Regulating Spillovers in Teamwork*

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Abstract

We study team incentives with positive spillovers and rewards based on ex-post credit for collective success. Compared to ex-ante efficient credit allocation, higher-ability or lower-cost agents are over-credited in equilibrium and, thus, over-motivated for team success when the spillover rate is low and under-credited/under-motivated when it is high. Therefore, organizations may optimally limit positive spillovers between team members by regulating peer communication and transparency. Alternatively, organizations may carefully compose teams to diffuse credit-sharing concerns. These concerns also make lower-ability agents less likely to invite collaborators or choose the most capable when they own the project.

Keywords: Teamwork, Spillovers, Credit Attribution

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1 Introduction

> "It is amazing what you can accomplish if you do not care who gets the credit." — Harry S. Truman, the 33rd U.S. President

> "In the real world, it matters who gets credit...That all goes into the bank account of how much value you bring to the organization and plays into promotion decisions, raises, and assignments." — Karen Dillon, the former editor of the Harvard Business Review and the author of *HBR Guide to Office Politics*

In many teamwork environments, agents contribute to joint success both directly and indirectly through their positive spillovers to others. In law enforcement, better intelligence gathering by a partner agency can enhance the surveillance efforts of another in tracking criminals. In scientific collaborations, researchers regularly learn from each other's efforts.[1] In artistic production, a movie star's performance can receive a boost from the co-stars.[2]

An implicit consensus in all these settings is that fostering positive spillovers *always* improves team incentives and efficiency. The substantial emphasis on more information sharing among law enforcement agencies since 9/11 is a case in point. In a Rand Corporation report, Hollywood and Winkelman (2015) document the substantial progress in improving the information-sharing ability of key law enforcement systems and review approaches to "overcoming the remaining barriers." The National Strategy for Information Sharing and Safeguarding (NSISS), signed by the Obama administration in 2012, encourages all federal and local agencies "to foster a culture that recognizes the importance of fusing information regarding all crimes with national security implications."

This paper argues that the consensus for increasing spillovers in teamwork is not entirely warranted because of two salient features in environments similar to those mentioned above. First, ex-post individual recognition for collective success is the primary source of reward, such as promotions, raises, and public funds, among other scarce resources (see the opening quotes). As a result, when one team member gets more credit for success, others get less.[3] Second, by its very nature, teamwork obscures individual contribution. In law enforcement,

[1]For example, Azoulay et al. (2010) find that the premature death of academic superstars reduces the productivity of their co-authors.

[2]Rossman et al. (2010) discuss the case of Robert Forster, a mostly obscure character actor nominated in 1998 for the Best Supporting Actor Oscar in the movie Jackie Brown, written and directed by Quentin Tarantino. His co-stars included prior nominees Samuel L. Jackson and Robert de Niro. Forster's career immediately "regressed to the mean" after Jackie Brown, demonstrating how much his nomination benefitted from Tarantino, Jackson, and De Niro.

[3]Perhaps because of its scarcity, claiming undue credit for success is not uncommon in the workplace (Gallo, 2015) and science (www.oxford-royale.com/articles/9-scientists-didnt-get-credit-deserved).

each partner agency likely seeks the bulk of the credit for a critical arrest. However, the law enforcement hierarchy only observes the arrest, not the individual efforts that led to it. Scientists greatly value the peer recognition of their roles in co-authored publications, but peers typically do not witness which researcher contributed the most. And, screenwriters working jointly on the script for a hit TV drama compete for plaudits, but the audience only sees the final script.

When team members seek ex-post recognition for their contributions to success, positive spillovers between them have nontrivial implications for ex-ante incentives. On the one hand, a higher spillover rate increases the chances of team success and motivates all members. On the other hand, increased spillovers dilute some agents' ex-post credit and de-motivate them. To understand this tradeoff and its implications for organizational design, we present a simple static model in which two agents with heterogeneous abilities expend unobservable efforts toward achieving a predetermined goal. A higher ability corresponds to a lower marginal cost of effort. Here, we interpret ability broadly as one's capacity to contribute. For example, an otherwise talented individual or well-run government agency may lack the time or resources to work on another project due to current precommitments. Importantly, abilities are common knowledge. Hence, we consider settings where the major difficulty for the outside parties is not assessing agents' potential to contribute to future projects but their actual contributions to the current.

We assume that the team's probability of success equals the agents' total *effective* contributions. As in the early literature on research joint ventures (e.g., D'Aspremont and Jacquemin, 1986; Kamien et al., 1992), an agent's effective contribution to team success is the sum of their effort and the boost from the teammate's due to the spillover (the research joint ventures literature similarly defines a firm's effective R&D investment). The spillover rate between agents can depend on the task at hand, working conditions, and collaboration tools provided by the organization.[4] The success generates one unit of output. Unlike most of the teamwork literature discussed below, we do not impose an exogenous sharing rule for this output. Instead, we envision that upon observing the success, such as an arrest, but not the efforts that led to it, the outside parties (the public) allocate credit according to their *perceived* relative effective contribution. Later, we will argue that this credit attribution rule can be micro-founded and welfare dominates the alternative based on relative effort. In our credit attribution equilibrium, the team's effort profile and the credit allocation must be

[4]The organization may have team members working in the same office or provide them with collaboration tools like Dropbox and Zoom. As hybrid-remote work becomes more common and cloud-based software improves, employers are expected to invest more in collaboration technologies (see https://www.officernd.com/blog/collaboration-technologies).

consistent.

As a benchmark, we first consider a social planner who maximizes the expected output net of total effort costs, which is equivalent to the agents' joint welfare in our setting. The planner can commit to credit allocation ex-ante to induce effort. Unsurprisingly, it is socially optimal for the agents to share the credit proportional to their abilities and increase their efforts with the spillover rate. Moreover, while exerting more effort, the high-ability agent always receives a higher utility than the low-ability teammate. With equilibrium credit allocation, these conclusions are largely overturned, depending on the degree of spillovers.

In the unique credit-attribution equilibrium, the low-ability agent's effort is, again, increasing, but the high-ability's effort is U-shaped in the spillover rate. To understand, consider the extreme case where the spillover between the agents is negligible, so the ex-post credit is determined solely by their relative efforts. Then, using his cost advantage, the high-ability agent is expected to take over the joint task and receive the entire credit from success in equilibrium, which is clearly inefficient given the convex cost of effort. A slight increase from this negligible spillover rate de-motivates the high-ability agent as it redistributes some credit to the low-ability. In contrast, a slight increase from an already high spillover rate would encourage the high-ability agent because his focus would be on team success instead of credit sharing, which would remain roughly at half. The analysis of this equilibrium delivers the following results.

(i) Efficiency of less than perfect spillovers. Compared to the social optimum, we find that for spillover rates below a threshold, the high-ability agent is over-credited ex-post and, in turn, over-motivated for success, while the opposite holds for the low-ability agent. Above the same threshold, the roles are reversed: the low-ability agent is over-rewarded and overworked for success. These findings challenge the conventional wisdom: even if it were costless to facilitate positive spillovers between agents through closer interaction, information sharing protocols, and job design, the organization would refrain from doing so and choose an intermediate spillover rate to elicit the optimal effort. The imperfect spillover rate corrects incentives distorted by ex-post credit concerns.

(ii) Optimal ability composition. In some environments, however, the degree of spillovers can be difficult to alter due to the nature of the task. In such environments, the organization may still reduce or even eliminate inefficiencies arising from agents' ex-post credit concerns through optimal team composition. We show that such optimal teams can be designed, provided that spillovers are not too pronounced. In particular, teams designed for tasks with higher spillover rates should be less heterogeneous, given that credit shares are expected to be closer.

(iii) Private incentives to collaborate. Our simple framework also yields insights into agents' private incentives to collaborate. In academia, a researcher often has the flexibility to work on a new idea solo or invite another researcher to work jointly. In law enforcement, an agency, such as the Department of Homeland Security, can claim jurisdiction over a case and exclude a sister agency, say the FBI, from participating in a team effort. This type of exclusion, called a *turf war*, seems more likely when the agency with jurisdiction is concerned with sharing credit with others. Perhaps surprisingly, we find that high-ability agents are more likely to invite collaborators when they can choose to work solo. Specifically, when the ability differential is sufficiently large, the high-ability agent favors teamwork regardless of the spillover rate. In contrast, more concerned about ex-post credit, the low-ability agent opts for teamwork only when the spillover rate is sufficiently high so that success is all but guaranteed. We also find that when agents can choose from a diverse pool of potential collaborators, ex-post credit concerns may lead to not picking the best among them. We discuss the implications of these results further in Section 6.

Related Literature. Our paper relates to the extensive literature in which a principal ex-ante contracts with multiple agents subject to moral hazard. Seminal works are by Alchian and Demsetz (1972), Lazear and Rosen (1981), and Holmström (1982). Notable recent contributions include Segal (2003), Winter (2004), Georgiadis (2015), Halac, Lipnowski, and Rappoport (2021), and Camboni and Porcellacchia (2024). We refer the reader to Fleckinger et al. (2024) for a comprehensive review of this literature. Our paper differs in that the principal cannot commit to rewards for success, as they are equilibrium objects in the form of ex-post credit.

