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a winning team**

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# On Broadway and strip malls: how to make a winning team\*

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## Abstract

A successful organization – or Broadway production – needs the right team. A potential issue is that an existing synergy between complementary agents (or assets) can reduce the marginal return of effort, creating a disincentive to invest. While agents always prefer to be in a team of complementary workers, a principal may wish to use non-complementary agents; this can occur if the loss from lower investment is sufficiently large. A principal, however, may opt for non-complementary agents when complementary workers would produce greater surplus. These insights have implications for job rotation, the centralization versus decentralization of decision making and mergers.

*Key words:* complementarity, task allocation, job rotation, assets, mergers.

*JEL classifications:* D21, L23

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# 1 Introduction

What does it take for success on Broadway? A Broadway production needs: a composer; a lyricist; a librettist who writes the dialogue and plot; a choreographer; a director; and a producer. But who should fulfill these roles? Analyzing Broadway shows between 1877 and 1990, Uzzi & Spiro (2005) find that the financial and critical success is increasing in the number of the team members who previously worked together (incumbents), but only up to a point; too many incumbents decrease the likelihood of a production's success. Therefore, the most successful teams comprise of some incumbents, but also some newcomers.

Incumbents have some natural advantages. They understand how each other works; they know others' strengths, weaknesses and communication idiosyncracies. Familiar team members probably have a better sense of what the others will like and dislike, helping agents to avoid proposing and arguing for ideas that will never be part of the final product. Given the advantage of using incumbents, why use newcomers? Uzzi & Spiro (2005) emphasize that new team members bring fresh ideas to the collaborative effort, increasing overall quality. We focus on a similar rationale for using unfamiliar, or inherently less complementary, team members; complementarity can decrease the incentive for agents to invest, ultimately reducing total output (or quality). Using this framework, we examine the preferred team composition (complements or non-complements) for the principal and the teammates themselves, and apply our findings to a variety of applications.

To analyze the choice of team composition we make two key assumptions: contracts are incomplete, creating an underlying hold-up problem; and final output depends on both the potential complementarities between workers and the efforts they make. Importantly, in equilibrium, each worker's choice of effort depends on the potential synergy between team members.

In our model, a principal decides whether a team is made up of two complementary or independent (non-complementary) agents. Once chosen, each team member makes a non-contractible effort. After these investments are sunk, all parties negotiate and receive their share of ex post surplus. Complementary workers, by their very nature, produce greater output for any given level of effort. On the other hand independent agents, perhaps because they have never worked together before, have no intrinsic synergy between them. We make the following important assumption: the additional surplus generated using complementary agents is decreasing in worker effort. As a result, there is a tradeoff when choosing the team; while complementary workers (incumbents) produce more surplus for any given level of effort, independent workers (newcomers) put in more effort in equilibrium. This tradeoff gives rise to several results. First, the (second-best) welfare maximizing team could include either complementary or independent workers. Second, a principal may opt for a team of either complementary or independent workers. Furthermore, while a principal will never choose complementary workers when independent workers produce more net surplus, a principal could opt for independent workers too often, failing to maximize welfare. Third, workers themselves always prefer teams of complementary agents,

even when welfare is maximized with independents.

Our model is essentially a moral hazard in teams model (see Alchain & Demsetz 1972, Holmstrom 1982 and Che & Yoo 2001, for example). Given the externality between team members, there is always underinvestment in effort. However, in our paper the team structure also affects agents' equilibrium efforts; consequently, the composition of the team needs to take into account its effect on incentives. Our analysis suggests that, if incumbents are complementary, using familiar workers could foster (relative) indolence. If this is the case, choosing non-complementary (unfamiliar) agents could be preferred, as such an arrangement leads to greater levels of effort.<sup>1</sup>

This idea has much in common with what social psychologists refer to as 'social loafing' or the 'Ringelmann effect' (see West 2004), a phenomenon observed in experiments by Ringelmann in the late 19th Century. Ringelmann found that people put in 75 per cent of the effort pulling a rope when they thought they were a member of a team of seven (they were blindfolded) compared with their effort as an individual undertaking the same activity (see Kravitz and Martin 1986).<sup>2</sup> This literature also makes a second observation: the types of individuals in the group make a difference to observed effort. For instance, Stroebe et al (1996) examine teams working on complex problems. While team performance exceeded that of individuals, performance was further improved when high-ability team members thought they were matched with a low-ability partner.<sup>3</sup> The predictions of our model are consistent with both of these findings: (i) people underinvest when they work as part of a team; and (ii) effort and output can be lower when complementary (high-ability) individuals are paired together relative to when there is a team of non-complements (one high- and one low-ability worker).

An existing literature – Segal (1999, 2003), Bernstein and Winter (2012) and Winter (2004, 2006), for example – examine incentive contract design when there are externalities between agents. These models typically investigate optimal contracting when the potential externalities are fixed (that is, they do not vary with effort). In contrast to most of these models, we focus on the tradeoff between effort and the relationship between agents, so that externality varies endogenously in equilibrium. The paper in this literature most similar to ours is Winter (2012), who examines how the structure of information inside a firm affects the agents' optimal incentive contracts. Specifically, he finds that creating an environment with greater information is

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<sup>1</sup>Team membership has also been explained by the technological complementarities between tasks (Brickley et al 2009) or arising from a multi-tasking incentive problem (see Holmstrom & Milgrom 1991 and Corts 2006, for example).

<sup>2</sup>Other experiments have found similar effects: people shouted in a team with only 74 per cent of the effort as they did individually (Ingham et al 1974); when solving mathematical problems individuals took on average five minutes, groups of 2 individuals took an average of 3-and-a-half minutes per-person and groups of 4 averaged 12 minutes per-person (Shaw 1932).

<sup>3</sup>Social psychologists have invoked various explanations for this phenomenon, ranging from individuals feeling that they would be embarrassed if it were revealed they put in more effort than others, coordination failures, loud talkers drowning out others or that individuals reduce their effort if they feel it will not be adequately recognized (West 2004).

beneficial when agents' efforts are complementary. This is because the dissemination of agent's effort (or lack thereof) can allow for effective punishment. The similarities in the two papers are that the work environment affects investment incentives. In Winter (2012) it is the flows of information; in our model it is the composition of the team. One key difference is that Winter explicitly considers incentive contracts based on output, whereas ours is an incomplete contract model in which each party's share of surplus arises from ex post renegotiation.

