# Turf Wars


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**Abstract**

Turf wars in organizations commonly occur in environments where competition undermines collaboration. We develop a game theoretic model and experimental test of turf wars. The model explores how team production incentives *ex post* affect team formation decisions *ex ante*. In the game, one agent decides whether to share jurisdiction over a project with other agents. Agents with jurisdiction decide whether to exert effort and receive a reward based on their relative performance. Hence, sharing can increase joint production but introduces competition for the reward. We find that collaboration has a non-monotonic relationship with both productivity and rewards. The laboratory experiment confirms the model's main predictions. We also explore extensions of the basic model, including one where each agent's productivity is private information.



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# 1 Introduction

The "turf war" is one the most commonly recognized organizational pathologies. When informally discussing turf wars with people with work experience, anecdotal accounts abound. While there is no consensus on the definition of the term, accounts of the phenomenon typically possess common elements. Agents, such as government bureau heads or corporate division managers, perceive themselves to be in competition with one another over resources, promotions, or publicity.[1] This friction hampers efficient team formation: given the opportunity to pursue an important task or assignment, these agents will then attempt to exclude rivals from participation. Tactics might include withholding crucial information, or using decision-making rights to shunt rivals' activities into low-profile tasks. Importantly, principals or other external actors may want agents to collaborate, but they do not always have the ability to enforce such behavior.

Unsurprisingly, turf battles are widely believed to have significant adverse effects on organizational performance. In his classic analysis of bureaucratic politics, Wilson (2000) devoted an entire chapter to describing the consequences of turf-motivated strategies. Moreover, examples involving some of the largest organizations and most significant pieces of legislation are not difficult to find. The following list illustrates four major instances of turf wars. All suggest persistent inefficient allocations of property rights that were ultimately addressed through external interventions typically enabled by exogenous events.

**U.S. Military Branches.** The National Security Act of 1947 established the basic structure of the modern U.S. national security bureaucracy. The law preserved the relative autonomy of the individual armed services, which led to competition and low levels of coordination between functionally similar units. In the Korean and Vietnam wars, the Navy and Air Force ran essentially independent air campaigns, and subsequent operations in Lebanon and Grenada in the early 1980s were marred by the services' inability to communicate. As Lederman (1999) documents, this performance record culminated in the 1986 Goldwater-Nichols Act. The reforms included the creation of Unified Combat Commands, which allowed local commanders to coordinate centrally the activities of all American forces operating in a given region.

[1] An alternative view, offered by Garicano and Posner (2005), is that turf wars are a form of influence activities (Milgrom and Roberts 1988).

**U.S. Intelligence Reform.** In its comprehensive analysis of the 9/11 attacks, the National Commission on Terrorist Attacks (2004) prominently criticized the organization of U.S. intelligence gathering. The report—commonly known as the *9/11 Commission Report*—argued that the 14 competing intelligence agencies spread across several federal departments hindered the aggregation of information relevant to the disruption of attacks. It recommended the creation of a central office to coordinate intelligence gathering activities across these agencies. The position of Director of National Intelligence was officially created by the Intelligence Reform and Terrorism Prevention Act of 2004.

**Pepsico's restaurants.** While it was the owner of Pizza Hut, Taco Bell, and KFC, Pepsico operated the restaurant chains as autonomous divisions that competed with each other and reported directly to the CEO (Dahlstrom et al. 2004). As a result, managers worked independently and rarely communicated with each other because they feared they would give away trade secrets. The restaurant chains often failed to coordinate their purchasing, headquarter tasks, data management, and real estate functions, effectively relinquishing an estimated $100 million per year in cost savings (Montgomery 2001). Some of these issues were subsequently addressed when the restaurant chains were spun off to form Tricon Global Restaurants, which allowed the creation of common procurement and information management divisions (Dahlstrom et al. 2004).

**Drug Enforcement.** Wilson (1978) discusses the U.S. Drug Enforcement Agency's (DEA) geographical drug enforcement program, which was used to allocate "buy money" for drug investigations. The money was allocated competitively across DEA regions on the basis of previous arrests, with more significant arrests earning larger rewards. This, however, resulted in perverse sharing incentives:

> "Many drug distribution networks cut across regional lines. One organization may bring brown heroin from Mexico in to Detroit, where it is cut and then sent on to Boston or New York to be sold on the street. Six DEA regions have an interest in this case ... If agent and regional directors believe they are rewarded for their stats, they will have an incentive to keep leads and informants to themselves in order to take credit for a Mexican heroin case should it develop. A more appropriate strategy would be for such information to be shared so that an interregional case can be made ... The perceived evaluation and reward system of the organization ... threatens to lessen the credit, and therefore (it is believed)

the resources, available for a given region."

The geographical drug enforcement program induced a bias toward capturing street-level offenders, even though most agents and outsiders would have preferred higher profile cases.[2] The DEA responded to these sharing issues by creating investigation-specific inter-regional task forces. However, these task forces often only displaced the turf issue, as regional offices were reluctant to share their best agents and the assignment of credit for a successful investigation could be difficult.

These examples illustrate that there exist many instances in which cooperation among competing agencies is hard to achieve, in spite of repeated interactions, and where *ex ante* transfers that implement the efficient allocation of resources are unavailable.[3]

This paper develops a model of organizational turf wars. It is, to our knowledge, the first model to consider how turf wars in organizations arise, and how they might be controlled. As Posner (2005) notes, "The literature on turf wars is surprisingly limited, given their frequency and importance" (p. 143). Accordingly, the model is simple and attempts to capture only the essential elements of a turf battle. We view these elements to be the following.

**Joint production.** Perhaps most obviously, questions about responsibility over a task can only arise between agents who are capable of contributing to the joint production of relevant outcomes.

**Property rights.** Agents have property rights over their jurisdiction. In other words, agents can choose whether they want to involve other agents in the production process they control or exclude them to protect their turf.[4]

[2]Wilson (1978) mentions variations of this behavior at several levels in the investigation and prosecution of drug law violators: e.g., by U.S. Attorneys, local police agencies, and the Federal Bureau of Investigation.

[3]Even within academia, activities such as co-authorships have a similar incentive structure to the DEA example above. When deciding whether to invite a second author into a promising new research idea or project, the first author faces a clear trade-off. While co-authorship with a more skilled second author is likely to increase significantly the quality of an article, it is also likely to lessen the individual credit and perhaps the promotion chances of the first author. This problem is most prominent in disciplines where the formation of research teams is a first order problem, such as medicine and biology.

[4]An important assumption of our model is that an external actor such as a legislature cannot simply force agents to share jurisdiction, which trivializes the problem. The motivating logic behind centralizing re-organizations such as those proposed by the *9/11 Commission Report* is that agents would be more easily induced to share if they were placed under one roof. While this approach has no doubt had its successes, such

**Competition.** Agents must be in competition. The competition might be over an explicit prize, for example a promotion in a rank-order tournament, or it may reflect the ability to undermine the production of other agents. The intensity of the competition might emerge from basic indivisibilities of prizes that are only awardable to a single "winner." Examples include gaining favorable media attention, or securing a prestigious project assignment.[5]

Our basic model considers two agents who can exert effort in order to contribute to a collective project. One agent, labeled the *originator*, begins the game by choosing the set of agents who will have jurisdiction over the project.[6] She may keep jurisdiction, which prevents the partner agent from working, she may refer jurisdiction, thus giving the partner exclusive authority, or she may share jurisdiction, allowing both agents to work on the project. Agents care about the project's overall output and an indivisible prize that is increasing in their joint production. Each agent's productivity is common knowledge, and the probability of winning the prize is increasing in each agent's relative contribution to the project. Sharing jurisdiction increases the project's overall output but reduces the originator's probability of receiving the prize. A turf war then occurs when the originator keeps jurisdiction when sharing would have been socially desirable.