There has been limited theoretical work on credit attribution. Previous studies in economics, such as Engers et al. (1999) and Ray ⓡ Robson (2018) have concentrated on authorship order as a signal of relative contributions. However, authorship order is an imperfect measure of relative contributions, which may explain why it is not the norm for allocating scientific credit across disciplines; see Kim and Kim (2015) for a review. In our model with pure moral hazard, the public deduce relative contributions based on the agents' known abilities and degree of spillovers. Hence, it is also different from Onuchic and Ray (2023) and Yildirim (2024), where, given the current output, the market infers team members' unknown abilities to predict their contributions to future projects rather than the current project, as in this study.

In this regard, the closest paper is our previous work. Like here, Ozerturk and Yildirim (2021) examine team incentives with equilibrium credit as rewards, but they assume away any spillover between team members. Therefore, that paper cannot address the equilibrium inefficiencies due to spillovers and their optimal organizational choice, which is central to this investigation.

In terms of equilibrium output sharing, our paper relates to several studies on team contests where the winning team is assumed to divide part of the prize equally (egalitarian) among its members while the rest is distributed proportionally to ex-post individual efforts (merit-based). See, for example, Nitzan (1991), Davis and Reilly (1999), Baik and Lee (2007), and the survey by Fu and Wu (2019). In our setting, the spillover between team members results in a similar decomposition for output sharing, but the public who divides the team output never observes individual efforts. As such, output sharing is an equilibrium object.

Our paper also complements those that emphasize the role of team composition in alleviating the free-rider problem; see, for instance, Franco et al. (2011), Kaya and Vereshchagina (2022), Bel et al. (2015), Bonatti and Rantakari (2016), Glover and Kim (2021), and Yildirim (2023). In our linear production model, the free-rider problem is absent when output shares are exogenously given. It is present when these shares are in the form of equilibrium public credit, a feature not considered in these papers.[5]

The paper is organized as follows. Section 2 sets up the model. Section 3 presents an optimal credit benchmark. Section 4 characterizes the team equilibrium. Section 5 explores the agents' private incentives to collaborate. Section 6 discusses our results and concludes. The Appendix contains the proofs and the technical details omitted from the main text.

2 The model

Our setup introduces positive spillovers to Ozerturk and Yildirim's (2021) static benchmark. Two risk-neutral agents $i \in \{1,2\}$ simultaneously exert one-time efforts to achieve a predetermined objective. Let $x_i \geq 0$ denote agent i's effort level, which is unobservable to others. To obtain closed-form solutions for clean comparative statics, the individual effort costs are assumed to have the quadratic form:[6]

$$c_i(x_i) = \frac{x_i^2}{2a_i}.$$

The parameter $a_i > 0$ captures agent i's "ability" to contribute to team success since a higher a_i implies a lower marginal cost for the same effort level. We assume that a_i is publicly

[5]Finally, our paper relates to the vast empirical work documenting positive spillovers in teamwork; see, for instance, Mas and Moretti (2009), Azoulay et al. (2010), Chan et al. (2014), Arcidiacono et al. (2017) and Jarosch et al. (2021).

[6]As illustrated in Appendix B, we have numerically verified that our main result, Corollary 1, holds more generally for the iso-elastic cost: $c_i(x_i) = x_i^k/(ka_i)$ where $k > 1$.

known, perhaps due to the agent's track record or other precommitments, ruling out any reputational concerns. As mentioned above, we acknowledge the importance of building a reputation for future projects but focus here on complementary settings where agents are mainly concerned with receiving credit for current success. Without loss of generality, we let $a_1 > a_2$ and refer to agent 1 as the high ability.

The agents contribute to team success not only directly but also indirectly through the positive impact of their efforts on their teammates. For an effort pair (x_i, x_j), with $j \neq i$, the *effective* contribution of agent i to team's success is given by

$$y_i = x_i + \beta x_j, \tag{1}$$

where $\beta \in (0, 1]$ is the common spillover rate between the agents. As we revisit in our analysis, β may be specific to the task at hand or the outcome of organizational design depending on the environment.

The specification in (1) follows the research joint venture literature (e.g., d'Aspremont and Jacquemin, 1986; Kamien et al., 1992). As in there, β represents the extent to which agents learn or take inspiration from each other's efforts. For example, the amount of actionable evidence x_i that law enforcement agency i produces in tracking a criminal network gets a boost βx_j from the efforts of their partner agency j. We assume the team's probability of success is the sum of effective contributions in (1):

$$y_1 + y_2 = (1 + \beta)X, \tag{2}$$

where $X = x_1 + x_2$ denotes the total effort.[7] The linear production in (2) is meant to introduce no free-riding incentive other than through sharing of the team output. The success generates one unit of output for the team, while the failure generates zero. To ensure that the success probability in (2) is interior in the analysis for any $\beta \in (0, 1]$, we impose throughout

$$a_1 + a_2 \leq 1/2.$$

In our setting, consistent with the examples of collaboration in law enforcement and the scientific community, agents receive no monetary incentives ex-ante. Instead, each gets rewarded ex-post based on his perceived responsibility or credit for team success. We assume that the public attributes credit to agent i proportional to his effective contribution:

$$q_i = \frac{y_i}{y_1 + y_2}. \tag{3}$$

[7] See Bonatti and Hörner (2011) for a similar additive probability of team success.

Since efforts are unobservable to others, including the public, we require that the effort profile and the credit allocation be consistent in (Nash) equilibrium. Three features of (3) deserve further comments.

(i) Scarcity of credit. The credit attribution rule in (3) implies that $q_1 + q_2 = 1$. Thus, the total credit for collective success is scarce. This feature is consistent with our motivating examples where credit is competitively distributed among team members to determine promotions, salary increases, or government funding, among other scarce resources. As Robbins (2019) points out "Recognition is about what people have already done and it is scarce. There's a limited amount of recognition to go around — everyone can't get a bonus or be mentioned by name in a memo — and it can be stressful when many people are vying for a finite amount of praise."

(ii) Micro-foundation. Eq.(3) can be formalized as in Ozerturk and Yildirim (2021). In their dynamic setting, the effective contribution y_i would capture agent i's exponential rate of achieving success (or breakthrough) and, in turn, q_i would refer to the public's Bayesian belief that it is agent i who is responsible for success.

(iii) Alternative rules. Eq.(3) posits that agent i receives credit based on his effective contribution, including the spillover βx_j from the teammate. Alternatively, the public could assign credit proportionally to agent i's total contribution, $x_i + \beta x_i$, to the probability of success. Then, (3) would be modified as:

$$\overline{q}_i = \frac{(1+\beta)x_i}{(1+\beta)X} = \frac{x_i}{X}. \tag{4}$$

Hence, eq.(4) is equivalent to an attribution rule purely based on relative effort, independent of the spillover rate. However, as we show below, (4) would be welfare dominated by (3): it would over-motivate the high-ability agent and under-motivate the low-ability. Consistent with the specification in (3), Arcidiacono et. al (2017) document evidence that a worker's compensation is largely dependent on own performance, but not on their positive impact on teammates' performances.[8]

To gain some initial insight into the role of spillover rate in credit allocation, note that (3) can be decomposed as

$$q_i = \underbrace{\frac{\beta}{1+\beta}}_{\text{fixed base credit}} + \underbrace{\frac{1-\beta}{1+\beta}\left(\frac{x_i}{X}\right)}_{\text{merit-based credit}}. \tag{5}$$

[8] Arcidiacono et al. (2017) use data from the National Basketball Association (NBA), where individual performances are observable. They explain the lack of compensation for the positive impact on teammates' performance by the difficulties of measuring such heterogeneous effects. With unobservable individual performances, such measurement challenges would be all the more relevant.

Hence, the public views the positive spillover as giving each agent a fixed base credit and allocating the rest proportional to their efforts. As β increases toward 1, the fixed credit portion increases toward $1/2$, resulting in less merit-based credit attribution. As mentioned in the Introduction, a similar output-sharing rule is widely used in contest theory; see Fu and Wu (2019) for a review.

3 Benchmark: optimal credit

Before studying the credit attribution equilibrium, we present an optimal benchmark. Suppose a (social) planner overseeing the agents can act as a Stackelberg leader and commit ex-ante to a credit or reward scheme $(q_1, q_2) \in [0,1]^2$ such that $q_1 + q_2 = 1$. While intended as a benchmark, such ex-ante commitment over a credit allocation may be realistic in some settings. For example, some scientific disciplines allocate authorship credit for multi-authored publications according to a harmonic progression formula (Hagen, 2010). In law enforcement, deciding beforehand which partner agency in a task force announces a significant breakthrough to the press can be seen as allocating credit ex-ante.

Having observed the credit scheme, the agents simultaneously make their one-shot effort choices. Expecting to receive q_i with the probability $(1+\beta)\,X$, agent i best responds to his teammate's conjectured effort x_j:

$$\max_{x_i} u_i = (1+\beta)\,Xq_i - c_i(x_i). \tag{6}$$

The unique solution to (6) is:

$$x_i = (1+\beta)q_i a_i, \tag{IC$_i$}$$

which is increasing in the spillover rate, credit for success, and the ability level, as expected.