In a different context, Franco et al (2011) consider how worker types are matched, when this choice affects the optimal incentive contracts, which depend on type and output. They find that a principal might prefer to forgo technological complementarities (by not matching two low-cost workers together) if this allows a better outcome in terms of effort and the cost of incentive compensation.<sup>4</sup> Their result – that positive associated matching need not hold once the effort and incentive contracts are considered – is a parallel result to our counterintuitive result that non-complementary workers might be preferred. Moreover, it is worth noting that both Franco et al (2011) and our paper assume observable worker type, unlike many other matching models in which agent type is unobservable (such as in Jeon 1996, Newman 2007 and Thiele & Wambach 1999).

Winter (2009) studies a related moral hazard in teams problem, in which higher incentives can induce lower efforts – a phenomenon he calls incentive reversal. This can occur when a larger payoff induces one agent to always invest, which in turn may generate an opportunity for other agents to free-ride.<sup>5</sup> We can also generate incentive reversal in our model, although we have a different mechanism at play. When agents are complementary there is greater surplus for any given level of effort than with non-complements; this is akin to larger payoffs studied in Winter (2009). This additional surplus may lead complementary workers to put in less effort, which is similar to incentive reversal. However, in our paper we go further and show that in equilibrium complementary agents, despite their natural synergy, can produce (and share) less output than independents. That is, not only do complementary agents exert less effort but they produce less output despite having a natural synergy between them.

We also draw on several other streams of literature. In particular, the model applies to the joint use or co-location of assets. Using some assets together rather than separately can generate an additional natural synergy, but this could also change parties' incentives to engage in ex ante investment. The standard predictions in the property-rights models (Hart and Moore 1990 and Hart 1995 for example) suggest that complementary assets should be owned together, so as to provide the best possible incentives for ex ante investment. Our model generates results in the same vein as Bel (2012), who finds that complementary assets need not be owned together when assets are substitutes at the margin.

There are many applications of our model. The model is directly applicable to team composition and job rotation.<sup>6</sup> Job rotation, by its very nature, breaks up old

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<sup>4</sup>Kaya & Vereshchagina (2010) make similar point regarding moral hazard in partnerships.

<sup>5</sup>Klor et al (2012) investigates incentive reversal further through a series of experiments.

<sup>6</sup>Other explanations for job rotation include eliciting information from agents (Arya & Mitten-

relationship in teams and makes workers start afresh with at least some new members. This practice is used by many consulting firms; McKinsey & Company, for example, insists on rotating senior management roles. Our model suggests there are potential benefits from committing to a job-rotation policy, as the agents, if left to their own devices, will always choose to be paired with a complementary partner even if the independent agents produce more. This could also be suggestive as to why some firms use predetermined rotation rules, so as to avoid influence costs (Milgrom & Roberts 1990). In a similar manner to the Broadway study mentioned above, Guimera et al (2005) find that the inclusion of newcomers in research teams increases the probability of a successful scientific collaboration in social psychology, economics, ecology and astronomy. In another situation, some airlines integrate a permutation constraint in their cabin crew assignment algorithm that prevents familiar pilots from being assigned together on the same flight.<sup>7</sup> There is likely to be a potential complementarity between familiar workers – for instance, crew members who know each other well can probably communicate more easily – but these airlines explicitly forgo this synergy. Crew that know each other well may be dissuaded from undertaking the same level of effort when teamed with each other (checking and cross checking and so on) than when teamed up with a stranger. With lower effort, the outcome (in terms of safety incidents) could be worse when complementary agents are paired together, despite the natural synergy.

The tradeoff we present also has implications for the allocation of decision-making rights. As noted, if they can, agents tend to choose to work with other complementary agents too often, whereas a principal can have too much incentive to choose independent agents. This has implications for how the choice of agents, or the aggregation of assets, is made. If encouraging effort is crucial, centralization could be preferred; the principal can commit to allocating independent agents to the task when the agents themselves cannot do so. For example, one landlord typically determines the tenants in a strip mall or a shopping mall. A Broadway production could also use centralized decision making, having a project leader tasked with assembling the team. A decentralized decision-making structure could be preferred when capturing the intrinsic synergy between agents or assets is relatively more important than inducing greater effort. Agents often choose their team-mates in rock bands and study groups, and the co-location decision is decentralized for many businesses like car lots and restaurants.

Finally, there have been some spectacular M&A failures - for example AT&T/NCR, Quaker Oats/Snapple and AOL/Time Warner. In all these cases the participants expected significant synergies that did not eventuate. The failure of M&As is conventionally attributed to cultural differences between the two firms or a failure to conduct proper due diligence. While these factors are undoubtedly important, they do not explain the observation that ‘the acquiring firms in ‘related’ mergers do not benefit or are actually worse off compared to unrelated as well as horizontal mergers’ (Chatterjee 2007). Our model suggests that – just like high-ability complementary

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dorf 2004), to overcome boredom of workers and to limit scope for corruption (Choi & Thum 2003).

<sup>7</sup>Anonymous industry source.

individuals being paired together – it is exactly the mergers that seem to have the greatest degree of complementarity between the assets that can create a disincentive to invest, leading to lower surplus overall.

## 2 The Model

Consider a model with principal  $P$  and two agents,  $A_1$  and  $A_2$ .<sup>8</sup>  $P$  owns an asset that is necessary for production and the two agents can use this asset to produce the final output or surplus. Moreover, each agent can expend some specific effort  $e_i \in [0, \bar{e}_i]$ ,<sup>9</sup> for  $i = 1, 2$ , with a cost of  $C_i(e_i)$ , where:  $C_i(0) = 0$ ;  $C_i(e_i)$  is twice differentiable; and strictly increasing and strictly convex in  $e_i$ . Thus, the marginal cost of effort is increasing with the level of investment, as summarized in Assumption 1.

**Assumption 1.** The cost function  $C_i(e_i)$  is non-negative, twice differentiable, strictly increasing in  $e_i$  and strictly convex; i.e.,  $C_i(e_i) \geq 0$ ,  $C_i(0) = 0$ ,  $C_i'(e_i) > 0$  and  $C_i''(e_i) > 0$  for  $e_i \in [0, \bar{e}_i)$  with  $C_i''(0) = 0$  and  $\lim_{e_i \rightarrow \bar{e}_i} C_i'(e_i) = \infty$  for  $i = 1, 2$ .

Each agent, making his investment  $e_i$  and working with the asset, can generate individual surplus of  $v_i(e_i)$  for  $i = 1, 2$ , respectively, as detailed below.

**Assumption 2.** The surplus  $v_i$  is a non-negative, increasing and concave production function; that is,  $v_i(e_i) \geq 0$ ,  $v_i(0) = 0$ ,  $v_i'(e_i) \geq 0$  and  $v_i''(e_i) \leq 0$  for  $i = 1, 2$ .