The most important predictions of the model concern the conditions that generate collaboration—the outcome where the originator shares and both agents work. As intuition would suggest, agents work when their productivity and the size of the prize are sufficiently high. Moreover, when both agents have the opportunity to work, they have a higher incentive to free-ride. The incentives to share their jurisdiction are more complex. Increasing the prize has two main effects. At low levels, it increases the originator's incentive to share through the inducement of work by the partner. However, at very high levels, it can reduce her incentive to share

reforms have not been uniformly successful. One reason for this is that competition may be more pronounced within organizations than between them (e.g., Posner 2005). In the U.S. Central Intelligence Agency, for example, the two main branches (operations and analytics) are historically fierce rivals (Gates 1987). Thus, we focus on the determinants of turf wars in environments where collaboration is plausibly non-contractible.

[5]This assumption is considered natural in the bureaucratic setting. For example, Downs (1966) argued that bureaucracies were in a constant state of competition, and in particular that "No bureau can survive unless it is continually able to demonstrate that its services are worthwhile to some group with influence over sufficient resources to keep it alive."

[6]Originator status may arise from technology or statutory assignments of responsibility, or from a principal's inability to re-assign property rights.

and induce a turf war. Thus, collaboration benefits from increasing the competitive prize in some instances and decreasing it in others. Somewhat surprisingly, the effect of increasing originator productivity can therefore be non-monotonic. This occurs because both the least and most productive originators always share when the partner is willing to work, but intermediate types may not.[7] In some cases, increasing the originator's productivity from a low level can actually reduce overall output.

We test the predictions of the model with a laboratory experiment. This exercise is especially relevant for our topic because turf wars are difficult to observe directly in the field.[8] In particular, lack of sharing and collaboration might be hard to observe and the incentives to do so might be hard to quantify, which makes a direct test of the model difficult to perform. The experiment focuses on some of the more interesting implications of our model. Namely, the potential non-monotonic effect of the competitive prize on sharing and joint production. Our results provide strong support for the predicted behavior of the model. We find that increasing the prize initially increases production as it provides an incentive to both agents to exert effort. Further increases, however, clearly result in suboptimal jurisdiction decisions and a considerable reduction in joint production when the originator is of intermediate productivity.

Our basic setup, despite its simplicity, is sufficient to obtain our core results. However, we also develop three extensions to the basic model in order to explore the robustness of its results. The first considers a constant prize rather than one that increases in joint production. The second examines the substitutability or complementarity of agents' efforts and allows for more than two agents. The final extension introduces incomplete information about both agents' productivity levels. By and large, the predictions from the three extensions are consistent with the basic model in that the most productive originators share when there are production synergies and increasing the prize can have a non-monotonic effect on overall output.

While there are no other formal models and only a few empirical attempts that explicitly

[7] Generally, the most productive originators share and work while the least productive ones tend to share and shirk. We also find that if agents are motivated more by joint output than by the prize of winning, a subset of originators with relatively low productivity will also share and work.

[8] The most salient empirical analyses of turf wars study how political institutions acquire new responsibilities. King (1994, 1997) analyze the evolution of the division of labor across U.S. Congressional committees. Consistent with our model, Wilson (2000) argues that bureaucracies' preferences over new jurisdiction are shaped in large part by their competitive environment.

address the idea of turf wars in organizations,[9] this paper is related to work on tournaments, sabotage, information sharing, and referrals.

The fact that agents who share jurisdiction compete for an indivisible prize that is awarded according to relative performance implies that our model is related to the literature on rank-order tournaments (Lazear and Rosen 1981). This line of research describes the relationship between effort and competition among individuals (e.g., Schotter and Weigelt 1992; Bull et al. 1987) as well as among groups (e.g., Nalbantian and Schotter 1997; Tan and Bolle 2007; Markussen et al. 2014).[10] We contribute to this literature by adding an initial sharing stage in which the originator effectively decides whether she wants to compete in a tournament with the partner agent. This allows us to study the conditions under which tournaments that would otherwise increase effort, result instead in lack of sharing between agents and low output.

A subset of the literature on rank-order tournaments that is important in relation to our model is that of sabotage (e.g., Lazear 1989; Konrad 2000; Chen 2003; Falk et al. 2008; Harbring and Irlenbusch 2005, 2011; Balafoutas et al. 2012). Although we do not model it here, sabotage might be one way in which turf battles are fought, especially when agents are brought together involuntarily. These models focus on inefficiencies that arise because competition gives agents in a given team an incentive to sabotage each other's output. By contrast, in our model, competition can result in inefficiencies due to jurisdictional tools available to the originator that allow her to choose the composition of the team. A distinctive feature of our model compared to the literature on sabotage is that because of the benefits of joint production, more intense competition does not necessarily lead to welfare losses.

A second related literature is that on information sharing. Like sabotage, the failure to reveal information relevant to collective outcomes might be considered a failure of collaboration. A central question in this work is the extent to which players reveal their private information, even when they are in competition. Okuno-Fujiwara et al. (1990) develop a

[9] A 2016 JSTOR article search of the term "turf war" in economics, political science, and management yields 7 title hits and 8 abstract hits, none of which are associated with a formal model of organizations.

[10] For recent reviews of the theoretical and experimental literatures see Connelly et al. (2014) and Sheremeta (2015), respectively. There is also a large literature on the rent-seeking model of Tullock (1980), which models the exertion of effort in order to win a fixed price as wasteful (for a review of this literature see Congleton et al. 2008; Dechenaux et al. 2015).

two-stage model in which players first decide non-cooperatively whether to make a verifiable report of their information, and derive conditions for full revelation.[11] Other models have developed this idea in more specific strategic contexts. Stein (2008) models two competitors who have complementary ideas in alternating periods. Each player is willing to reveal her idea to the competitor if she uses it to form a better idea that will be passed back in turn. High levels of complementarity and skill sustain information sharing in equilibrium.

Finally, our model is related to that of Garicano and Santos (2004), who study the market for referrals of tasks between agents under incomplete information (see also, Landini et al. 2013). Like us, they model a situation where inefficiencies arise due to agents failing to share jurisdiction over tasks. However, their paper focuses on institutional solutions to matching problems, rather than on the possibilities for joint production.

## 2 The model

In this section, we describe the game theoretic model and the main theoretical results. This core setup resembles that of Garicano and Santos (2004) but crucially also features collaboration (or lack thereof) between agents in a single project, which is the central focus of our analysis. There are two agents, labeled A1 and A2. One agent (without loss of generality, A1) has initial jurisdiction over a task. We label A1 the *originator*. The originator's key decision is to what extent to share jurisdiction with A2.

Each agent $i$ generates an output level $x_i \in \{0, \theta_i\}$ for the task when she has jurisdiction over it. When A$i$ does not have jurisdiction, her output is $x_i = 0$. The parameter $\theta_i \in [0, 1]$ represents $i$'s productivity and is common knowledge. A$i$'s output level is given simply by $e_i\theta_i$, where $e_i \in \{0, 1\}$ is $i$'s effort level. We assume that the effort costs of agent A$i$ are $e_ik$. We denote by $x = x_1 + x_2$ the total output of the agents.