Notice that given the credit scheme, agent i's effort is independent of j's. That is, there is no free-riding incentive between the agents. While specific to linear production, this feature will help us isolate the externality through equilibrium credit allocation. The planner cares about the expected team output net of the total cost of achieving it. Formally, the planner solves

$$\max_{q_1,q_2,x_1,x_2} w = (1+\beta)\,X - c_1(x_1) - c_2(x_2) \tag{OC}$$
$$\text{subject to } q_1 + q_2 = 1, \text{ and (IC}_i\text{) for } i = 1,2.$$

Note that $w = u_1 + u_2$, so (OC) is equivalent to the planner maximizing utilitarian welfare. Let q_i^o and x_i^o denote the optimal or *efficient* solution, and u_i^o the resulting utility for agent i.

Lemma 1 *The solution to (OC) is given by* $q_i^o = \frac{a_i}{a_1+a_2}$ *and* $x_i^o = (1+\beta)\frac{a_i^2}{a_1+a_2}$*. In particular, the high-ability agent works harder* ($x_1^o > x_2^o$)*, receives more credit* ($q_1^o > q_2^o$) *and obtains a higher utility* ($u_1^o > u_2^o$) *than his low-ability teammate for all* β*.*

The properties of this benchmark solution are all as expected. The planner allocates credit proportional to the agents' abilities. Intuitively, the (IC_i) implies that the planner can elicit greater effort per unit credit, x_i/q_i, from the high-ability agent. Therefore, she asks this agent to work harder in return for a greater credit and utility. Finally, since a higher spillover rate increases the likelihood of success, given a credit allocation, both agents work harder as the spillover rate β increases.

Remark 1 *The optimal solution in Lemma 1 does not depend on the specific form of ex-post credit attribution rule, since the planner can commit ex-ante to a credit scheme* $(q_1, q_2) \in [0,1]^2$.

Remark 2 *With additional social goals, the planner may value success more than the unit output it generates, say at* $1+s$ *where* $s \geq 0$*. For instance, the FBI may care more about the future deterrent effect of an arrest by a task force. However, extending the benchmark in this direction would add no new insights, as shown in Appendix C. In fact, by creating another channel for equilibrium underinvestment, it would cloud our results below, which is why we set* $s = 0$ *in the model.*

4 Equilibrium credit attribution

We now analyze the setting where the planner lacks commitment to a credit scheme ex-ante. Instead, the public allocates credit to agent i proportional to his *perceived* effective contribution to success, as described in (3). Since the agents' efforts are unobservable, even ex-post, the public assigns credit based on their conjectured levels. Let x_i^* and q_i^* denote agent i's effort and credit in equilibrium. They must satisfy (5) and (IC_i):

$$
\begin{aligned}
q_i^* &= \frac{\beta}{1+\beta} + \frac{1-\beta}{1+\beta}\left(\frac{x_i^*}{X^*}\right) \text{ and} \\
x_i^* &= (1+\beta)q_i^* a_i \text{ for } i = 1, 2.
\end{aligned} \tag{7}
$$

Unlike the above benchmark, agent i now best responds to his *perceived* credit, q_i^*, which needs to be correct in equilibrium. Substituting for q_i^* in x_i^*, (7) reveals

$$x_i^* = \frac{X^* \beta a_i}{X^* - a_i + \beta a_i}, \tag{8}$$

which, given $x_1^* + x_2^* = X^*$, leads to the following fixed-point condition for X^*:

$$\frac{X^* \beta a_1}{X^* - a_1 + \beta a_1} + \frac{X^* \beta a_2}{X^* - a_2 + \beta a_2} = X^*. \tag{9}$$

Eq.(9) yields a unique closed-form solution that we present in Appendix A. Here, we report the main properties of the credit attribution equilibrium.

Proposition 1 *(**characterization**) In the unique credit attribution equilibrium, the high-ability agent works harder ($x_1^* > x_2^*$) and thus receives more credit from success ($q_1^* > q_2^*$) for all β. However, the high-ability agent receives higher utility ($u_1^* > u_2^*$) only for $\beta < \frac{1}{2}$, and lower utility for $\beta > \frac{1}{2}$. Furthermore,*

- **(a)** *x_1^* is strictly convex in β, attaining its minimum at $\beta_{\min} = \frac{1}{2}\sqrt{1 - \frac{a_2}{a_1}}$, with $\lim_{\beta \to 0} x_1^* = \lim_{\beta \to 1} x_1^* = a_1$, which is agent 1's stand-alone effort.*
- **(b)** *x_2^* is strictly increasing and concave in β, with $\lim_{\beta \to 0} x_2^* = 0$ and $\lim_{\beta \to 1} x_2^* = a_2$, which is agent 2's stand-alone effort.*
- **(c)** *q_1^* is strictly decreasing while q_2^* is strictly increasing in β.*
- **(d)** *$x_1^* + x_2^*$ is strictly increasing in β, but at a lower rate than $x_1^o + x_2^o$.*

As in the benchmark, the high-ability agent works harder in equilibrium. However, unlike in the benchmark, part (a) indicates that the high-ability's equilibrium effort is U-shaped in the spillover rate β, as illustrated in Figure 1(a) below. The high-ability effort x_1^* is decreasing in an initial interval $(0, \beta_{\min})$, which expands with the ability gap. Since the optimal effort, x_1^o, is monotone increasing in β, the non-monotonicity in x_1^* is driven by the equilibrium credit attribution.

To understand the intuition, observe from (7) that the spillover rate β affects an agent's effort decision through two channels. The first channel works through the team's success probability. For a fixed credit allocation (q_1^*, q_2^*), an increase in β motivates both agents as they anticipate the team to succeed with a higher probability. This channel is also the only one in the benchmark. The second channel arises due to credit attribution. Given an effort pair (x_1^*, x_2^*), an increase in β redistributes the total credit of one in favor of the low-ability agent. Put differently, since $x_1^* > x_2^*$, the low-ability agent benefits more from an increased spillover rate. Thus, the second channel negatively impacts the high-ability agent's incentives.

For a sufficiently small β, the negative effect due to credit attribution dominates for the high-ability agent. At negligible values of β, credit allocation is entirely driven by the agents' perceived relative efforts. This purely merit-based credit allocation motivates the high-ability agent more than his low-ability teammate. Indeed, as Figure 1(a) illustrates, $x_1^* \approx a_1$ and $x_2^* \approx 0$, implying $q_1^* \approx 1$ for $\beta \approx 0$. As β increases from these low levels, credit allocation becomes less merit-based, causing the high-ability agent to decrease his effort and the low-ability agent to increase it. Once β exceeds a threshold, $\beta_{\min}$, the positive effect of the first channel dominates for the high-ability agent. He turns his attention from credit allocation, which is sufficiently similar due to spillover, to the team's success.

As part (b) shows, the low-ability agent's effort monotonically increases in β since both effects described above are positive for this agent. A higher β improves the team's success probability and re-allocates credit in favor of the low-ability agent. The same reasoning also explains part (c). The low-ability agent's credit share increases; thus, the high-ability's share decreases in β (see Figure 1(b)). Finally, part (d) shows that, despite the initial decrease in the high-ability agent's effort, the team's total equilibrium effort increases with β but does so more slowly than the optimal benchmark, again due to credit sharing concerns.

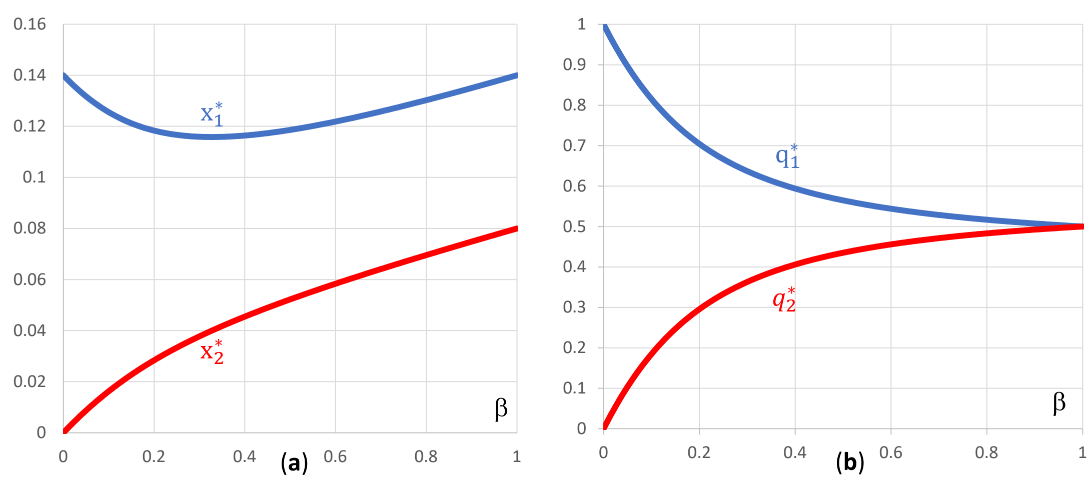

Figure 1: The left panel illustrates the equilibrium efforts whereas the right panel illustrates equilibrium credit shares as a function of spillover rate β for the ability pair (a_1, a_2)= (0.14, 0.08).

