1-p)^2 p}{p(1-p)^2(1-\alpha p)}, \frac{c(2-p)(1-p(1-p)) + o(1-p)^3}{p(1-p)(2-p)(1-\alpha p)}\right\}.$$

The company induces normal effort at $t = 0$ if its expected profit is then greater than under high effort or no effort, respectively,

$$p(V+o-w_0^n)+(1-p)p(\alpha V-w_1^n)\geq p(2-p)(V+o-w_0^h) +(1-p(2-p))p(\alpha V-w_1^n);$$
$$p(V+o-w_0^n)+(1-p)p(\alpha V-w_1^n)\geq o+p(\alpha V-w_1^n).$$

Hence $(c(1-p(1-p)^2)-o(1-p)^2p)/(p(1-p)^2(1-\alpha p))\geq V\geq (c+o)(1-p)/(p(1-\alpha p))$. Here, when $o > cp(2-p)/(1-p)^2$, the above condition does not hold; thus it is not optimal to induce normal effort in $t = 0$.

We conclude that, when $o > cp(2-p)/(1-p)^2$, it is never optimal to induce normal effort in $t = 0$ or $t = 1$.

3. In $t = 1$, the company induces *no* effort if its profit is then greater than under high effort or normal effort, respectively,

$$o\geq p(2-p)(\alpha V-w_1^h),\qquad o\geq p(\alpha V-w_1^n).$$

It follows that $\alpha V\leq (c+(c+o)(1-p))/(p(1-p)(2-p))$ and $\alpha V\leq (c+o)/p$ or, equivalently, $\alpha V\leq \min\{(c+(c+o)(1-p))/(p(1-p)(2-p)), (c+o)/p\}$.

Given no effort at $t = 1$, project manager i exerts high effort at $t = 0$ if $w_0p(2-p)-2c > w_0p-c$, which yields an optimal wage of $w_0^h = c/(p(1-p))$. Project manager i exerts normal effort at $t = 0$ if $w_0p-c > 0$, which gives the optimal wage $w_0^n = c/p$.

The company induces high effort at $t = 0$ if its expected profit is then greater than under normal effort or no effort, respectively,

$$p(2-p)(V-w_0^h)+o\geq p(V-w_0^n)+o,$$
$$p(2-p)(V-w_0^h)+o\geq o+o.$$

Therefore, $V\geq c/(p(1-p)^2)$ and $V\geq (c+(c+o)(1-p))/(p(1-p)(2-p))$ or, equivalently, $V\geq \max\{c/p(1-p)^2, (c+(c+o)(1-p))/(p(1-p)(2-p))\}$.

The company induces normal effort at $t = 0$ if its expected profit is then greater than under high effort or no effort, respectively,

$$p(V-w_0^n)+o\geq p(2-p)(V-w_0^h)+o,$$
$$p(V-w_0^n)+o\geq o+o;$$

these expressions yield $c/(p(1-p)^2)\geq V\geq (c+o)/p$.

Proof of Lemma 4

Suppose that, in $t = 1$, one project manager is in trouble and the other manager is available for help. Then the company earns $(p+hp(1-p))(\alpha V-2c/(hp(1-p)))$ if it induces cooperation or earns $p(2-p)(\alpha V-c/(p(1-p)))+o$ if it induces high effort by the troubled manager. The level of help complementarity h at which the firm prefers inducing cooperation to inducing high effort is found by solving

$$(p+hp(1-p))\left(\alpha V-\frac{2c}{hp(1-p)}\right)\geq p(2-p)\left(\alpha V-\frac{c}{p(1-p)}\right)+o.$$

Endnotes

[1] Here we have replaced the Puranam et al. generic term "task interdependence" with the more specific term "project interdependence."

[2] We generalize this binary effort setup in Section 5.2 by allowing for high, normal, and no effort.

[3] In Section 5.1 we incorporate the notion that h is random and private information: whereas the firm has an expectation regarding h, only the project managers observe the *actual* complementarity of help.

[4] This assumption is in line with empirical PM evidence and also accords with widely held conceptualizations (Adler et al. 1995, 1996; Kwon et al. 2010). However, we verified that our model's key insights do not depend on it.

[5] Figure 2—and each subsequent figure—is parameterized with $c = 1$ and $o = 0.25$. This normalization is without loss of generality.

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