Agents receive utility from two sources. First, they value aggregate output, with A$i$ receiving $mx$, where $m > 0$. This represents a kind of "policy" motivation or the share received by an agent according to a revenue-sharing incentive scheme. Second, they compete for a prize

[11] A few papers on information sharing in oligopoly competition also consider the question of whether competitors share information in settings where they can commit to doing so prior to its revelation (e.g., Gal-Or 1985; Creane 1995; Raith 1996). See also Modica (2010), who shows how competing firms might contribute to open source projects, and Baccara and Razin (2007), who develop a bargaining model in which innovators share ideas in order to develop them but worry that by doing so their ideas could be stolen.

of value $\beta x$, where $\beta > 0$ and $k \in (0, m+\beta)$. The upper bound on $k$ ensures that exerting effort is undominated. The prize might represent a form of credit for superior performance, such as a promotion, a bonus, or public recognition. When only A$i$ has jurisdiction, she wins the prize with certainty. When both agents have jurisdiction, the probability of victory depends on relative outputs and a random noise term. A1 then wins when $x_1 > x_2 + \varepsilon$, where $\varepsilon \sim U[-1, 1]$. Hence, A$i$'s probability of victory is easily calculated as:[12]

$$\omega_i(x_i, x_{-i}) = \frac{x_i - x_{-i} + 1}{2}. \tag{1}$$

Putting all of the elements together, A$i$ receives the following utility:

$$u_i = \begin{cases} m\left(x_1 + x_2\right) + \beta\left(x_1 + x_2\right)\omega_i - e_i k & \text{if both have jurisdiction} \\ m x_i + \beta x_i - e_i k & \text{if only A}i\text{ has jurisdiction} \\ m x_{-i} & \text{if only A}{-i}\text{ has jurisdiction.} \end{cases} \tag{2}$$

The game begins with A1 choosing $s \in \{\text{share}, \text{keep}, \text{refer}\}$. Under "share," both agents have jurisdiction. Under "keep," only A1 has jurisdiction, while under "refer," A1 passes jurisdiction to A2. After the assignment of jurisdiction, the agents with jurisdiction choose effort $e_i \in \{0, 1\}$. This choice is simultaneous when both agents have jurisdiction. We derive the subgame perfect equilibrium.

### 2.1 Equilibrium

We begin with the effort choice. Consider first the subgame following A1's choice to share. The best responses are easy to derive. A$i$ works, i.e. exerts effort, when her partner works if $m(\theta_1 + \theta_2) + \beta(\theta_1 + \theta_2)\,\omega_i(\theta_i, \theta_{-i}) - k \geq m\theta_{-i} + \beta\theta_{-i}\,\omega_i(0, \theta_{-i})$, and she works when her partner does not work if $m\theta_i + \beta\theta_i\,\omega_i(\theta_i, 0) - k \geq 0$. Both expressions result in the same threshold:

$$\theta_i \geq \theta^H \equiv \frac{-\left(m + \frac{\beta}{2}\right) + \sqrt{\left(m + \frac{\beta}{2}\right)^2 + 2\beta k}}{\beta}. \tag{3}$$

[12]We follow the convention in the rank-order tournament literature and determine the winner using differences in output and random noise, which can be interpreted as the result of output not being perfectly observable (Lazear and Rosen 1981). An alternative would be to follow the rent-seeking literature and use a contest success function based on relative output differences: $\omega_i(x_i, x_{-i}) = \frac{x_i^d}{x_i^d + x_{-i}^d}$. The rent-seeking approach is equivalent to a rank-order tournament if production functions are linear and noise is exponentially distributed (Loury 1979).

This threshold is strictly positive and decreasing in $m$. Thus, A$i$ has a weakly dominant strategy to work when $\theta_i \geq \theta^H$. Note that with a non-uniform distribution, agents may not have a dominant strategy, but the incentive to work would still be increasing in $\theta_i$.

Next, consider the subgame in which only one agent has jurisdiction. This happens to A2 when A1 refers, as well as to A1 when she keeps jurisdiction. A$i$ works when alone if $(m+\beta)\theta_i - k > 0$, and not otherwise, namely if:

$$\theta_i \geq \theta^L \equiv \frac{k}{m+\beta} \tag{4}$$

The following lemma establishes the relationship between the two thresholds. We provide all the paper's proofs in the appendix.

**Lemma 1** *Second stage effort thresholds.*

$$\begin{aligned} k = 0 \quad &\Longleftrightarrow \quad \theta^L = \theta^H = 0 \\ k \in (0, m+\beta) \quad &\Longleftrightarrow \quad 0 < \theta^L < \theta^H < 1 \\ k = m+\beta \quad &\Longleftrightarrow \quad \theta^L = \theta^H = 1. \end{aligned}$$

Thus we have three disjoint regions that characterize effort as a function of productivity. The least able agents, with productivity $\theta_i \in (0, \theta^L)$, always choose $e_i^* = 0$. The most able agents, with productivity $\theta_i \in (\theta^H, 1)$, always choose $e_i^* = 1$. Finally, agents with intermediate productivity $\theta_i \in (\theta^L, \theta^H)$ choose $e_i^* = 1$ only if they alone have jurisdiction, otherwise they choose $e_i^* = 0$. As intuition would suggest, each agent's incentive to work is increasing in her productivity. She is also more inclined to work when she has sole jurisdiction as opposed to shared jurisdiction, since the latter entails a positive probability of losing $\beta$ even when the partner exerts no effort.

Moving to the first stage sharing choice, it is convenient to use the labels listed in Table 1 to refer to the different jurisdiction-effort profiles in the game. Observe that A1 would never share if A2 would not work, and so we ignore this combination. In addition, the outcome where A1 keeps jurisdiction and exerts effort is labeled as *autarchy* if it is efficient in terms of total welfare and as a *turf war* if it is inefficient.

There are three cases corresponding to the region containing $\theta_2$. First, when $\theta_2 \in (0, \theta^L)$, A1 anticipates no effort from A2. A1's decision then depends only on whether she herself will work. If $\theta_1 < \theta^L$, the result is indifference, while if $\theta_1 > \theta^L$, A1 does strictly better by keeping and the result is autarchy.

**Table 1. Jurisdiction-effort profiles**

| LABEL | JURISDICTION | EFFORT |
|---|---|---|
| *Indifference* | any | none |
| *Autarchy/Turf war* | A1 | A1 |
| *Referral* | A2 | A2 |
| *Delegation* | A1, A2 | A2 |
| *Collaboration* | A1, A2 | A1, A2 |

Second, when $\theta_2 \in (\theta^L, \theta^H)$, sharing results in no effort by A2. Thus, A1 keeps if she prefers to work and refers if she prefers that A2 works alone. A1 prefers refer to keep if:

$$\theta_1 \quad > \quad \frac{m\theta_2 + k}{m + \beta}. \tag{5}$$

As with the case for $\theta_2 \in (0, \theta^L)$, higher values of $\theta_1$ are associated with autarchy. But now with a stronger A2, a weaker A1 has a strict preference for a referral. The threshold (5) is obviously strictly greater than $\theta^L$, since an originator who never works would clearly prefer referral to autarchy. This implies that the range of $\theta_1$ values that generate autarchy is strictly smaller as A2 moves from low to moderate productivity.

The third and most complex case is when $\theta_2 > \theta^H$. The experiment in Section 3 focuses on this case. It is clear that referrals and indifference are not possible in this setting. Since A2 is guaranteed to work, both outcomes are dominated by the delegation outcome. Moreover, not giving jurisdiction to A2 is inefficient in terms of total welfare. Hence, A1's choice boils down to a decision over turf war, delegation, and collaboration.