While not our primary focus, another observation highlighting the role of ex-post credit attribution is the equilibrium utility comparison between the two agents. Proposition 1 reveals, as expected that the high-ability agent always works harder and receives more credit in equilibrium. However, he may be strictly worse off than his low-ability teammate for a sufficiently high spillover rate, $\beta > 0.5$.[9] To gain intuition, let us use (3) to observe that $(1+\beta)X^* q_i^* = x_i^* + \beta x_j^*$. In other words, each agent expects to receive his effective contribution in equilibrium via credit attribution. Thus, agent i's equilibrium utility can be written as

$$u_i^* = x_i^* + \beta x_j^* - \frac{x_i^{*2}}{2a_i}. \tag{10}$$

Given the equilibrium condition $x_i^* = (1+\beta)q_i^* a_i$, the expression for q_i^* in (5) and u_i^* in (10), we can write the equilibrium utility differential between agents as[10]

$$u_1^* - u_2^* = \underbrace{(1-\beta)(x_1^* - x_2^*)}_{\text{difference in effective contributions}} - \underbrace{\left(\frac{x_1^* - x_2^*}{2}\right)}_{\text{difference in effort cost}}. \tag{11}$$

Since $x_1^* > x_2^*$, each term in (11) is nonnegative. The first term represents the fact that the high-ability agent expects a greater reward for team success. The second term in (11) shows that he also expects to incur a greater cost of effort. When the spillover rate is sufficiently high, $\beta > .5$, the cost effect prevails for the high-ability agent, since then credit attribution is much less merit-based. In contrast, for $\beta < .5$, the high-ability agent expects sufficient credit to compensate for his effort cost.

We next compare the credit attribution equilibrium with the optimal or efficient credit benchmark. Specifically, we ask: does the public attribute too much or too little credit to an agent in equilibrium? Do agents exert too much or too little effort? The comparison below answers these questions, paving the way for our efficiency result next.

Proposition 2 ***(equilibrium vs. optimal credit)*** *Let $\beta^* = \frac{1}{1+\frac{a_1}{a_2}+\frac{a_2}{a_1}} \in (0, 1/3)$. Then, the credit attribution equilibrium compares with the optimal credit benchmark as follows.*

- **(a)** *For $\beta < \beta^*$, the high-ability works too much $(x_1^* > x_1^o)$ and is over credited for team's success $(q_1^* > q_1^o)$ while the opposite holds for the low-ability.*
- **(b)** *For $\beta > \beta^*$, the high-ability works too little $(x_1^* < x_1^o)$ and is under credited $(q_1^* < q_1^o)$ for team's success while the opposite holds for the low-ability.*
- **(c)** *The team expends too much effort $(X^* > X^o)$ for $\beta < \beta^*$, and too little $(X^* < X^o)$ for $\beta > \beta^*$.*

[9] This utility reversal with respect to β is consistent with Ozerturk and Yildirim (2021) and Yildirim (2023) for the extreme values $\beta \to 0$ and $\beta = 1$, respectively.

[10] To derive the expression in (11), we make use of the fact that, given the quadratic cost function, the equilibrium cost differential between agents becomes $c_1(x_1^*) - c_1(x_1^*) = (x_1^* - x_2^*)/2$.

The inefficiencies that Proposition 2 identifies arise from the fact that by allocating credit ex-post, the public does not internalize its incentive effects. Compared to the planner, the public over-motivates the high-ability agent through excessive credit when the spillover rate is sufficiently low, and thus, credit attribution is sufficiently merit-based. For the same reason, for sufficiently low β, the low-ability agent is under-motivated by expecting too little recognition from joint success. Figure 2 illustrates these observations.

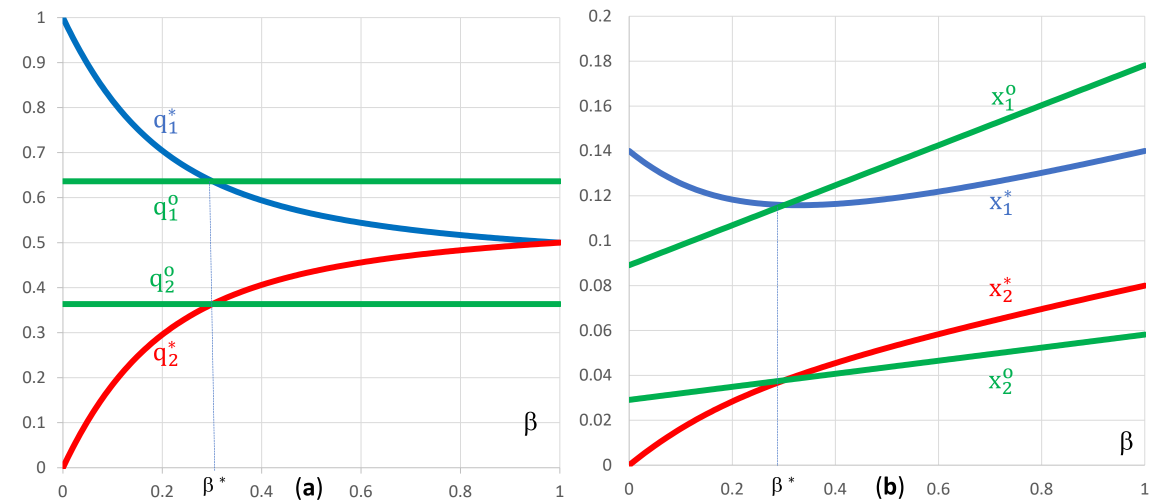

Figure 2: The left panel illustrates the equilibrium credit shares versus the optimal benchmark credits whereas the right panel illustrates equilibrium efforts versus the optimal benchmark efforts as a function of spillover rate β for the ability pair (a_1,a_2)= (0.14, 0.08)

More formally, consider a spillover rate β close to zero. In this case, as Proposition 1 shows, the high-ability agent expends almost all the effort and receives close to full credit in equilibrium. Given the convex effort cost, this is excessive from an efficiency viewpoint. At the other extreme, when β is close to one, the relative effort plays a minimal role in the equilibrium credit, leading to almost equal credit shares from success. As a result, the high-ability agent underinvests in success while the low-ability overinvests. Indeed, by continuity, this result holds for sufficiently high spillover rates.

Proposition 2 raises an important organizational design question: unable to commit to a credit allocation ex ante, can the social planner induce the efficient effort profile by controlling the spillover rate in the team? The following result, a byproduct of Proposition 2, answers this question.

Corollary 1 ***(efficient spillover)***

(a) *Given the team's ability profile (a_1, a_2), the spillover rate $\beta^* \in (0, 1/3)$ defined in Proposition 2 implements the efficient effort profile: $x_i^* = x_i^o$ for all i, where β^* is decreasing in the relative ability $\frac{a_1}{a_2} \in [1, \infty)$. Moreover, there is no payoff reversal at β^*.*

(b) *Conversely, given the spillover rate $\beta \leq \frac{1}{3}$, the team with the relative ability*

$$\frac{a_1}{a_2} = \frac{\left(\frac{1}{\beta} - 1\right) + \sqrt{\left(\frac{1}{\beta} - 1\right)^2 - 4}}{2}$$

exerts the socially optimal effort. For $\beta > \frac{1}{3}$, no such team can be designed, and the high-ability is bound to be under credited for the success.

Part (a) of Corollary 1 is the main result of this paper. While the increased spillover always motivates the low-ability agent, it may de-motivate the high-ability by making the public's credit attribution less merit-based. To alleviate the high-ability agent's concern about recognition for joint success, the planner prefers an imperfect spillover rate. However, the planner would not eliminate spillovers and make the credit attribution purely merit-based since that would over-motivate the high-ability and under-motivate the low-ability agent.[11] The efficiency of an intermediate spillover rate contrasts with the benchmark in which an organization that could pre-commit to a credit allocation would promote perfect spillover, $\beta = 1$; see Lemma 1. Part (a) also demonstrates that credit attribution is sufficiently merit-based under the efficient spillover rate to ensure that the high-ability agent is not worse off than his low-ability teammate.

Proposition 2 offers a critical insight into the efficiency implications of effort spillovers between team members in environments with weak ex-ante monetary incentives. When individual team members seek ex-post recognition for their contributions to joint success, an organization could abstain from facilitating perfect effort spillover between them. In particular, even if it were *costless*, the organization might not invest in sophisticated collaboration tools, such as Dropbox and Zoom, or facilitate close working conditions to induce socially optimal efforts.

In some contexts, the spillover rate may be fixed and beyond the planner's control due to the nature of the project or the working environment. Part (b) of Corollary 1 states that an organization may still overcome inefficiencies by carefully selecting the team members.

[11] By Proposition 1, the equilibrium efforts are $x_1^* \to a_1$ and $x_2^* \to 0$ for $\beta \to 0$.

However, such optimal teams are only possible if the spillover rate is low enough, so credit-sharing is not a significant concern for high-ability team members. Furthermore, the ability gap in an optimally composed team should decrease with the spillover rate, given that the credit allocation becomes less merit-based and thus more similar between the agents.

Remark 3 *Under the alternative credit attribution rule in (4), no spillover rate can ensure efficiency.*[12] *To see this, we replace* q_i *with* $\overline{q}_i$ *in (7) and verify that the unique equilibrium has the effort profile* $\overline{x}_1^* = (1+\beta)a_1$ *and* $\overline{x}_2^* = 0$*, implying* $\overline{q}_1^* = 1$*. Thus, using Lemma 1,* $\overline{x}_1^* > x_1^o$ *and* $\overline{x}_2^* < x_2^o$ *for any* β*. Intuitively, being purely merit-based, credit based on relative effort induces the low-ability agent to expect no recognition and thus exert no effort, which is clearly inefficient for the team given the convex cost. Hence, this rule is welfare-dominated by (3) under which* β^* *guarantees efficiency.*

The following section explores the agents' private incentives to work together and whether the optimal spillover rate β^* would induce voluntary teamwork.