The agents can also work together as a team. If the agents work together they produce a joint surplus  $v_{12}$ , where  $v_{12}(e_1, e_2) \geq v_1(e_1) + v_2(e_2)$ . The additional surplus produced from joint rather than individual production is the potential synergy  $S(e_1, e_2)$  between the two parties. The synergy between the agents is defined below. This also allows us to define *complementary* and *independent* agents.

**Definition 1.**  $S(e_1, e_2) = v_{12}(e_1, e_2) - v_1(e_1) - v_2(e_2)$  represents the synergy between the two agents, who can be: (a) *complementary* if  $S(e_1, e_2) \geq 0 \forall e_1, e_2$  and  $S(0, 0) > 0$ ; or (b) *independent* if  $S(e_1, e_2) \equiv 0$ .

We also make the following assumption regarding the nature of the synergy between agents.

**Assumption 3.**  $\frac{\partial S(e_1, e_2)}{\partial e_i} \leq 0$  for  $i = 1, 2$ .

Assumption 3 implies that the synergy between the two complementary agents is non-increasing in their effort; that is, efforts are substitutes at the margin. For instance, consider the case of two agents who know each other very well. Because they understand each other they can coordinate their activities with relatively low effort. On the other hand, consider two team members who do not know each other.

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<sup>8</sup>This model can be extended both in terms of the number of agents and the exact nature of the synergies between them.

<sup>9</sup>Note that  $\bar{e}_i > 0$  and it is possible that  $\bar{e}_i = \infty$ .



of the distributed shares is equal to the total available surplus in the grand coalition, so that

$$\sum_{j \in N} B_j(e_1, e_2) = v_{12}(e_1, e_2). \quad (1)$$

Following Hart and Moore (1990), the Shapley value  $B_j(e_1, e_2)$  is defined as:

**Definition 2.** Party  $j$ 's share of gross surplus is given by the Shapley value

$$B_j(e_1, e_2) = \sum_{M|i \in M} p(M)[v(M | e_1, e_2) - v(M \setminus \{i\} | e_1, e_2)], \quad (2)$$

where  $p(M) = \frac{(|M|-1)!(|N|-|M|)!}{(|N|)!}$ .

Note that because the game is convex the Shapley value is always in the core.<sup>10</sup>

### 3 The incentives to invest

There will be different incentives to invest, depending on whether the agents are independent or complementary. In this section we compare investment incentives and the welfare implications of the two alternative team structures. To provide a benchmark for these comparisons, we first analyze the first-best team structure.

#### 3.1 First-best incentives

Let us compare the first-best incentives and the choice between complementary and independent agents. The first-best investments in the case of complementary workers solve:

$$\frac{\partial v_i(e_i)}{\partial e_i} + \frac{\partial S(e_1, e_2)}{\partial e_i} = \frac{\partial C_i(e_i)}{\partial e_i}, \quad \forall i = 1, 2. \quad (3)$$

The first-best investments in the case of independent workers are:

$$\frac{\partial v_i(e_i)}{\partial e_i} = \frac{\partial C_i(e_i)}{\partial e_i}, \quad \forall i = 1, 2. \quad (4)$$

The solution for each agent's investment choice exists and is unique given Assumptions 1,2 and 4. Note that, given  $S(e_1, e_2) \geq 0 \forall e_1, e_2$ , both total and net surplus are always weakly higher with complementary rather than with independent agents. This means net surplus is maximized using complementary agents.

**Result 1.** The first-best outcome always entails using complementary rather than independent agents.

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<sup>10</sup>See Osborne and Rubinstein (1990, exercise 295.5), for example.

*Proof.* The proof follows from the discussion above.  $\square$

As  $S \geq 0$ , total surplus is weakly higher with complementary agents – for any level of effort, a switch to complements from independent agents will increase gross surplus without altering costs. If an enforceable contract could be written on effort, it would always be first-best optimal to use complementary agents.

### 3.2 Second-best incentives

However, a complete contract cannot always be written. Now consider the investment decision of the two workers, taking into account ex post bargaining. Since the principal is indispensable and at least one of the agents is indispensable<sup>11</sup>, the ex ante payoff given by the Shapley value for each agent is<sup>12</sup>:

$$\frac{1}{2}v_i(e_i) + \frac{1}{3}S(e_1, e_2) - C_i(e_i), \quad \forall i = 1, 2. \quad (5)$$

Anticipating renegotiation, the complementary agents will set their effort to maximize their ex ante payoff. The equilibrium levels of effort  $e_1^C$  and  $e_2^C$  solve the following first-order conditions:

$$\frac{1}{2}v_i'(e_i) + \frac{1}{3} \frac{\partial S(e_1, e_2)}{\partial e_i} = \frac{\partial C_i(e_i)}{\partial e_i}, \quad \forall i = 1, 2. \quad (6)$$

On the other hand, if the agents are independent, their equilibrium levels of investment  $e_1^I$  and  $e_2^I$  are given by:

$$\frac{1}{2}v_i'(e_i) = \frac{\partial C_i(e_i)}{\partial e_i}, \quad \forall i = 1, 2. \quad (7)$$

Similar to the first-best case, the solution for each agent's investment choice exists and is unique due to Assumptions 1,2 and 4. Moreover, given Assumptions 2 and 3 it follows that:

$$e_i^C \leq e_i^I, \quad \forall i = 1, 2, \quad (8)$$

as summarized below.

**Result 2.** An agent exerts a lower level of effort when paired with a complementary rather than an independent agent; that is,  $e_i^C \leq e_i^I$ ,  $\forall i = 1, 2$ .

This leads to the following Corollary that we will make use of in our subsequent analysis.

**Corollary 1.**  $\Delta C_i(e_i) = C_i(e_i^I) - C_i(e_i^C) \forall i = 1, 2$  is always non-negative.

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<sup>11</sup>An assumption that the two team members are indispensable would alter the shares each party receives but leads to the same qualitative tradeoffs.

<sup>12</sup>See the Appendix for a detailed derivation of the shares of gross surplus for the agents and the principal.

The equilibrium effort - and effort cost - is always greater for an agent paired with an independent rather than with another complementary worker. The marginal return from effort is lower with complementary agents; this is because the synergy  $S$  – the advantage of complementary workers over their independent alternatives – is decreasing in effort (Assumption 3).

### 3.3 The principal's choice of team composition

We now consider the principal's choice of team-mates. It follows that, when the surplus generated by greater effort is relatively more important than protecting the intrinsic synergy between complementary workers, the ex post surplus may be higher with independent rather than with complementary agents. At date 0, the principal will choose to select two complementary (independent) agents if and only if:

$$\frac{1}{2}v_1^I + \frac{1}{2}v_2^I \leq (\geq) \frac{1}{2}v_1^C + \frac{1}{2}v_2^C + \frac{1}{3}S^C, \quad (9)$$

where  $S^C$  is defined as the synergy  $S$  generated when complementary agents invest  $e_1^C$  and  $e_2^C$ .<sup>13</sup> We also simplify notation by indicating the effort level as a superscript in the value function.