It will be useful to introduce three new parameters that give the values of $\theta_1$ at which A1 is indifferent between share and keep. First, when $\theta_1 > \theta^H$, so that both agents are expected to work if they have jurisdiction, A1 is indifferent between collaboration and turf war at the following values of $\theta_1$:

$$\theta^{\pm} \equiv \frac{1}{2} \pm \sqrt{\frac{1}{4} - \theta_2 \left( \frac{2m}{\beta} + 1 - \theta_2 \right)} \tag{6}$$

When $\theta^+$ and $\theta^-$ are not real-valued, A1 always prefers collaboration to autarchy. Next, when $\theta_1 \in (\theta^L, \theta^H)$, A1 is indifferent between delegation and autarchy at the following value of $\theta_1$:

$$\tilde{\theta} \equiv \frac{m\theta_2 + \frac{1}{2}\beta\theta_2 (1 - \theta_2) + k}{m + \beta}. \tag{7}$$

The next result summarizes outcomes for all combinations of $\theta_1$ and $\theta_2$. The main finding when $\theta_2 > \theta^H$ is that a turf war can occur for "moderate" values of $\theta_1$. The originator chooses to keep jurisdiction because sharing would greatly reduce her chances of receiving the prize to a high-ability partner. By contrast, when the originator's productivity is low enough to make her either unwilling to exert effort or unlikely to win, the result is delegation. Finally, when the originator's productivity level guarantees a sufficiently high probability of winning the prize, the result is collaboration.

**Proposition 1 (Outcomes)**

*(i) If* $\theta_2 \in (0, \theta^L)$ *then*
$$\begin{cases} \textit{indifference} & \textit{if } \theta_1 < \theta^L \\ \textit{autarchy} & \textit{if } \theta_1 > \theta^L. \end{cases}$$

*(ii) If* $\theta_2 \in (\theta^L, \theta^H)$ *then*
$$\begin{cases} \textit{referral} & \textit{if } \theta_1 < \frac{m\theta_2+k}{m+\beta} \\ \textit{autarchy} & \textit{if } \theta_1 > \frac{m\theta_2+k}{m+\beta}. \end{cases}$$

*(iii) If* $\theta_2 \in (\theta^H, 1)$ *and* $\theta^H < \tilde{\theta}$ *then*

*when* $\theta^-$ *and* $\theta^+$ *are not real-valued or* $\theta^+ < \theta^H$
$$\begin{cases} \textit{delegation} & \textit{if } \theta_1 \in (0, \theta^H) \\ \textit{collaboration} & \textit{if } \theta_1 \in (\theta^H, 1), \end{cases}$$

*and when* $\theta^-$ *and* $\theta^+$ *are real-valued and* $\theta^+ > \theta^H$
$$\begin{cases} \textit{delegation} & \textit{if } \theta_1 \in (0, \theta^H) \\ \textit{collaboration} & \textit{if } \theta_1 \in (\theta^H, \theta^-) \\ \textit{turf war} & \textit{if } \theta_1 \in (\max\{\theta^H, \theta^-\}, \theta^+) \\ \textit{collaboration} & \textit{if } \theta_1 \in (\theta^+, 1), \end{cases}$$
*where* $(\theta^H, \theta^-)$ *is possibly empty.*

*Else if* $\theta_2 \in (\theta^H, 1)$ *and* $\theta^H > \tilde{\theta}$ *then*
$$\begin{cases} \textit{delegation} & \textit{if } \theta_1 \in (0, \tilde{\theta}) \\ \textit{turf war} & \textit{if } \theta_1 \in (\tilde{\theta}, \max\{\theta^H, \theta^+\}) \\ \textit{collaboration} & \textit{if } \theta_1 \in (\max\{\theta^H, \theta^+\}, 1). \end{cases}$$

For high values of $\theta_2$, there are three possible patterns of outcomes as $\theta_1$ increases from 0 to 1: delegation → collaboration, delegation → turf war → collaboration, and delegation → collaboration → turf war → collaboration. The final pattern may appear somewhat anomalous because the "collaboration region" is non-convex. The intuition for this is that the condition $\tilde{\theta} < \theta^H$ holds when $\theta_2$ and $m$ are relatively high. An originator with a relatively low $\theta_1$ will then collaborate because she cares about output and would be unable to contribute enough to collective output in a turf war.

Two general patterns emerge from this equilibrium. First, only high types are willing to work. Second, conditional upon A2 being willing to work, high-productivity and possibly

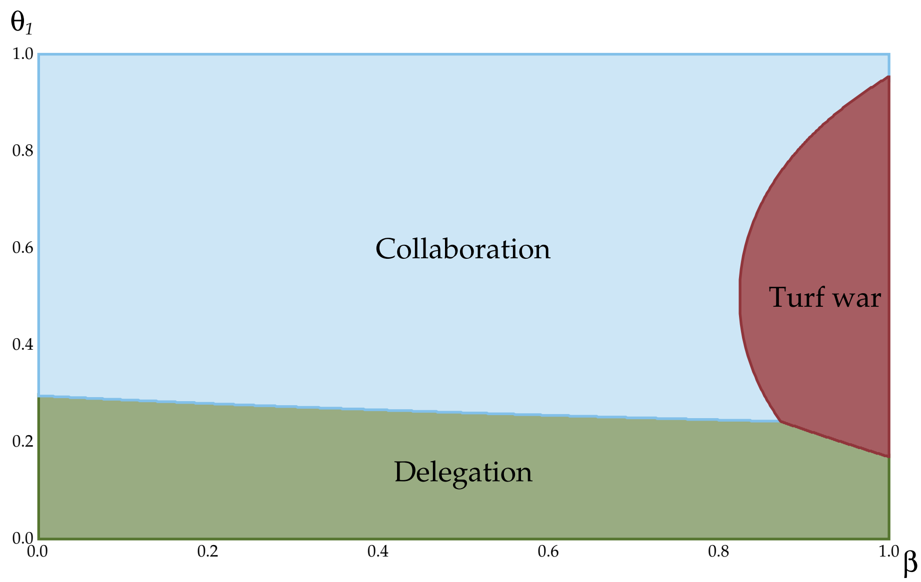


**Figure 1. Outcomes as a function of $\beta$ and $\theta_1$**

*Note:* Here $2m + \beta = 1$, $k = 0.15$, and $\theta_2 = 0.95$, which ensures that A2 always works when given jurisdiction. Delegation maximizes welfare for $\theta_1 < 0.15$, while collaboration maximizes welfare for $\theta_1 > 0.15$.

low-productivity originators share. Only intermediate-productivity originators do not share, and so sharing and working may be non-monotonic in originator type.

## 2.2 Comparative statics and welfare

For the next result as well as the subsequent experiment, we will focus on the effect of competition ($\beta$). To distinguish between the effects of increasing competition and increasing the size of the "pie," we keep the size of the total reward constant by fixing $2m + \beta = W$ for some $W > 0$.

Figure 1 illustrates the equilibrium outcomes as a function of $\beta$ and $\theta_1$ for a set of parameters satisfying $\theta_2 > \theta^H$ and $W = 1$. For $\beta \in (0, 0.83)$, $\theta^H < \tilde{\theta}$ and the outcome pattern is delegation $\rightarrow$ collaboration. For $\beta \in (0.83, 0.87)$, the delegation $\rightarrow$ collaboration $\rightarrow$ turf war $\rightarrow$ collaboration pattern appears. Finally for higher values of $\beta$, $\theta^H > \tilde{\theta}$ and the pattern becomes delegation $\rightarrow$ turf war $\rightarrow$ collaboration.

The figure also helps to clarify the welfare implications of the game. The agents' joint welfare increases by $(2m + \beta)\theta_i - k$ if agent A$i$ works. Thus if this quantity is positive for both agents, then collaboration maximizes welfare. Under the parametric assumptions from

Figure 1, collaboration is efficient whenever $\theta_1 > 0.15$, and referral or delegation is efficient otherwise. The equilibrium is therefore inefficient when a turf war occurs, but also when delegation occurs for $\theta_1 > 0.15$. Inefficiencies are therefore possible across all values of $\beta$ when $\theta_1$ is "moderate," but somewhat counterintuitively, the range of values for which such inefficiencies occur is not minimized when $\beta$ is smallest. Rather, moderate values of $\beta$ come "closest" to producing efficient outcomes.

Proposition 2 generalizes this figure and presents some basic comparative statics on the most important outcome regions.