5 Private incentives for teamwork

In the baseline model, we have assumed that the two agents are working together as a team from the outset, perhaps because their supervisor or organization assigned them to the same task. However, there are situations where agents can choose to form a team or work independently. For instance, a law enforcement agency may claim jurisdiction and choose to work a case alone, or invite a sister agency to collaborate for better results. Similarly, a researcher may have an innovative idea and choose to develop it solo or ask another researcher to join the effort and work as a team. This section examines endogenous team formation in environments where the credit shares for team members are determined ex-post in an attribution equilibrium. In particular, we investigate whether higher spillover rates facilitate collaboration when commitment to ex-ante reward schemes is limited.

We now assume that one of the agents owns the project in question, perhaps because it falls under their jurisdiction or they came up with the idea first. This agent may propose to the other agent to form a team or choose to work alone. If the other agent accepts the offer, the game proceeds as our credit attribution framework outlines.[13] If the other agent declines, he receives no payoff, whereas the agent who owns the project works alone and receives the full credit if successful. We continue to assume that abilities a_1 and a_2 are fixed and publicly known.

[12] Recall from Remark 1 that the efficiency benchmark does not depend on the specific credit attribution rule.

[13] Hence, we assume the public cannot distinguish who has initiated a team project.

Formally, suppose agent i owns the project and chooses to work solo. This implies that agent i forgoes positive spillovers and succeeds only with probability x_i. Therefore, agent i chooses x_i to maximize the solo expected payoff:

$$u_i = x_i - \frac{x_i^2}{2a_i},$$

which yields the optimal effort and utility as $x_i^{solo} = a_i$ and $u_i^{solo} = a_i/2$.

Agent i's equilibrium utility with teamwork is given by (10). Accordingly, agent i successfully teams up if

$$u_i^* \geq u_i^{solo} \text{ and } u_j^* \geq 0.$$

Clearly, $u_j^* \geq 0$ always holds because an agent can choose to exert no effort.

To determine agent i's incentive to invite j for collaboration, we first consider the case where it is the low-ability agent ($i = 2$) who owns the project. Recall from Proposition 1 that $\lim_{\beta \to 0} x_2^* = 0$, $\lim_{\beta \to 1} x_2^* = a_2$, and $\lim_{\beta \to 1} x_1^* = a_1$. Combining these with (10), we find

$$\lim_{\beta \to 0} u_2^* = 0 < u_2^{solo} = \tfrac{a_2}{2} \quad \text{and} \quad \lim_{\beta \to 1} u_2^* = \tfrac{a_2}{2} + a_1 > u_2^{solo}.$$

Furthermore, Appendix A shows that u_2^* is strictly increasing in the spillover rate β. Therefore, there exists a unique $\beta_2^* \in (0, 1)$ such that the low-ability agent prefers to work solo for $\beta < \beta_2^*$ and as a team for $\beta \geq \beta_2^*$. That is, the low-ability agent prefers to ask the high-ability to join the project only when the spillover rate is sufficiently high. This is intuitive. When the agents are unlikely to improve each other's effective contributions with collaboration, the low-ability agent worries that the public would attribute credit mostly to the high-ability partner, who is expected to work harder and contribute more to their joint success. This can be formally seen in (11), where the difference in effective contributions is found to be $(1 - \beta)(x_1^* - x_2^*)$, which is strictly decreasing in β.[14]

Consider now the case when the high-ability agent owns the project. Since $\lim_{\beta \to 0} x_1^* = \lim_{\beta \to 1} x_1^* = a_1$ and $\lim_{\beta \to 1} x_2^* = a_2$ by Proposition 1, it follows from (10) that

$$\lim_{\beta \to 0} u_1^* = u_1^{solo} = \tfrac{a_1}{2} \quad \text{and} \quad \lim_{\beta \to 1} u_1^* = \tfrac{a_1}{2} + a_2 > u_1^{solo}.$$

As shown in Appendix A, u_1^* is monotone increasing in β when $a_1 \geq 3a_2$. This observation implies that when the ability gap between the two agents is sufficiently large, the high-ability agent does not worry about receiving enough credit; thus, he prefers to team up and does so regardless of the spillover rate. Perhaps surprisingly, the high-ability agent

[14] In the proof of Proposition 1, we show that $x_1^* - x_2^*$ is strictly decreasing in β.

proposes teamwork even when the spillover rate is relatively high, i.e., $\beta > 1/3$. We know from Propositions 1 and 2 that the high-ability agent expects to be under-credited for success and even fare worse than his low-ability teammate when $\beta > 1/2$. He nevertheless proceeds with teamwork because a significant spillover rate would substantially motivate the low-ability agent.

Suppose the ability gap is relatively small and satisfies $a_1 < 3a_2$. In this case, the high-ability agent chooses to work solo if the spillover rate is sufficiently low, so he is unlikely to receive a boost from his teammate's effort. Although the public would assign significantly more credit to the high-ability agent in this case, it would not compensate for the cost of effort. However, if the spillover rate is sufficiently large, the high-ability agent prefers to team up. As explained in Proposition 1, a higher spillover rate turns the high-ability agent's attention from credit attribution to the project's success since the effective contributions of both agents toward success are now comparable. These observations are summarized below.

Proposition 3 ***(voluntary teams)*** *Suppose one agent owns the project and can exclude the other from it.*

(a) *The low-ability agent teams up if and only if the spillover rate is sufficiently high.*

(**b**) *If the ability differential is large, the high-ability agent teams up for any spillover rate. Otherwise, he teams up only when the spillover rate is sufficiently high so that his focus shifts from taking credit to ensuring the project's success.*

Proposition 3 suggests that the higher-ability agent is more likely to invite a collaborator because he is less concerned about ex-post credit attribution by the public. This lesser concern for credit sharing especially facilitates team formation by the high-ability agent when the ability differential between agents is sufficiently high. When the abilities are closer, and hence credit attribution becomes more of an issue for the high-ability agent, a sufficiently high spillover rate can ensure teaming up by making the project's success more likely.

As in the baseline model, the above analysis assumes that the abilities of the two agents are fixed. In certain settings, however, the agent who owns the project may be flexible in choosing a collaborator from a diverse pool of candidates. Although selecting a highly skilled collaborator would increase the likelihood of success and decrease the workload of the project owner, it would also mean sharing the credit for the success. As the following result illustrates, the project owner may not pick the best teammate available due to credit sharing concerns unless the spillover rate is sufficiently high.

Proposition 4 ***(choosing the teammate)*** *Suppose agent i owns the project and chooses a teammate from the ability pool $a_{-i} \in [0, \overline{a}]$. Let a^*_{-i} denote his optimal choice that maximizes his equilibrium utility in (10).*

- *If the spillover rate is sufficiently low, $\beta < \frac{1}{5}$, there exist ability levels $0 < A_i(\beta) < a_i < B_i(\beta)$ such that*
$$a^*_{-i} = \begin{cases} A_i(\beta) & \text{if } A_i(\beta) < \overline{a} < B_i(\beta) \\ \overline{a} & \text{otherwise,} \end{cases}$$
where $A_i(\beta) = \frac{5-7\beta-\sqrt{(1-\beta)(1-5\beta)}}{2(2-\beta)} a_i$.

- *If $\beta \geq \frac{1}{5}$, then $a^*_{-i} = \overline{a}$.*

Proposition 4 says that agent i does not select the best teammate in the pool if the spillover rate is low, i.e., $\beta < 1/5$, and the ability pool is moderate. Indeed, he selects a less able teammate.[15] Only when the ability gap or the spillover rate is substantial, $\beta \geq 1/5$, agent i chooses a more able partner. To gain intuition, let the agent who owns the project have ability $a_i = .1$ and access to a candidate pool $a_{-i} \in [0, .21]$. Furthermore, suppose the spillover rate is $\beta = .15$. Then, agent i optimally recruits a less able teammate with $a^*_{-i} = .07$ (an explicit formula for a^*_{-i} is given in the proof of Proposition 4). In equilibrium, the team succeeds with probability .12, yielding agent i the credit $q^*_i = .70$ in exchange for the effort $x^*_i = .08$. If, instead, agent i were to recruit the best partner in the pool, namely, $a_{-i} = .21$, that would significantly increase team success probability to .23 and reduce his effort to $x^*_i = .03$. However, teaming up with the ablest partner would also reduce agent i's credit from joint success to $q^*_i = .22$.

While offering valuable insights into the agents' private incentives for teamwork, Propositions 3 and 4 also raise another important organizational design question: does the organization need to adjust its optimal spillover rate, β^*, found in Proposition 2 to induce teamwork *voluntarily*? This question is especially pertinent because when setting its β, the organization may not even know which agent – the high or low ability – will have a project. The following result states that the answer is "no."

Corollary 2 *The optimal spillover rate β^* identified in Proposition 2 strictly incentivizes both agents to collaborate.*

[15]Note that $A_i(0) = a_i$, so agent i selects an identical teammate in the absence of spillovers. This special case is consistent with Proposition 6 in Ozerturk and Yildirim (2021) since our static setup also means sufficiently impatient agents.

Intuitively, β^* optimizes team effort by sufficiently mitigating credit-sharing concerns. In the process, it also facilitates significant spillovers between agents, making teamwork more attractive than working solo.