Now consider the payoff to each agent when matched with either a complementary or independent co-worker. Using a revealed-preference argument, if an agent is paired with a complementary partner, the agent  $i$ 's payoff will be at least as large with a choice of effort  $e_i^C$  rather than with a choice of  $e_i^I$ . The same argument can be made for an agent on an independent team –  $e_i^I$  yields at least as much return to an agent in an independent team as does exerting  $e_i^C$ . Using this logic, the rational choice of individual  $i$  ensures that:

$$\frac{1}{2}v_i^I + \frac{1}{3}S(e_1^I, e_2^C) - C_i(e_i^I) \leq \frac{1}{2}v_i^C + \frac{1}{3}S^C - C_i(e_i^C), \quad \forall i = 1, 2; \quad (10)$$

and

$$\frac{1}{2}v_i^I - C_i(e_i^I) \geq \frac{1}{2}v_i^C - C_i(e_i^C), \quad \forall i = 1, 2. \quad (11)$$

Summing for both agents, these two conditions are:

$$\frac{1}{2}v_1^I + \frac{1}{2}v_2^I + \frac{2}{3}S(e_1^I, e_2^C) - \Delta C_1(e_1) - \Delta C_2(e_2) \leq \frac{1}{2}v_1^C + \frac{1}{2}v_2^C + \frac{2}{3}S^C \quad (12)$$

and

$$\frac{1}{2}v_1^I + \frac{1}{2}v_2^I - \Delta C_1(e_1) - \Delta C_2(e_2) \geq \frac{1}{2}v_1^C + \frac{1}{2}v_2^C. \quad (13)$$

Comparing (9) and (12), a sufficient condition for choosing complementary agents is:

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<sup>13</sup>Note that for ease of exposition we allow the principal to choose either team structure if the equation holds with equality.

$$\Delta C_1(e_1) + \Delta C_2(e_2) \leq \frac{2}{3}S(e_1^I, e_2^C) - \frac{1}{3}S^C. \quad (14)$$

Given Assumption 3, it follows that  $S(e_1^I, e_2^C) \geq S^I$ , where  $S^I$  is the synergy generated when complementary agents invest  $e_1^I$  and  $e_2^I$ . This means the following condition ensures that (14) is satisfied

$$\Delta C_1(e_1) + \Delta C_2(e_2) \leq \frac{2}{3}S^I - \frac{1}{3}S^C. \quad (15)$$

For convenience this condition can be rewritten as

$$X \leq \frac{2}{3}Y - \frac{1}{3}, \quad (16)$$

where we introduce the following notation  $X = \frac{\Delta C_1(e_1) + \Delta C_2(e_2)}{S^C}$  and  $Y = \frac{S^I}{S^C}$ .

Comparing (9) and (13), it turns out that a sufficient condition for choosing independent workers is:

$$\Delta C_1(e_1) + \Delta C_2(e_2) \geq \frac{1}{3}S^C, \quad (17)$$

which is

$$X \geq \frac{1}{3}. \quad (18)$$

In summary, we have outlined the sufficient conditions required for the principal to use complementary agents and, secondly, when she will choose independent agents. These conditions are detailed in the following result.

**Result 3.** A sufficient condition for the principal to choose complementary agent is that  $\Delta C_1(e_1) + \Delta C_2(e_2) \leq \frac{2}{3}S^I - \frac{1}{3}S^C$ , while the sufficient condition for principal to choose independent agents is that  $\Delta C_1(e_1) + \Delta C_2(e_2) \geq \frac{1}{3}S^C$ .

Figure 2 shows the potential level of output with the two alternative team structures. Focusing on  $e_1$  (and suppressing the role of  $e_2$  for exposition),  $v_{12}$  is the potential surplus with complementary agents, while  $v_1 + v_2$  is the potential surplus with independent agents. From Assumption 3, the additional surplus that complementary agents generate is monotonically decreasing in effort  $e_1$ . This means that the marginal return of  $e_1$  is less for complementary workers, and their equilibrium investment level is  $e_1^C < e_1^I$ . Hence there is a tradeoff; the intrinsic synergy with complementary workers must be compared with the additional surplus generated by higher effort put forth by independent agents. Critically, this comparison needs to be made at the equilibrium levels of effort for the two alternatives.

The principal will choose to allocate the type of agents that will maximize her return, which is her share of gross surplus at renegotiation, see equation (9). It is possible, as shown in Figure 2, that the effort effect with independent agents dominates the synergy effect with complementary agents, so the principal would opt to use independent workers.

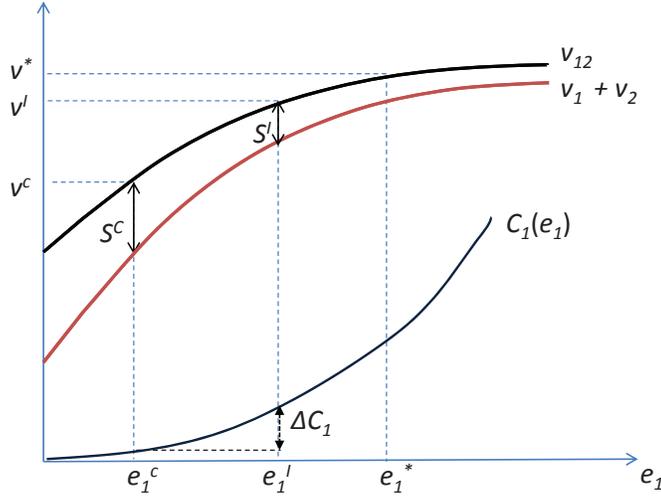


Figure 2: Surplus with complementary and independent workers

It is worth comparing this result with Proposition 3 in Che and Yoo (2001). They find that a principal will opt for individual rather than team production if there is no synergy between the workers. In contrast, our result suggests that a principal might opt for independent agents even when a potential synergy exists, provided there is a sufficient change in effort.

### 3.4 The agents' choice of team structure

We now turn to the preferences of the agents themselves as to the makeup of their team. Agent  $i$  will choose to be paired with a complementary agent if:

$$\frac{1}{2}v_i^I - \Delta C_i(e_i) \leq \frac{1}{2}v_i^C + \frac{1}{3}S^C \quad (19)$$

for  $i = 1, 2$ . Given (10), this inequality will always hold, ensuring that the agents themselves will always want to be paired with a complementary partner.