**Proposition 2 (Comparative Statics)**
*The set of $\theta_1$ values for which a turf war occurs is increasing in $\beta$ and weakly decreasing in $k$. The set of $\theta_1$ values for which delegation occurs is decreasing in $\beta$ and increasing in $k$. Specifically, for $\theta_2 \in (\theta^H, 1)$, if $\theta^H < \tilde{\theta}$ then comparative statics are:*

| Region | Outcome | $\beta$ | $k$ |
|---|---|---|---|
| $(0, \theta^H)$ | delegation | decreases | increases |
| $(\theta^H, \theta^-)$ | collaboration | ambiguous | decreases |
| $(\theta^-, \theta^+)$ | turf war | increases | constant |
| $(\theta^+, 1)$ | collaboration | decreases | constant |

*And if $\theta^H > \tilde{\theta}$, then comparative statics are:*

| Region | Outcome | $\beta$ | $k$ |
|---|---|---|---|
| $(0, \tilde{\theta})$ | delegation | decreases | increases |
| $(\tilde{\theta}, \theta^+)$ | turf war | increases | decreases |
| $(\theta^+, 1)$ | collaboration | decreases | constant |

Proposition 2 shows that the observation about the effect of $\beta$ on outcomes from Figure 1 is general. Since $\theta^H$ is decreasing in $\beta$, the reduction in delegation implies an expansion in the collaboration region when there is no turf war region, i.e., in the first expression in Proposition 1(iii). Thus when both agents have jurisdiction, *increasing the prize induces efficient outcomes* for a wider range of $\theta_1$. While the well-known effort inducing effect of the prize is always underlying, a turf war emerges for a large enough prize. As a prescription, a principal would therefore want to increase $\beta$ (at the expense of $m$) up to the point where turf wars become possible. For values of $\beta$ that generate a turf war, increasing $\beta$ has the opposite effect of reducing the region where efficient outcomes can occur.

We finally make two observations about the role played by effort costs in this model. First, unlike $\beta$ and $m$, increasing $k$ never encourages collaboration. However, when $\theta^H > \tilde{\theta}$ and $\theta_2 \in (\theta^H, 1)$ (so that A2 always works) increasing $k$ has no effect. Second, in the special case of costless effort, collaboration is non-monotonic. It is easily verified that $k = 0$ implies $\theta^H = \theta^L = 0$, so both agents always work. It follows that the outcomes of indifference, referral, and delegation cannot occur in equilibrium. The equilibrium is characterized by Proposition 1(iii), where $\theta^H < \tilde{\theta}$. Collaboration therefore occurs for both low and high productivity originators, with a turf war resulting for intermediate productivities. Intuitively, very able originators collaborate as they are not threatened by potentially sharing some of their prize/credit, while low skilled originators collaborate despite the likely loss of the prize as they would not be able to produce a valuable-enough project alone. Moderate ability originators are the competitive types that generate inefficiencies.

## 3 Experimental design

In this section we present the results from a laboratory experiment used to test the more notable implications of our model. In particular, we examine the nonlinear effect of competition ($\beta$) on production and welfare. As with the comparative statics in Section 2.2, we focus on the case where the total reward is constant and is given by $W = 2m + \beta$. In other words, we compare situations that differ only in the importance of the incentive to compete as a fraction of the total compensation.

In the experiment, subjects were grouped in pairs. In each pair, one subject played the role of A1 (the originator) and the other played the role of A2. As in our model, A1 first decided between keeping, referring, or sharing. Subsequently, A1 and/or A2 chose between exerting effort or not. The subjects' monetary payoffs were based on equation (2) and were calculated in points. However, instead of implementing $\omega_i(x_1, x_2)$ as $i$'s probability of winning the whole prize, we implemented $\omega_i(x_1, x_2)$ as $i$'s share of the total prize. This change has the advantage that it simplifies the game and limits the effects of risk aversion (we assume agents are risk neutral in our model).[13] In all our treatments, we set $k = 220$ points and $W = 380$

[13]Experimental evidence comparing winner-take-all and proportional-prize contests finds that the former

points. Since the detrimental effects of competition occur when A2's productivity is high (see Proposition 1), we set $\theta_2 = 0.95$ throughout. The parameters that we varied were A1's productivity, which could take values $\theta_1 \in \{0.55, 0.75, 0.95\}$, and the size of the prize, which could equal $\beta \in \{57, 190, 304, 361\}$ points (these values of $\beta$ imply $m \in \{161.5, 95, 38, 9.5\}$ points respectively). To facilitate the interpretation of our results, from now on, we normalize $W$, $k$, $\beta$, and $m$ such that $W = 1$. This way, $\beta \in \{0.15, 0.50, 0.80, 0.95\}$ is simply the fraction of the total reward that is due to the competitive prize. The three values of $\theta_1$ and the four values of $\beta$ give us twelve treatments, each corresponding to a parameter combination. We refer to each treatment by these two values (e.g., treatment $\theta_{95}\beta_{15}$ corresponds to the case where $\theta_1 = 0.95$ and $\beta = 0.15$).

In the experiment, subjects played 60 periods (repetitions) of the game. Given the complexity of the game, we had subjects play multiple periods to give them the opportunity to learn. However, in order to approximate play in a one-shot game, subjects were informed that they would be randomly rematched at the beginning of each period with another subject in the room and that they would not be able to identify other subjects (there were sixteen subjects per session). We rematched subjects within a matching group of eight, which has been shown to be sufficiently large to eliminate repeated-game effects (e.g., see Camera and Casari 2009). In addition, subjects knew that they would be paid the outcome of only one period, which would be randomly selected at the end of the experiment (the same period was paid for all subjects in a session). At the end of each period, subjects were informed of the outcome of the game and their earnings in that period.

Subjects were randomly assigned to the role of A1 or A2 at the beginning of each period. Subjects knew that the productivity of A2 would always be $\theta_2 = 0.95$ and that the productivity of A1 would be randomly determined every period among the values $\theta_1 \in \{0.55, 0.75, 0.95\}$.

Each session was divided into four parts of 15 periods each. The payoffs in each part were based on one value of $\beta \in \{0.15, 0.50, 0.80, 0.95\}$. In the instructions, subjects were told that the payoffs of the game would change during the experiment and that they would be informed of the change when it occurred. At the beginning of each part (i.e., in periods 1, 16, 31, and 46), subjects were shown the payoffs implied by the respective $\beta$ and were given as much time as they wanted to evaluate the change. In order to control for order effects, each session was

results in higher effort and lower efficiency than the latter(Cason et al. 2010). In our experiment, this difference ought to play less of a role as effort cannot be high-enough to reduce efficiency.