6 Conclusion

This paper offers a novel perspective on how positive spillovers among team members can affect their incentives when their main reward is public recognition or credit for their contributions to joint success. Our main result shows that compared to the optimal ex-ante credit benchmark, spillover rates below a certain threshold over credit and over-motivate higher-ability agents, whereas, above the same threshold, the lower-ability agents receive too much credit and are over-motivated (Proposition 2). Hence, the spillover rate that elicits the optimal effort is intermediate (Corollary 1).

Our main result challenges the commonly-held belief in organizational design that fostering positive spillovers always improves team efficiency. It might be beneficial for an organization or a team designer to maintain certain barriers to spillovers, even if removing them were costless. Otherwise, exacerbating their credit concerns, the designer might demotivate higher-ability team members while over-motivating the lower-ability ones under perfect spillovers. Such credit-sharing concerns are particularly relevant in law enforcement and similar governmental agencies, where receiving ex-post credit for a successful outcome is the key incentive. Therefore, contrary to the recent big push for sharing information and expertise between agencies to facilitate spillovers, some lack of transparency might be efficient.

An extension of our baseline analysis, which takes the team as given from the outset, reveals further the implications of positive spillovers for private incentives to collaborate. These incentives are, again, relevant in governmental agencies as, by claiming jurisdiction, it is common for an agency to exclude another from joint work, a practice commonly known as a turf war. Here, the low-ability agent, when owning the project, requires a sufficient degree of spillovers to invite collaboration over working solo. In contrast, the high-ability agent prefers teamwork even without spillovers when the ability gap is sufficiently pronounced (Proposition 3). Hence, we find that the high-ability agent is more eager to collaborate. We also find that the optimal spillover rate that induces efficient effort in a given team provides both types of agents with sufficient incentives to form one. Therefore, optimally limiting spillovers, the government can prevent turf wars while ensuring ex-post efficient effort incentives when team members seek ex-post credit for their contributions to success

(Corollary 2).

In closing, we note two possible extensions for future work. The first delves into the potentially costly aspect of positive spillovers: agents will likely benefit from each other's efforts to the extent they pay attention. This consideration suggests they must multitask between working on the project and learning from their peers. Relatedly, the second extension may allow the agents to decide on the degree of positive spillover to their peers; they choose how much to interact and share information with them at the outset (see Rotemberg 1994 for a related setting). In each case, it would be interesting to see if credit-sharing concerns further limit positive spillovers and leave the organization a more active role in fostering them.

Appendix A: Proofs

Proof of Lemma 1. Recall from (IC_i) that agent i's optimal effort given the credit q_i is

$$x_i = (1+\beta)q_i a_i. \tag{A-1}$$

Substituting for x_i in (OC), the planner's program reduces to

$$\max_{q_1,q_2}(1+\beta)^2\,(q_1a_1+q_2a_2) - \frac{[(1+\beta)q_1a_1]^2}{2a_1} - \frac{[(1+\beta)q_2a_2]^2}{2a_2}$$
$$\text{subject to } q_1+q_2=1.$$

Plugging $q_2 = 1-q_1$ into the objective, the program further reduces to

$$\max_{q_1}\frac{(1+\beta)^2}{2}\left[(2-q_1)q_1a_1+(1-q_1^2)a_2\right].$$

From here, the optimal credit is immediate:

$$q_i^o = \frac{a_i}{a_1+a_2}. \tag{A-2}$$

Inserting this into (IC_i), we obtain optimal individual efforts

$$x_i^o = (1+\beta)\left(\frac{a_i^2}{a_1+a_2}\right) \tag{A-3}$$

and, in turn, the optimal total effort

$$X^o = (1+\beta)\left(\frac{a_1^2+a_2^2}{a_1+a_2}\right). \tag{A-4}$$

Notice that the optimal probability of team's success $(1+\beta)X^o < 1$ for all $\beta \in [0,1]$, given our assumption that $a_1+a_2 < 1/2$.

Furthermore, we compute the utilities in this benchmark as

$$u_i^o = (1+\beta)\,X^o q_i^o - \frac{\left(x_i^o\right)^2}{2a_i} = \frac{(1+\beta)^2}{\left(a_1+a_2\right)^2}\left[\left(a_1^2+a_2^2\right)a_i - \frac{a_i^3}{2}\right] > 0.$$

Comparison of utilities yields

$$u_1^o - u_2^o = \ (1+\beta)^2\,\frac{\left(a_1-a_2\right)\left(a_1^2-a_1a_2+a_2^2\right)}{2\left(a_1+a_2\right)^2} > 0 \text{ for } a_1 > a_2.$$

■

Proof of Proposition 1. Solving for X^* from (9), we find the unique total effort:

$$X^* = \frac{1}{2}\left(a_1 + a_2 + \sqrt{(a_1 - a_2)^2 + 4\beta^2 a_1 a_2}\right). \tag{A-5}$$

It is readily verified that the equilibrium probability of team's success $(1+\beta)X^* < 1$, given $a_1 + a_2 < 1/2$. Plugging (A-5) into (8), the individual efforts are given by

$$x_1^* = \frac{a_1}{2(a_1 - a_2)}\left(a_1 - a_2 - 2\beta a_2 + \sqrt{(a_1 - a_2)^2 + 4\beta^2 a_1 a_2}\right) \tag{A-6}$$

and

$$x_2^* = \frac{a_2}{2(a_1 - a_2)}\left(a_1 - a_2 + 2\beta a_1 - \sqrt{(a_1 - a_2)^2 + 4\beta^2 a_1 a_2}\right), \tag{A-7}$$

where $a_1 - a_2 > 0$ by assumption.

Straightforward algebra reveals that

$$\frac{\partial(x_1^* - x_2^*)}{\partial\beta} = \frac{2a_1 a_2}{(a_1 - a_2)}\left(\frac{(a_1 + a_2)\,\beta}{\sqrt{(a_1 - a_2)^2 + 4\beta^2 a_1 a_2}} - 1\right).$$

Clearly,

$$\frac{\partial}{\partial\beta}\left[\frac{\partial(x_1^* - x_2^*)}{\partial\beta}\right] > 0.$$

Hence, $\frac{\partial(x_1^* - x_2^*)}{\partial\beta}$ achieves its maximum value at $\beta = 1$, which is simply

$$\left.\frac{\partial(x_1^* - x_2^*)}{\partial\beta}\right|_{\beta=1} = 0,$$

implying that $\frac{\partial(x_1^* - x_2^*)}{\partial\beta} < 0$ for $\beta \in (0,1)$. That is, the equilibrium effort difference, $x_1^* - x_2^*$, between the two agents is strictly decreasing at a decreasing rate in $\beta \in (0,1)$.

From here, it follows that $x_1^* - x_2^*$ achieves its minimum value for $\beta = 1$, which is

$$x_1^* - x_2^*|_{\beta=1} = a_1 - a_2 > 0.$$

Hence, $x_1^* > x_2^*$ and, in turn, $q_1^* > q_2^*$ for all $\beta \in (0,1]$.

The equilibrium utility comparison directly follows from (11):

$$u_1^* - u_2^* = \left(\frac{1}{2} - \beta\right)(x_1^* - x_2^*),$$

which, given $x_1^* > x_2^*$, implies $u_1^* > u_2^*$ for $\beta < \frac{1}{2}$, and $u_1^* < u_2^*$ for $\beta > \frac{1}{2}$.

For parts (a) and (b), note that

$$\lim_{\beta\to 0} x_1^* = \lim_{\beta\to 1} x_1^* = a_1.$$

Furthermore, letting $\Delta_a \equiv a_1 - a_2$ for convenience, (A-6) implies

$$\frac{\partial x_1^*}{\partial \beta} = -\frac{2a_1 a_2}{2\Delta_a} + \frac{a_1}{2\Delta_a}\frac{4\beta a_1 a_2}{\sqrt{\Delta_a^2 + 4\beta^2 a_1 a_2}} \tag{A-8}$$

and

$$\frac{\partial^2 x_1^*}{\partial \beta^2} \overset{sign}{=} \frac{\Delta_a^2}{\left(a_1^2 + a_2^2 - 2a_1 a_2(1-2\beta^2)\right)^{3/2}} > 0. \tag{A-9}$$

Equating (A-8) to zero and solving for β reveals that x_1^* reaches its minimum at $\beta_{\min} = \frac{1}{2}\sqrt{1 - \frac{a_2}{a_1}}$.