**Result 4.** Agents always want to be in a team with complementary agents.

Agents always prefer complementary workers in their team, and this is true regardless as to the type of structure (complements or independents) that produce greater surplus. Being paired with a complementary partner allows an agent to enjoy their share of the intrinsic synergy. It also allows the agents to reduce their effort, of which they receive the full savings.

### 3.5 Second-best optimal choice of team structure

We show earlier that a principal might choose to use independent agents, forgoing a intrinsic synergy between complementary team members. Now we consider the choice

of team composition made by a social planner, whose goal is to maximize (second-best) total welfare. In particular, this allows us to compare the welfare maximizing team composition to the principal's choice.

Welfare will be higher with complementary (independent) team members if and only if:

$$v_1^I + v_2^I - C_1(e_1^I) - C_2(e_2^I) \leq (\geq) v_1^C + v_2^C + S^C - C_1(e_1^C) - C_2(e_2^C). \quad (20)$$

Comparing (12) and (20), it turns out that a sufficient condition for welfare to increase with complementary team members is:

$$\Delta C_1(e_1) + \Delta C_2(e_2) \leq \frac{4}{3}S(e_1^I, e_2^C) - \frac{1}{3}S^C. \quad (21)$$

Given Assumption 3, it follows that  $S(e_1^I, e_2^C) \geq S^I$ . Using the same argument as above, if

$$\Delta C_1(e_1) + \Delta C_2(e_2) \leq \frac{4}{3}S^I - \frac{1}{3}S^C \quad (22)$$

then (21) is satisfied. Inequality (22) can be rewritten as

$$X \leq \frac{4}{3}Y - \frac{1}{3}. \quad (23)$$

Comparing (13) and (20), it turns out that a sufficient condition for welfare to increase with independent team members is:

$$\Delta C_1(e_1) + \Delta C_2(e_2) \geq S^C, \quad (24)$$

or that

$$X \geq 1. \quad (25)$$

From the arguments above, we construct sufficient conditions for when independent or complementary agents maximize welfare, summarized in the result below.

**Result 5.** A sufficient condition for total welfare to be higher with complementary rather than independent agents is that  $\Delta C_1(e_1) + \Delta C_2(e_2) \leq \frac{4}{3}S^I - \frac{1}{3}S^C$ , while a sufficient condition for total welfare to be higher with independent agents is that  $\Delta C_1(e_1) + \Delta C_2(e_2) \geq S^C$ .

We are now in a position to compare the principal's choice of team composition (Result 3) with the welfare maximizing one (Result 5). To help analyze this issue, consider Figure 3 that outlines various regions for  $Y = \frac{S^I}{S^C}$ , the relative synergy produced with either independent or complementary agents, and  $X = \frac{\Delta C_1(e_1) + \Delta C_2(e_2)}{S^C}$ , the increase in costs associated with using independent rather than complementary agents relative to the synergy in equilibrium with complementary agents. Note that we are only interested in area  $Y \leq 1$  because  $S^I \leq S^C$ , and  $X \geq 0$  because of Corollary 1.

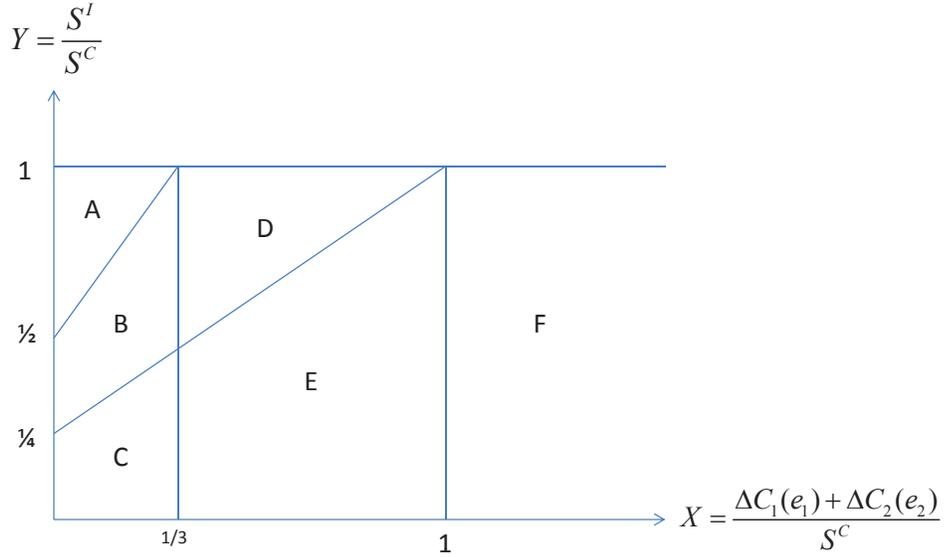


Figure 3: Total welfare and firm choice of independent or complementary workers

In the Figure, in region  $A$  the principal will always choose complementary agents. The vertical line  $X = \frac{1}{3}$  indicates the necessary condition for complementary agents to be chosen by the principal (more precisely  $X \leq \frac{1}{3}$ ); the principal will only ever choose complementary agents (but not necessarily will) in regions  $A$ ,  $B$  and  $C$ . From the diagram, we can also see that the sufficient condition for the principal to opt for independent agents is to be in regions  $D$ ,  $E$  and  $F$  (where  $X \geq \frac{1}{3}$ ).

From a social planner's perspective, the diagonal line running from  $Y = \frac{1}{4}$  indicates the sufficient conditions required for complementary agents to produce greater net surplus in equilibrium; complementary agents are required to maximize surplus in regions  $A$ ,  $B$  and  $D$ . The sufficient condition for independent agents to maximize welfare is satisfied in region  $F$  (where  $X \geq 1$ ).

Note in region  $D$ , the principal will choose a team of independent workers, but the welfare-maximizing choice is for complementary agents to be used. From a social welfare point of view, the principal opts for the wrong type of workers. This point is summarized in the following proposition.

**Proposition 1.** *When  $X \geq \frac{1}{3}$  and  $1 \geq Y \geq \frac{3}{4}X + \frac{1}{4}$  hold, the principal chooses independent agents, even though (second-best) welfare is maximized by using complementary agents.*

*Proof.* The proof follows from the discussion above.  $\square$

This suggests that, for some parameter values the principal has too much propensity to choose independent workers. This arises because the principal considers her share of ex post surplus but does not consider the increase in ex ante costs,  $\Delta C_1(e_1) + \Delta C_2(e_2)$ , as these costs are borne by the agents. If the increase in costs

is relatively high as compared with the decrease in the size of the synergy between the independent and complementary levels of effort, the principal tends to choose independent workers too often.

To capture more insights from our general setup, we now consider the case in which agents' efforts are perfect substitutes and the synergy is a concave function.

### 3.6 Perfect substitutes with concave synergy

In this subsection consider the case when the synergy only depends on the total effort of the team; that is, it is assumed that the efforts are perfect substitutes.