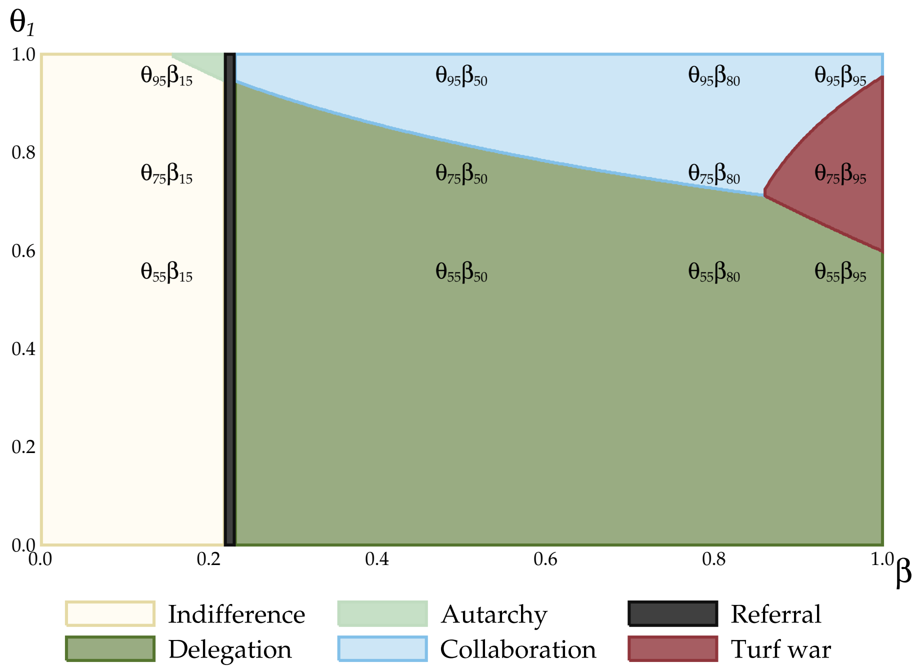


**Figure 2. Predicted outcome as a function of $\theta_1$ and $\beta$**

*Note:* Predicted equilibrium outcomes according to Proposition 1 for $\theta_1 \in (0, 1)$, $\beta \in (0, 1)$, $W = 1$, $\theta_2 = 0.95$, and $k = 0.58$. The twelve treatments implemented in the experiment are shown at their corresponding values of $\theta_1$ and $\beta$.

run using a different sequence of $\beta$s. We ran one session for each of the 24 possible sequences.

We ran the experiment in the CELSS laboratory of Columbia University in the fall of 2013. Subjects were recruited with an online recruitment system (Greiner 2004) and the computerized experiment was programmed in z-Tree (Fischbacher 2007). We used standard experimental procedures, including random assignment of subjects to roles and treatments, anonymity, neutrally worded instructions, dividers between the subjects' cubicles, and monetary incentives. A sample of the instructions is available in the appendix. In total, 192 subjects participated in the 90-minute long experiment. Each subject took part in only one session. Total compensation, including a $5 show-up fee, varied between $9 and $33.30 and averaged $23.32.

### 3.1 Predictions

Figure 2 depicts the predicted equilibrium outcome for all values of $\theta_1$ and $\beta$ given the other parameters in the experiment (i.e., for $W = 1$, $\theta_2 = 0.95$, and $k = 0.58$). The figure also shows the twelve treatments implemented in the experiment. These parameter combinations

**Table 2. Predicted differences in behavior depending on Proposition 1**

| Agent | Action | Predicted treatment comparisons |
|---|---|---|
| A1 | Keep | Delegation = Collaboration < Turf war |
| | Refer | Delegation = Collaboration = Turf war |
| | Share | Turf war < Delegation = Collaboration |
| | Effort (after keep) | Indifference = Delegation < Collaboration = Turf war |
| | Effort (after share) | Indifference = Delegation < Collaboration = Turf war |
| A2 | Effort (after refer) | Indifference < Delegation = Collaboration = Turf war |
| | Effort (after share) | Indifference < Delegation = Collaboration = Turf war |
| Both | Welfare | Indifference < Turf war < Delegation < Collaboration |

*Note:* Predicted comparisons based on the equilibrium strategies (see Proposition 1). Figure 2 displays the treatments that correspond to each equilibrium outcome.

were chosen in order to obtain three different patterns as we increase $\beta$ depending on the productivity of A1. For A1s with low productivity, $\theta_1 = 0.55$, increasing $\beta$ results in the pattern: indifference $\rightarrow$ delegation. For A1s with high productivity, $\theta_1 = 0.95$, increasing $\beta$ results in the pattern: indifference $\rightarrow$ collaboration. Finally, for A1s with intermediate productivity, $\theta_1 = 0.75$, increasing $\beta$ results in the pattern: indifference$\rightarrow$ delegation $\rightarrow$ collaboration $\rightarrow$ turf war. While this last pattern is arguably the most interesting one, observing the results for the other two patterns allows us to test whether the detrimental effect of increasing competition occurs when the model predicts it will.

Based on the model's predicted equilibrium strategies, we formulate hypotheses concerning the differences in behavior we expect to find across the various treatments. For simplicity, we formulate the hypotheses based on the model's predicted outcomes as opposed to individual treatments. The hypotheses are presented in Table 2.

# 4 Results

In order to observe how subjects behave compared to the theoretical predictions, Figure 3 presents the mean actions taken by A1s and A2s over all periods, pooling treatments according to the model's theoretical predictions.[14] Going from the top-left to the bottom-right, the first

[14]On average, subjects played 15 periods when the equilibrium prediction was indifference, 20 periods when it was delegation, 20 periods when it was collaboration, and 5 periods when it was a turf war.

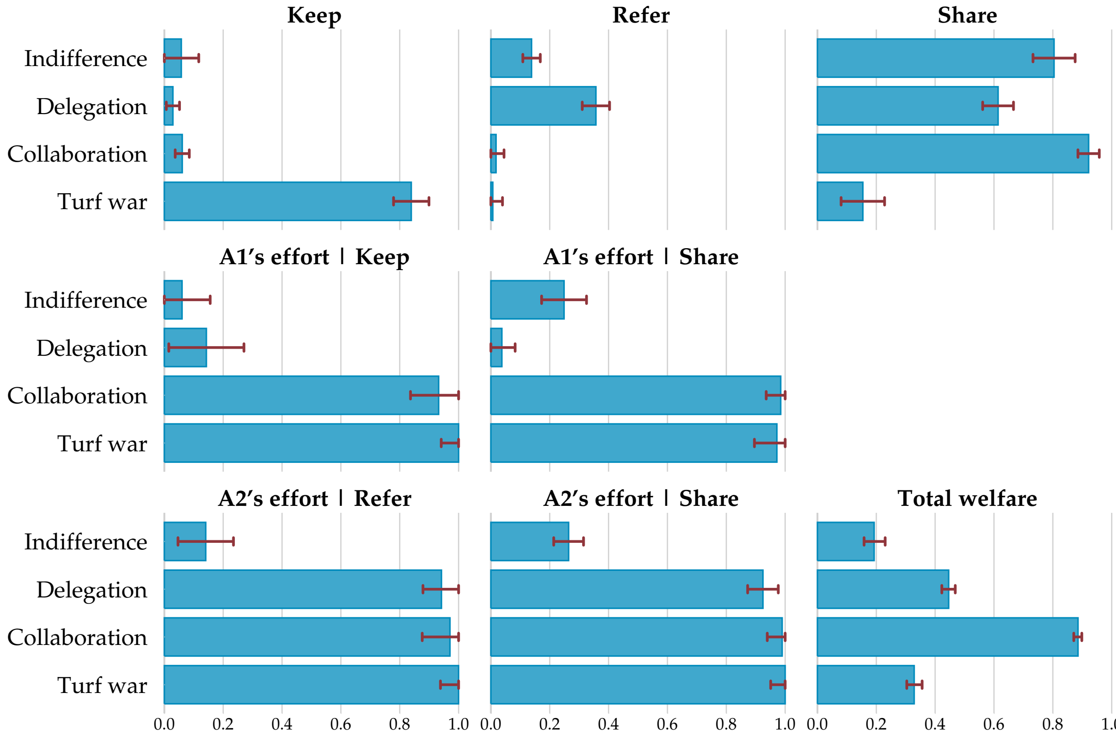


**Figure 3. Means of selected variables by equilibrium prediction**

*Note:* From the top-left to the bottom-right: the first three graphs show the mean rate at which A1 keeps, refers, or shares jurisdiction; the next four graphs show the mean effort rate of A1/A2 depending on A1's jurisdiction choice; and last graph shows mean total welfare as a fraction of the maximum welfare. Error bars correspond to 95% confidence intervals.

three graphs show the mean fraction of times A1s choose to keep, refer, or share jurisdiction. The next four graphs show the mean fraction of times A1s/A2s exert effort, depending on whether they were sharing jurisdiction or not. Naturally, effort rates are calculated conditional on having jurisdiction. Lastly, the eighth graph shows mean total welfare as a fraction of the maximum welfare (i.e., the sum of both players' payoffs when both have a high productivity, jurisdiction, and exert effort: $W(\theta_1 + \theta_2) - 2k = 0.74$). To provide a visual representation of the variance of each mean, the figure also displays 95% confidence intervals, which we calculated with regressions using treatment dummy variables as independent variables and clustering standard errors on matching groups. We used a multinomial probit regression for the jurisdiction choice, a probit regression for each effort choice, and an ordered probit regression for welfare (these regressions are available in the appendix).