Similarly, using (A-7),

$$\lim_{\beta \to 0} x_2^* = 0 \text{ and } \lim_{\beta \to 1} x_2^* = a_2.$$

Furthermore,

$$\begin{aligned}\frac{\partial x_2^*}{\partial \beta} &= \frac{a_1 a_2}{\Delta_a} - \frac{2\beta a_1 a_2^2}{\Delta_a \sqrt{\Delta_a^2 + 4\beta^2 a_1 a_2}} \\ &> 0,\end{aligned}$$

where the inequality holds because $\sqrt{\Delta_a^2 + 4\beta^2 a_1 a_2} > 2\beta a_2$ since $\Delta_a \equiv a_1 - a_2$. Concavity of x_2^* follows since

$$\frac{\partial^2 x_2^*}{\partial \beta^2} \overset{sign}{=} \frac{-\Delta_a^2}{\left(a_1^2 + a_2^2 - 2a_1 a_2(1-2\beta^2)\right)^{3/2}} < 0.$$

To prove part (c), substitute (A-6) and (A-5) into the expression for q_1 in (5) to obtain

$$q_1^* = \frac{\Delta_a - 2\beta a_2 + \sqrt{\Delta_a^2 + 4\beta^2 a_1 a_2}}{2\left(1+\beta\right)\Delta_a}. \tag{A-10}$$

The result then follows since

$$\frac{\partial q_1^*}{\partial \beta} = -\frac{\Delta_a^2 + \left(a_1 + a_2\right)\sqrt{\Delta_a^2 + 4\beta^2 a_1 a_2} - 4\beta a_1 a_2}{2\Delta_a\left(1+\beta\right)^2\sqrt{\Delta_a^2 + 4\beta^2 a_1 a_2}} < 0$$

for all $\beta \in (0,1]$ given that $\left(a_1 + a_2\right)\sqrt{4\beta^2 a_1 a_2} - 4\beta a_1 a_2 > 0$, and that $q_2^* = 1 - q_1^*$.

Finally, for part (d), notice from (A-4) and (A-5) that

$$\frac{\partial X^*}{\partial \beta} = \frac{2\beta a_1 a_2}{\sqrt{\left(a_1 - a_2\right)^2 + 4\beta^2 a_1 a_2}} < \frac{2a_1 a_2}{a_1 + a_2} \text{ and } \frac{\partial X^o}{\partial \beta} = \frac{a_1^2 + a_2^2}{a_1 + a_2}.$$

Hence, $\frac{\partial X^o}{\partial \beta} > \frac{\partial X^*}{\partial \beta} > 0$. ■

Proof of Proposition 2. Given the closed-form solutions for the optimal credit benchmark and the credit attribution equilibrium, this proposition is immediate, with the explicit cutoff $\beta^* = \frac{1}{1+\frac{a_1}{a_2}+\frac{a_2}{a_1}}$. It is verified that β^* achieves its maximum value of $\frac{1}{3}$ when $\frac{a_1}{a_2} = 1$. ■

Proof of Corollary 1. Proposition 2 readily implies that given the ability profile, the spillover rate β^* implements the socially optimal effort profile (and the optimal credit). It can be verified that β^* is decreasing in the relative ability $\frac{a_1}{a_2} \in [1, \infty)$. Moreover, since $\beta^* < 1/2$, we have $u_1^* > u_2^*$ at β^* by Proposition 1.

Conversely, fix a spillover rate $\beta \in (0, 1]$. Setting $\beta^* = \beta$ and solving for $\frac{a_1}{a_2}$, we find

$$\frac{a_1}{a_2} = \frac{\left(\frac{1}{\beta} - 1\right) + \sqrt{\left(\frac{1}{\beta} - 1\right)^2 - 4}}{2}.$$

This solution is real if and only if $\left(\frac{1}{\beta} - 1\right)^2 - 4 \geq 0$, or equivalently, $\beta \leq \frac{1}{3}$, as claimed. For $\beta > \frac{1}{3}$, there is no ability profile that would implement the socially optimum in the credit attribution equilibrium. More precisely, $\beta > \beta^*$ in this case, which would imply too low credit for the high-ability team member by Proposition 2. ■

Proof of Proposition 3. Recall from (10) that the equilibrium utility of each agent is given by

$$u_i^* = x_i^* + \beta x_j^* - \frac{x_i^{*2}}{2a_i}. \tag{A-11}$$

To prove part (a), suppose the low-ability agent (agent 2) owns the project. Plugging the equilibrium efforts x_1^* and x_2^* from (A-6) and (A-7) into (A-11), we find

$$u_2^* = \underbrace{\frac{a_2}{2\Delta_a}\left(\Delta_a + 2\beta a_1 - z\right)}_{x_2^*} + \beta \underbrace{\frac{a_1}{2\Delta_a}\left(\Delta_a - 2\beta a_2 + z\right)}_{x_1^*} - \frac{1}{2a_2}\left(\frac{a_2}{2\Delta_a}\left(\Delta_a + 2\beta a_1 - z\right)\right)^2 \tag{A-12}$$

where $\Delta_a \equiv a_1 - a_2$ and $z \equiv \sqrt{\Delta_a^2 + 4\beta^2 a_1 a_2}$. It follows from (A-12) that

$$\lim_{\beta \to 0} u_2^* = 0 < u_2^{solo} = \frac{a_2}{2} \quad \text{and} \quad \lim_{\beta \to 1} u_1^* = \frac{a_2}{2} + a_1 > u_2^{solo}. \tag{A-13}$$

To prove the existence and uniqueness of a threshold $\beta_2^* \in (0, 1)$ such that agent 2 prefers to work solo for $\beta < \beta_2^*$ and as a team for $\beta \geq \beta_2^*$, it suffices to show that u_2^* in (A-12) is strictly increasing in β. Re-writing (A-12) and eliminating the terms that do not depend on β, we obtain

$$\frac{\partial u_2^*}{\partial \beta} \overset{sign}{=} \underbrace{a_1\left(z + \Delta_a\right)\Delta_a + 2\beta a_2 \left(4\beta a_1^2 - 3z a_1 + \underbrace{a_2^2 + z a_2 - a_1 a_2}_{a_2(z - \Delta_a) > 0}\right)}_{f(a_1, a_2, \beta)}. \tag{A-14}$$

The right hand side of (A-14) that we denote by $f(a_1, a_2, \beta)$ has the following properties:

$$\lim_{\beta\to 0} f(a_1, a_2, \beta) = 2(a_1 - a_2)^2 a_1 < \lim_{\beta\to 1} f(a_1, a_2, \beta) = 2(a_1 - a_2)^2 (a_1 + 2a_2).$$

Furthermore, $f(a_1, a_2, \beta)$ is convex in β and $f(a_1, a_2, \beta) > 0$ for all β. By the continuity of u_2^*, this establishes the existence of a unique $\beta_2^* \in (0,1)$ such that $u_2^* < u_2^{solo}$ for $\beta < \beta_2^*$ and $u_2^* \geq u_2^{solo}$ for $\beta \geq \beta_2^*$.

To prove part (b), suppose the high-ability agent (agent 1) owns the project. We can write the equilibrium utility for the high-ability agent as

$$u_1^* = \underbrace{\frac{a_1}{2\Delta_a}(\Delta_a - 2\beta a_2 + z)}_{x_1^*} + \beta \underbrace{\frac{a_2}{2\Delta_a}(\Delta_a + 2\beta a_1 - z)}_{x_2^*} - \frac{1}{2a_1}\left(\frac{a_1}{2\Delta_a}(\Delta_a - 2\beta a_2 + z)\right)^2 \quad \text{(A-15)}$$

and observe

$$\lim_{\beta\to 0}\ u_1^* = u_1^{solo} = \tfrac{a_1}{2} \quad \text{and} \quad \lim_{\beta\to 1}\ u_1^* = \tfrac{a_1}{2} + a_2.$$

Re-writing (A-15), eliminating the terms that do not depend on β and differentiating with respect to β, we find

$$\frac{\partial u_1^*}{\partial \beta} \overset{sign}{=} \underbrace{\left(2\beta a_1^2 - z a_2 + a_2 \Delta_a\right)\Delta_a}_{>0} + \underbrace{8\beta^2 a_1 a_2^2}_{>0} + 2\beta z a_1 (a_1 - 3a_2). \quad \text{(A-16)}$$

The first term on the right hand side of (A-16) is positive. To establish this, we need to show

$$\begin{aligned}
\frac{2\beta a_1^2}{a_2} + \Delta_a \quad &> \quad \underbrace{\sqrt{\Delta_a^2 + 4\beta^2 a_1 a_2}}_{z} \\
&\Rightarrow \quad \Delta_a^2 + \frac{4\beta^2 a_1^4}{a_2^2} + \frac{4\beta a_1^2 \Delta_a}{a_2} > \Delta_a^2 + 4\beta^2 a_1 a_2 \\
&\Rightarrow \quad \frac{\beta a_1^3}{a_2^2} + \frac{a_1 \Delta_a}{a_2} > \beta a_2 \\
&\Rightarrow \quad \beta a_1^3 + a_1 a_2 \Delta_a > \beta a_2^3
\end{aligned}$$

which is always true. It follows from (A-16) that if $a_1 > 3a_2$, then u_1^* is monotone increasing in β for all $\beta \in (0,1)$. Therefore, when $a_1 > 3a_2$, the high-ability agent prefers to team up and does so *regardless* of the spillover rate.