**Assumption 5.**  $S(e_1, e_2) = S(e_1 + e_2)$ .

In addition, we assume that the synergy  $S$  is a concave function; that is, the synergy decreases more quickly with an increase in effort  $e_i$  for  $i = 1, 2$ .

**Assumption 6.**  $\frac{\partial S^2(e_1, e_2)}{\partial e_1^2} = \frac{\partial S^2(e_1, e_2)}{\partial e_2^2} = \frac{\partial S^2(e_1, e_2)}{\partial e_1 \partial e_2} \leq 0$ .

With the aid of these assumptions it is possible to give a more precise lower bound for  $S(e_1^I, e_2^C)$ . Specifically,

$$S(e_1^I, e_2^C) \geq \frac{S^I + S^C}{2}. \quad (26)$$

Given (26), condition (14) will be satisfied if

$$\Delta C_1(e_1) + \Delta C_2(e_2) \leq \frac{S^I + S^C}{3} - \frac{1}{3}S^C. \quad (27)$$

Furthermore, (27) can be rewritten as

$$X \leq \frac{Y}{3}. \quad (28)$$

Similarly, for (21) to hold it is necessary that

$$\Delta C_1(e_1) + \Delta C_2(e_2) \leq \frac{2(S^I + S^C)}{3} - \frac{1}{3}S^C, \quad (29)$$

which can be simplified to

$$X \leq \frac{2Y + 1}{3}. \quad (30)$$

Figure 4 has the same structure as Figure 3 above, although Assumptions 5 and 6 allow us to more precisely characterize the various parameter regions. In region  $A$  the principal will always choose complementary agents. The vertical line  $X = \frac{1}{3}$  indicates the necessary condition for complementary agents to be chosen by the principal (regions  $A$  and  $B$ ). This also indicates that the sufficient condition for the principal to opt for independent agents is to be in regions  $C$ ,  $D$  or  $E$  (where  $X \geq \frac{1}{3}$ ).

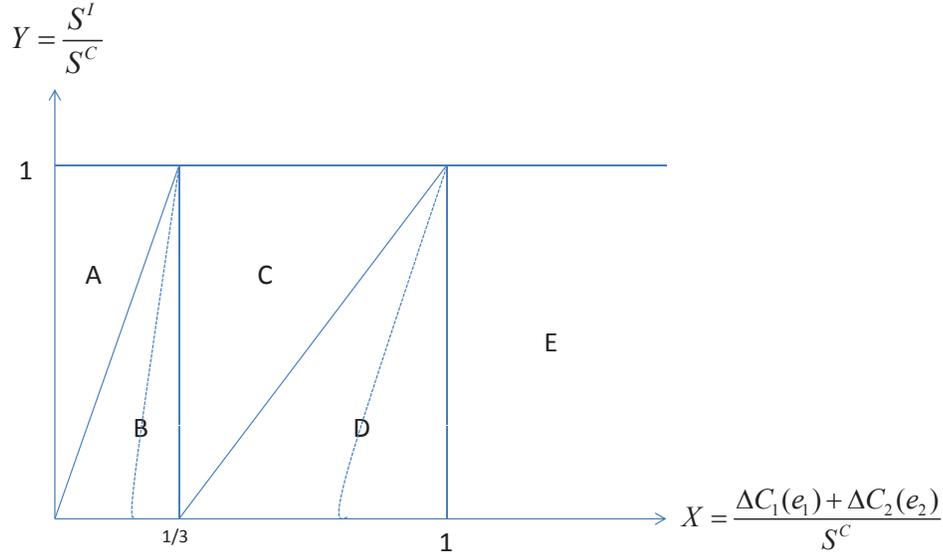


Figure 4: Firm choice with perfect substitutable efforts and concave synergy

From a social planner's perspective, the diagonal line running from  $X = \frac{1}{3}$  indicates the sufficient condition required for complementary agents to produce greater welfare in equilibrium; complementary agents are required to maximize welfare in regions  $A$ ,  $B$  and  $C$ . Being in region  $E$  where  $X \geq 1$  is sufficient for independent agents to maximize welfare.

In region  $C$ , the principal will choose a team of independent workers, but complementary agents are welfare-maximizing. Note also that the necessary condition for the principal to choose complementary agents, and the sufficient condition for complementary agents to maximize welfare do not intersect for positive values of  $Y$ . This means, as we discuss in subsection 3.7 below, if a principal chooses complementary agents, it can never be the case that independent agents maximize social welfare.

The following example highlights some of the results of the previous discussion.

### Example 1

Assume that the coalition containing only one agent  $i$  and the principal generates a surplus of  $v_i = 2\alpha e_i$ , while the coalition containing both agents and the principal generates additional surplus of  $S = \max[3\beta(A - (e_1 + e_2)^2), 0]$ . The costs for both agents are  $C_i(e_i) = \alpha e_i^2$  for  $i = 1, 2$ . Note that when  $\alpha > 0$ ,  $\beta > 0$  and  $A > 1$  Assumptions 1-4 are satisfied. In the first-best case, the optimal efforts are

$$e_1^* = e_2^* = \begin{cases} \frac{\alpha}{\alpha+6\beta}, & \text{if } A \geq \frac{4\alpha}{\alpha+6\beta}; \\ 1, & \text{if } A < \frac{4\alpha}{\alpha+6\beta}. \end{cases} \quad (31)$$

In the case of complementary agents, the optimal efforts solve the following system:

$$\begin{cases} \alpha - 2\beta(e_1 + e_2) = 2\alpha e_1, \\ \alpha - 2\beta(e_1 + e_2) = 2\alpha e_2. \end{cases} \quad (32)$$

This gives  $e_1^C = e_2^C = \frac{\alpha}{2\alpha+4\beta} < \frac{1}{2}$ . From equation 7, with independent agents the optimal efforts are  $e_1^I = e_2^I = \frac{1}{2}$ .

Given these equilibrium efforts, we can calculate  $S^C = 3\beta(A - \gamma^2)$ ,  $S^I = 3\beta(A - 1)$ , and  $\Delta C_1(e_1) + \Delta C_2(e_2) = \frac{1}{2}\alpha(1 - \gamma^2)$ , where  $\gamma = \frac{\alpha}{\alpha+2\beta}$ . This gives  $X = \frac{\Delta C_1(e_1)+\Delta C_2(e_2)}{S^C} = \frac{\gamma(1+\gamma)}{3(A-\gamma^2)}$  and  $Y = S^I/S^C = \frac{A-1}{A-\gamma^2}$ . Dividing  $X$  by  $1 - Y$  and simplifying yields  $Y = 1 - \frac{3(1-\gamma)}{\gamma}X$ . Note that, as  $0 < \gamma < 1$ , all the points with  $0 < Y < 1$  and  $X > 0$  are feasible for this specification.