To evaluate whether the differences observed in Figure 3 are statistically significant we use the fact that all subjects participated in the four predicted outcomes, which allows us to evaluate the effect the equilibrium predictions at the individual level. However, since subjects repeatedly interacted with each other within matching groups, we construct our independent observations by averaging the subjects' behavior within each matching group. This procedure gives us 24 observations per equilibrium prediction. Table 3 presents all pairwise comparisons between equilibrium predictions for the jurisdiction decision, effort choices, and welfare. Specifically, for each variable, it shows the observed difference in means between treatments within the various equilibrium predictions and it indicates whether this difference is statistically significant according to a Wilcoxon signed-ranks test. Given that we are performing multiple pairwise tests for each variable, we determine statistical significance based on Bonferroni-adjusted $p$-values.[15] As mentioned previously, we also performed these comparisons using regressions. Since the results from the regressions are consistent with those of the nonparametric tests, we relegate the regression analysis to the appendix.

By and large, we find that the subjects' behavior fits well with the main predictions of our model. Starting with the effort decision, we observe that effort rates are high when exerting effort is in the subjects' self interest. Specifically, the fraction of A1s who exert effort is significantly higher when the equilibrium prediction is collaboration or turf war (above 93%) compared to when it is indifference or delegation (below 25%). Similarly, the fraction of A2s who exert effort is significantly higher when the equilibrium prediction is delegation, collaboration, or turf war (above 92%) compared to when it is indifference (below 26%).[16] Thus, the only discernible deviation from the theoretical predictions is that the effort rate of A1 under shared jurisdiction is significantly higher in indifference than in delegation, which is driven by the noticeably high effort rate in indifference.[17] Positive effort levels in indifference

[15]For the jurisdiction decision, we multiply $p$-values by 18 since we run one test per pairwise comparison for each of the three outcomes (keep, refer, and share). For A1's/A2's effort choice, we multiply $p$-values by 12 since we run one test per pairwise comparison for each jurisdiction choice. Lastly, for welfare, we multiply $p$-values by 6 since we run one test per pairwise comparison.

[16]There is one exception. In spite of the large difference in effort rates between indifference and turf war after A1 refers, this difference is not statistically significant. However, the lack of significance is due to there being too few independent observations for this test because referrals are very rare in turf war (they occur only 1% of the time).

[17]Although we see statistically significant differences in effort rates between delegation and collaboration/turf war, the magnitude of these differences is very small (8 percentage points or less). Therefore, we do not consider them to be a substantial deviation from the theoretical predictions.

**Table 3. Observed differences in behavior depending on equilibrium predictions**

| Agent | Action | Treatment comparisons: Indifference vs. Delegation | Indifference vs. Collaboration | Indifference vs. Turf war | Delegation vs. Collaboration | Delegation vs. Turf war | Collaboration vs. Turf war |
|---|---|---|---|---|---|---|---|
| A1 | Keep | 0.03 | 0.00 | $-0.78^{**}$ | $-0.03^{**}$ | $-0.81^{**}$ | $-0.78^{**}$ |
| | Refer | $-0.22^{**}$ | $0.12^{**}$ | $0.13^{**}$ | $0.34^{**}$ | $0.35^{**}$ | 0.01 |
| | Share | $0.19^{**}$ | $-0.12^{**}$ | $0.65^{**}$ | $-0.31^{**}$ | $0.46^{**}$ | $0.77^{**}$ |
| | Effort (after keep) | −0.08 | $-0.87^{**}$ | $-0.94^{**}$ | $-0.79^{*}$ | $-0.86^{*}$ | −0.07 |
| | Effort (after share) | $0.21^{**}$ | $-0.74^{**}$ | $-0.72^{**}$ | $-0.95^{**}$ | $-0.93^{**}$ | 0.01 |
| A2 | Effort (after refer) | $-0.80^{**}$ | $-0.83^{**}$ | −0.86 | −0.03 | −0.06 | −0.03 |
| | Effort (after share) | $-0.66^{**}$ | $-0.73^{**}$ | $-0.74^{**}$ | $-0.07^{**}$ | $-0.08^{**}$ | −0.01 |
| Both | Welfare | $-0.26^{**}$ | $-0.70^{**}$ | $-0.12^{**}$ | $-0.43^{**}$ | $0.14^{**}$ | $0.58^{**}$ |

*Note:* Mean differences in observed behavior between equilibrium predictions. ** and * indicate statistical significance at 1% and 5% according to Wilcoxon signed-ranks tests using matching-group means and Bonferroni-adjusted $p$-values.

than in delegation are consistent with the large literature on cooperation in social dilemmas, which shows that some individuals are willing to cooperate when everyone's dominant strategy is to defect (Fehr and Gächter 2000) but are less willing to do so if cooperation is in the monetary interest of other players (e.g., see Reuben and Riedl 2009; Glöckner et al. 2011).

In the preceding decision, we observe strong differences in A1's jurisdiction decision depending on the predicted equilibrium. Remarkably, the rate at which A1s keep jurisdiction is less than 6% when the equilibrium prediction is delegation or collaboration, but it increases significantly to 84% when the equilibrium prediction is a turf war. Contrary to the model's predictions, however, we observe that A1s choose to refer jurisdiction to A2s when the equilibrium prediction is delegation resulting in significantly less sharing in delegation than in collaboration. We will come back to this behavior when we analyze the individual treatments. Finally, although the model does not make a prediction for the jurisdiction decision when the equilibrium prediction is indifference, we observe that A1s choose to share jurisdiction most of the time (80%). Note that sharing in this case is consistent with the fact that effort rates are not exactly zero and are slightly higher when A1 shares.

Lastly, we observe that the total welfare in the experiment conforms with the predicted comparative statics. Namely, welfare increases significantly as we move from indifference to delegation and then to collaboration, but it subsequently decreases significantly when the prediction becomes a turf war.[18] In fact, we clearly observe the detrimental effect of turf wars as total welfare is significantly lower when the equilibrium prediction is a turf war compared to when it is delegation even though the players' mean productivity is higher in the former case.

Next, we take a look at behavior in the individual treatments. We provide a detailed statistical analysis based on both regressions and nonparametric tests in the appendix. Here, we concentrate on the behavioral patterns observed above. Figure 4 presents the same statistics as Figure 3 for each combination of $\beta$ and $\theta_1$. On the whole, we do not find that behavior in treatments with the same equilibrium prediction differ substantially from each other. There are some differences, however, which we will highlight below.

Once again, let us start with the effort decision. We can see that, as predicted, the fraction

[18]Observed total welfare is close to the model's point predictions: it is slightly higher if the equilibrium prediction is indifference (0.19 vs. 0.00) or a turf war (0.31 vs. 0.23), and it is slightly lower if the prediction is delegation (0.45 vs. 0.50) or collaboration (0.89 vs. 0.94).

of A1s and A2s who exert effort increases with the amount of competition. Specifically, effort rates are high, above 89%, when $\beta$ is high enough to give subjects a monetary incentive to exert effort (i.e., for $\beta \geq 0.50$ if $\theta_i = 0.95$ or $\beta \geq 0.80$ if $\theta_i = 0.75$), otherwise effort rates do not exceed 48%. Figure 4 also reveals that the high effort rate observed when the equilibrium prediction is indifference is driven by players with high productivity. This observation is consistent with the literature on social dilemmas, which has documented that individuals are more willing to cooperate when the benefits of doing so are high relative to the cost (e.g., Brandts and Schram 2001).