Now consider the case when $a_1 < 3a_2$. This implies that the last term on the right hand side of (A-16) is negative. In particular, let $a_1 - 3a_2 = -\varepsilon$ where $0 < \varepsilon < 3a_2$. When ε is sufficiently small so that there is still sufficient ability gap, the two positive terms in (A-16) ensure that u_1^* is still monotone increasing in β for all $\beta \in (0,1]$. When ε is sufficiently close to $3a_2$ and hence the ability gap becomes sufficiently small, however, there exists a threshold β^* such that u_1^* is monotone decreasing in β for $\beta \in (0, \beta^*)$ and u_1^* is monotone increasing in β for $\beta \in (\beta^*, 1)$. Since $\lim_{\beta \to 1} u_1^* = \frac{a_1}{2} + a_2$, there exists a unique threshold $\beta_1^* \in (\beta^*, 1)$ where $u_1^* > \frac{a_1}{2}$ for all $\beta \geq \beta_1^*$ and the high-ability agent is better off teaming up. ■

Proof of Proposition 4. Suppose agent i owns the project. Adapting the subscripts and plugging (A-6) and (A-7) into (A-11), we can explicitly write i's equilibrium utility in terms of the parameters:

$$u_i^* = U(a_i, a_{-i}, \beta).$$

Then, agent i's optimal choice a_{-i}^* solves

$$\max_{a_{-i} \in [0, \overline{a}_{-i}]} U(a_i, a_{-i}, \beta).$$

It can be verified that $U_{a_{-i}}(.) = 0$ has exactly two roots:

$$a_{-i} = \frac{5 - 7\beta \pm \sqrt{(1-\beta)(1-5\beta)}}{2(2-\beta)} a_i. \tag{A-17}$$

Moreover, $U(a_i, 0, \beta) = \frac{a_i}{2} > 0$ (solo payoff) and $\lim_{a_{-i} \to 0} U_{a_{-i}}(.) = \beta^2 > 0$.

For $\beta < \frac{1}{5}$, the two roots in (A-17) are distinct, real and positive. Therefore, the smaller root, which we denote by $A_i(\beta)$, is a local utility maximizer, where it can be shown that $A_i(\beta) < a_i$. The larger root in (A-17) is a local utility minimizer and exceeds a_i. Hence, for $\beta < \frac{1}{5}$, $U(.)$ is S-shaped in a_{-i} (first increasing, then decreasing, and then increasing again). Clearly, if the highest ability in the pool satisfies $\overline{a} > A_i(\beta)$, agent i cannot receive lower utility than $U(a_i, A_i(\beta), \beta)$, the local maximum. To see when $a_{-i} = A_i(\beta)$ is the global maximum, consider the indifference equation: $U(a_i, a_{-i}, \beta) = U(a_i, A_i(\beta), \beta)$. Let $a_{-i} = B_i(\beta)$ be its unique solution. Since $B_i(\beta)$ must be greater than the larger root in (A-17), it follows $B_i(\beta) > a_i$. Hence, if $A_i(\beta) < \overline{a} < B_i(\beta)$, then $a_{-i}^* = A_i(\beta)$. Otherwise, $a_{-i}^* = \overline{a}$, either because $U(a_i, A_i(\beta), \beta) \leq U(a_i, \overline{a}, \beta)$ for $\overline{a} \geq B_i(\beta)$, or $U(a_i, a_{-i}, \beta)$ is strictly increasing in a_{-i} for $\overline{a} \leq A_i(\beta)$.

For $\beta \geq \frac{1}{5}$, both roots in (A-17) are nonreal (or equal for $\beta = 1$). This simply means that $U(.)$ is strictly increasing in a_{-i} for all a_{-i}, implying $a_{-i}^* = \overline{a}$. ■

Proof of Corollary 2. By definition, $x_i^* = x_i^o$ under teamwork for $\beta = \beta^*$, where x_i^o and β^* are given by Lemma 1 and Proposition 2, respectively. Plugging these into (10) yields

$$u_i^* = \left(1 + \frac{(2a_i + a_j)a_j^3}{(a_i^2 + a_i a_j + a_j^2)^2}\right) \frac{a_i}{2} > \frac{a_i}{2} = u_i^{solo},$$

as claimed. ■

Appendix B: Robustness to Iso-elastic Cost

As claimed in Footnote 6, consider the general iso-elastic cost:

$$c_i(x_i) = \frac{x_i^k}{ka_i}, \text{ with } k > 1. \tag{B-1}$$

Then, (IC$_i$) is modified to be

$$x_i = [(1+\beta)q_i a_i]^{\frac{1}{k-1}}. \tag{IC$_i$'}$$

Inserting (B-1) and replacing (IC$_i$) with (IC$_i$') in (OC), we find the optimal credit profile (q_1^o, q_2^o). Given this optimal credit profile, (IC$_i$') yields the optimal effort (x_1^o, x_2^o). To find the efficient spillover rate that implements the optimal effort, we plug (q_1^o, q_2^o) and (x_1^o, x_2^o) into (7) and solve for β^*:

$$q_i^o = \frac{\beta^*}{1+\beta^*} + \frac{1-\beta^*}{1+\beta^*}\left(\frac{x_i^o}{X^o}\right).$$

Using this procedure for different values of the iso-elastic cost parameter $k > 1$, we have numerically computed the optimal spillover rate β^* that a social planner would choose to implement the efficient effort profile as an equilibrium and the equilibrium credits (q_1^*, q_2^*) attributed to the two agents. The main conclusions that emerge from this analysis are summarized below.

- For values $1 < k \leq 1.5$, it is efficient to have only the high ability agent expend effort and receive all the credit as there is not enough convexity in the cost function. In this parameter range, it is also efficient to set the spillover rate to zero (see Figure 3).

- For $k > 1.5$, our main result in Corollary 1 that establishes the efficiency of an interior optimal spillover rate β^* is verified numerically. The optimal β^* is increasing in the iso-elastic cost parameter k (see Figure 3(b)). The intuition is that increasing the spillover rate becomes an incentive device when it becomes costlier for the agents to expend effort. However, even in this case, it is optimal to limit β^* due to credit-sharing concerns.

- For $k > 1.5$, the equilibrium high-ability credit q_1^* that implements the efficient effort profile is decreasing in k, and it approaches $1/2$ as k increases (see Figure 3(b)). There are two channels at play. First, as k increases, the high-ability agent's ability advantage becomes less pronounced, reducing the effort gap between agents. Furthermore, as k increases, the optimal spillover rate β^* increases, making credit attribution less merit-based. Both of these effects imply q_1^* approaches $1/2$.

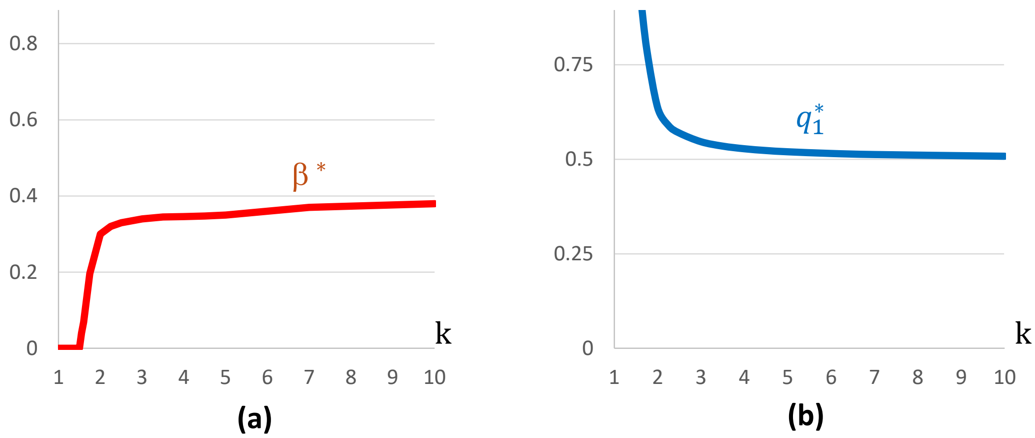

Figure 3: The left panel illustrates the simulation results for the optimal spillover rate β * as a function of the iso-elastic cost parameter k>1. The right panel plots the equilibrium credit share of the high ability agent as a function of k>1. As in the figures in the main text, we consider the ability pair (a_1,a_2)= (0.14, 0.08).

Appendix C: Benchmark Revisited

To verify Remark 2, suppose the planner's value of team success is $1+s$ where $s \geq 0$. Then, (OC) is modified as:

$$\max_{q_1,q_2,x_1,x_2} w = (1+\beta)\, X(1+s) - \frac{x_1^2}{2a_1} - \frac{x_2^2}{2a_2} \qquad \text{(OC-s)}$$
$$\text{subject to } q_1 + q_2 = 1, \text{ and } \ (\text{IC}_i) \text{ for } i = 1,2.$$

To avoid uninteresting corner solutions, we assume here $s < \frac{a_2}{a_1 - a_2}$. Following the same steps as in the proof of Lemma 1, we find

$$q_i^o(s) = \frac{a_i}{a_1 + a_2} + s\frac{a_i - a_{-i}}{a_1 + a_2} \text{ and } x_i^o(s) = (1+\beta)a_i q_i^o(s).$$

From here, Proposition 2 seamlessly extends with the cutoff:

$$\beta^*(s) = \frac{(a_1 + s(a_1 - a_2))(a_2 - s(a_1 - a_2))}{(a_1^2 + a_2^2)\,(1+s)^2 + a_1 a_2\,(1 - 2s^2)},$$

where $\beta^*(s) \in (0,1)$, and it is strictly *decreasing* in s.

In particular, $X^o(s) > X^* \iff \beta > \beta^*(s)$, which means underinvestment in success is more likely with a higher s. Intuitively, as the planner values success more, i.e., a higher s, she optimally elicits greater effort from the high-ability agent to increase the probability of success. Since equilibrium efforts do not depend on s, this introduces an additional wedge between the two cases. For instance, $\beta^*(\frac{a_2}{a_1 - a_2}) = 0$, implying underinvestment for all β when s is large enough.

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