Given the specific functions used, the actual condition for the principal to choose complementary agents (condition 9) is  $Y \geq \frac{18X^2-1}{6X-1}$ , illustrated in Figure 4 by the dashed line that cuts area  $B$ . Similarly, the actual condition for which complementary workers maximize welfare (condition 20) is  $Y \geq \frac{6X^2-3X-1}{3X-1}$ , the dashed line cutting area  $D$ .  $\square$

### 3.7 Principal's choice of a complementary team and total welfare

Next, consider the case when the principal opts to use complementary workers. As it turns out, if the principal chooses complementary agents it is always the case that complementary agents is the team composition that maximizes social welfare. The intuition for this can be demonstrated with the aid of Figure 2. The principal is concerned about their share of gross surplus (from their Shapley value) from the two alternatives, respectively. If the principal anticipates a higher payoff with complementary agents it must be the case that complements also maximize net surplus because not only is  $v_C > v_I$ , but effort costs are also lower with complements (Corollary 1). This result is captured in Figure 4 when we consider the case of perfectly substitutable efforts; the two dashed lines do not intersect. This discussion is summarized in the following proposition.

**Proposition 2.** *Whenever a principal chooses complementary agents in equilibrium, a social planner would have also chosen complementary agents; that is using complementary agents is (second-best) welfare maximizing.*

*Proof.* See Appendix.  $\square$

In our framework, if we observe a principal opting for complementary agents, this choice also maximize (second-best) welfare. But as noted in subsection 3.4, agents always prefer complements. In this case there is no difference between a centralized (principal) or decentralized (agents-based) decision about team composition; both decision-making structure yield the same outcome.

## 4 Incentive reversal

As noted in the Introduction, Winter (2009) shows the possibility of incentive reversal in which an increase in the payoffs (incentives) can result in most agents reducing their effort. In this section we show that we can produce equivalent results. In our framework, incentive reversal would be when an improvement in the production technology, such that there is a proportional increase in either one of the surpluses or the synergy generated for every level of effort, leads to a decrease in equilibrium efforts of all agents. To make a more direct comparison with Winter (2009), we relax Assumption 3, allowing efforts to be either complements or substitutes at the margin.

Let us first establish the conditions when incentive reversal cannot occur in equilibrium, a parallel result to Proposition 1 in Winter (2009). This is outlined in the following proposition.

**Proposition 3.** *Equilibrium efforts are immune to incentive reversal if efforts are complements at the margin.*

*Proof.* See Appendix. □

In Winter (2009), incentive reversal relies on increasing returns with respect to agents' efforts and is not possible with decreasing returns. Here, we only consider the case of decreasing returns to scale. In our model, as noted in Proposition 3, incentive reversal will not be observed if efforts are complementary at the margin. Incentive reversal is possible in our framework, however, if efforts are not complementary at the margin. This is illustrated in the Example below. Moreover, we show that in equilibrium incentive reversal can reduce total welfare.

### Example 2

Let us augment Example 1 by assuming  $A = 1.1$ ,  $\alpha = 1$  and  $\beta \in [0, 1]$ . In the case of complementary agents, the optimal efforts are  $e_1^C = e_2^C = \frac{\alpha}{2\alpha+4\beta} = \gamma/2$ . One can see that efforts are decreasing with  $\beta$ ; that is, there is an incentive reversal. Let us calculate total welfare

$$W = v_{12}(e_1^C, e_2^C) - C_1(e_1^C) - C_2(e_2^C) = \frac{\alpha}{2\gamma}(4\gamma^2 + 3(1 - \gamma)(A - \gamma^2) - \gamma^3); \quad (33)$$

and the principal's payoff

$$P = \frac{1}{2}v_1(e_1^C) + \frac{1}{2}v_2(e_2^C) + \frac{1}{3}S(e_1^C, e_2^C) = \frac{\alpha}{2\gamma}(2\gamma^2 + (1 - \gamma)(A - \gamma^2)). \quad (34)$$

Figure 5 shows total welfare and the principal's payoff, both as a function of  $\beta$ . When  $\beta \leq \beta_1$  the total welfare is maximized with the independent agents; complementary agents produce more surplus in equilibrium if  $\beta > \beta_1$ . The principal's interests are different however. When  $\beta \leq \beta_2$ , the principal prefers independent agents. It is only when  $\beta > \beta_2$ , that she would opt for complements. Importantly, for  $\beta_1 \leq \beta \leq \beta_2$  the

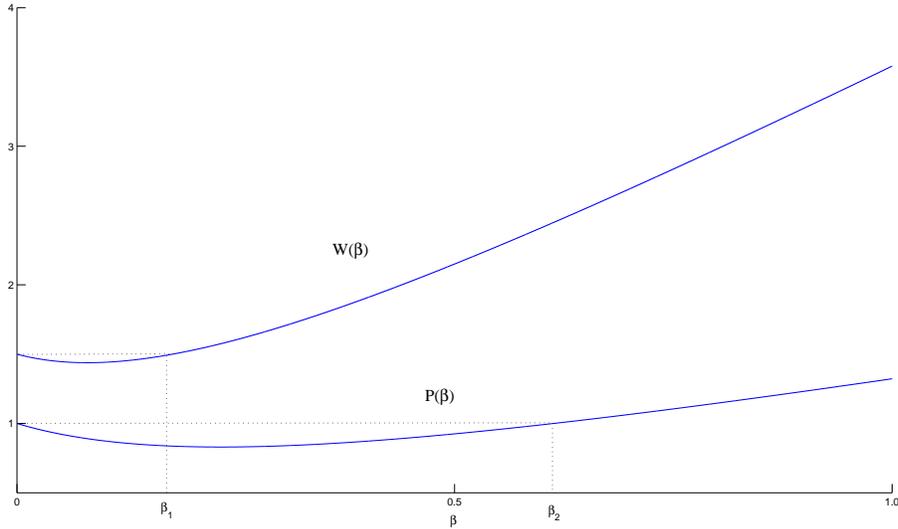


Figure 5: Total welfare and principal's payoff

principal chooses independent agents even though complementary agents are welfare maximizing choice, as described in Proposition 1.  $\square$

In Winter (2009), in contrast to our paper, effort is a discrete choice, which results in a discontinuity in an agent's best-response function. If another party's payoff increases sufficiently so that they have a dominant strategy to invest, an agent's best response might be to switch to low effort. In our model the agents' choice is continuous; incentive reversal arises due to the fact that efforts are substitutes at the margin as we show in the Example above. Another important point of comparison is that in our model incentive reversal may result in all agents decreasing their effort. This is not possible in Winter (2009) where only a subset of agents decrease their effort.

Given that it may decrease total welfare, incentive reversal is another illustration of how the environment – here the production technology – can affect worker effort and total welfare in a counter-intuitive way. In such a situation a principal, if they could, would opt to not implement the more efficient production technology, realizing its negative impact on overall output after changes in agents' effort are accounted for.

## 5 Discussion and concluding comments

Getting the right team matters a great deal. Our analysis suggests that just choosing the most natural team-mates might not be the best option. Rather, overall performance might be better with agents who do not have an intrinsic connection or synergy. This could be why teams are sometimes selected so as to include non-complementary

members. It is often said that a champion team will beat a team of champions. Our analysis suggests that even if a team of champions would perform better *for a given level of effort*, a team of journeymen could outperform them precisely because the less lauded unit has a greater incentive to put in effort (both in training and in the game).

There are several key elements driving our result. First, there is contractual incompleteness in the model, in that the agents cannot write contingent contracts on either surplus or effort *ex ante*. If parties have the ability to contract on effort *ex ante*, the first-best outcome can be achieved, and complementary workers will always be used together. Second, we assume that the additional benefit of using two complementary workers is decreasing in the effort or investment made; this means that the marginal return from effort is lower for complementary workers than it is for independent workers. The combination of these effects can together mean that (second-best) surplus is higher with independent rather than complementary workers. What the model suggests is that the true nature of complementary agents needs to be considered in equilibrium – agents that end up producing more output might be the team members who do not necessarily intrinsically work best together. It is also worth noting that while our focus has been on complementary versus independent agents, the same point can be made for agents who are independent or substitute workers; provided that the marginal return of effort is lower for independent agents, the relative differences between the two options are qualitatively the same as the complements/independents tradeoff we examined. That is, it could be that a firm or principal chooses to hire substitute workers even though they intrinsically produce less output for a given level of effort, provided this choice induces greater effort.<sup>14</sup>

There are many applications of the model. As noted, if complementary worker put in less effort, a team of independents might produce greater net output. Similarly, if incumbency reduces the incentive to invest, it could be that a policy of job rotation increases total surplus (in consulting projects, musical productions or in research projects). When choosing the composition of a team, an organization might wish to choose workers that do not otherwise have a natural synergy between them. Note that our result differs from the usual moral-hazard in teams result (see Holmstrom 1982 for example); we get under-investment in our model due to holdup regardless as to the type of worker, but the under-investment problem is accentuated with complementary workers.

Our framework also has implications for the allocation of decision-making rights. A principal can have a tendency to choose independents too often; the agents themselves always prefer to have complementary team-mates, even if independents produce greater net surplus. This suggests that when inducing greater effort (from independents) is more important, the choice of team should be made centrally by the principal; on the other hand, when taking advantage of a natural synergy is relatively more

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<sup>14</sup>One example we have in mind is a firm hiring a difficult or obnoxious worker – their presence might naturally hinder output relative to a more congenial colleague, but this could be made up for if their presence on the team creates an additional incentive to work harder.

important, it might be advantageous for the principal to commit not to get involved by having the decision decentralized to the agents themselves.

Finally, it is worth considering the implications of our model for the joint use (or co-location) of assets. Take an example in which two assets can be co-located together (perhaps geographically, such as in the same shopping mall). Each asset requires a manager who can put in effort to increase the potential surplus generated. Given co-location, there is some spillover between the two production units. The questions arising in the context of our model are: (i) should these assets be complementary?; and (ii) who should decide which assets are used? Each manager's incentive to invest is dependent on the characteristic of the other asset. Given our assumptions, independent assets will induce greater effort from each manager. If the principal has the decision-making rights on the assets to be combined, this decision is centralized (perhaps under the auspices of one firm). The alternative is to decentralize this choice to the unit managers. As noted above, centralization (common ownership) is preferred when choosing independent assets is important. This is somewhat contradictory to the standard prediction in the property-rights literature that complementary assets should be owned together (Hart and Moore 1990, for example). This difference arises because here we break the nexus between marginal and total returns (Assumptions 5 and 6 in Hart and Moore 1990).

## Appendix

### Derivation of the surplus shares for the principal and agent

Let us derive the ex ante payoffs given by the Shapley value for each team member and the Principal with the help of equation 2. The payoffs of coalitions are as follows:  $v(A, E_1, E_2) = v_{12}$ ,  $v(A, E_1) = v_1$  and  $v(A, E_2) = v_2$ , while all other coalitions give zero payoffs. Consequently,

$$B_1 = \frac{1}{6}v_1 + \frac{1}{3}(v_{12} - v_2) = \frac{1}{2}v_1 + \frac{1}{3}S, \quad (35)$$

$$B_2 = \frac{1}{6}v_2 + \frac{1}{3}(v_{12} - v_1) = \frac{1}{2}v_2 + \frac{1}{3}S, \quad (36)$$

and

$$B_P = \frac{1}{6}v_1 + \frac{1}{6}v_2 + \frac{1}{3}v_{12} = \frac{1}{2}v_1 + \frac{1}{2}v_2 + \frac{1}{3}S. \quad (37)$$

□

### Proof of Proposition 2

First, from equation 9 if  $v_1^I + v_2^I - v_1^C - v_2^C < \frac{2}{3}S^C$ , the principal will choose two complementary agents. Second, from equation 20, when  $v_1^I + v_2^I - v_1^C - v_2^C < S^C + \Delta C_1(e_1) + \Delta C_2(e_2)$  it is efficient to choose complementary agents. The difference between the right-hand side of these two equations is  $\frac{1}{3}S^C + \Delta C_1(e_1) + \Delta C_2(e_2) > 0$ .

Consequently, if equation 9 is satisfied, equation 20 is satisfied as well. This proves the proposition.  $\square$

### Proof of Proposition 3

With complementary agents, the equilibrium levels of investment solve the following first-order conditions:

$$\frac{1}{2}v'_i(e_i) + \frac{1}{3}\frac{\partial S(e_1, e_2)}{\partial e_i} = \frac{\partial C_i(e_i)}{\partial e_i}, \quad \forall i = 1, 2. \quad (6)$$

Given agents are complementary,  $\frac{\partial S(e_1, e_2)}{\partial e_i} > 0$ . If there is a change so that for some  $a > 1$  either  $v'_1(e_1) \equiv av_1(e_1)$  or  $v'_2(e_2) \equiv av_2(e_2)$  or that  $S'(e_1, e_2) \equiv aS(e_1, e_2)$ , this will strengthen incentives for agents to invest, leading to higher investment levels. See Mai et al (2012) for an equivalent proof.  $\square$

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