In the jurisdiction decision, we observe that increasing competition has a strong effect on whether A1s keep jurisdiction to themselves, but only if A1 is of intermediate productivity ($\theta_1 = 0.75$). The rate at which A1s with intermediate productivity keep jurisdiction is at most 8% when $\beta \leq 0.80$ but it rises to 84% when $\beta = 0.95$. By contrast, A1s with low or high productivity ($\theta_1 = 0.55$ or $\theta_1 = 0.95$) keep jurisdiction at most 9% of the time at all four values of $\beta$. As mentioned above, a behavior that is not in line with the model's predictions is the referral rate when the equilibrium prediction is delegation. We can see in Figure 4 that the high referral rate occurs in the two delegation treatments where $\beta = 0.50$. In other words, in the two treatments where the difference between referring and sharing jurisdiction is the lowest. Therefore, once again, deviations from the model's predictions occur when such deviations are not very costly. It is a common finding in experiments for deviations from Nash equilibria to occur more often when they are less harmful. We would like to note, however, that while such low-cost deviations can lead to substantial differences in behavior and welfare in some games (see Goeree and Holt 2001), this is not the case in our model. More precisely, the unexpectedly high effort and referral rates do not affect our model's more notable implications such as the nonlinear effect of competition and productivity on production and welfare.

Finally, consistent with the theoretical predictions, we can see that even though the incentive to provide effort increases with competition at all productivity levels, total welfare does not. In particular, in pairs in which A1 is of intermediate productivity, welfare increases as $\beta$ goes from 0.15 to 0.80, but subsequently decreases when $\beta$ reaches 0.95. In pairs where A1 is of low or high productivity, welfare does not decrease as $\beta$ increases. As a consequence, pairs with an A1 with $\theta_1 = 0.75$ and $\beta = 0.95$ end up producing *less* than pairs with a less productive A1 ($\theta_1 = 0.55$, as long as $\beta \geq 0.50$).

In summary, our experimental results are in line with our model's theoretical results. First,

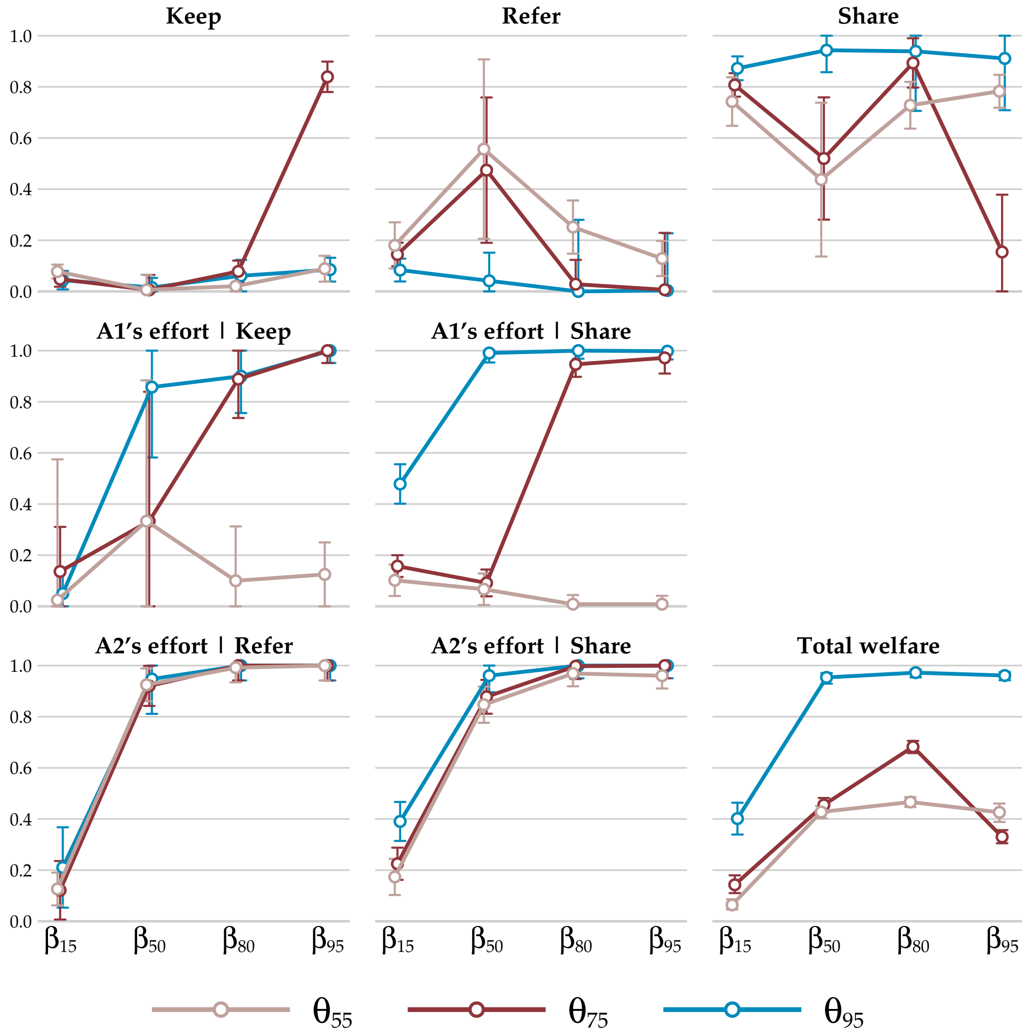


**Figure 4. Means of selected variables by treatment**

*Note:* From the top-left to the bottom-right: the first three graphs depict the mean rate at which A1 keeps, refers, or shares jurisdiction; the next four graphs depict the mean effort rate of A1/A2 depending on the A1's jurisdiction choice; and last graph depicts mean total welfare as a fraction of maximum welfare (i.e., the sum of payoffs when both players have high productivity, jurisdiction, and exert effort). Error bars correspond to 95% confidence intervals.

we clearly observe how increasing the incentive to compete initially increases production as it provides an incentive to exert effort. Second, we also observe that further increases in competitive incentives can result in suboptimal jurisdiction decisions and a considerable reduction of production (and welfare). Third, we find that such turf wars occur when the productivity difference between A1 and A2 is neither too large nor too small.

# 5 Extensions

Here we discuss three interesting variations of the basic game, which are formally solved in the appendix. Our objective is to show that the theoretical predictions from the basic model are robust to small changes in payoff structure, effort assumptions, and informational assumptions.

## 5.1 Fixed prize

A straightforward extension addresses environments where the competitive prize is a fixed amount. This may be the case, for example, if agents compete for a promotion to a predetermined office. The model with a fixed prize is identical to the basic model, with the exception that the prize for victory is simply $\beta$ instead of $\beta(x_1 + x_2)$.

The results are qualitatively similar to those of the basic model. An agent remains more inclined to work when she has sole jurisdiction compared to shared jurisdiction since the latter entails a positive probability of losing the prize. A1's anticipation of A2's effort response results in similar patterns of outcomes. If A2 is not very productive, productive originators prefer autarchy, while less productive ones prefer indifference or referral. If A2 is productive enough, the equilibrium outcome is delegation if the originator is of low productivity, collaboration if the originator is of high productivity, and a turf war if the originator is moderately productive. The comparative statics on outcomes behave in an intuitive manner, and resemble those of the basic model. A bigger prize enlarges the set of $\theta_1$ values for which there is a turf war and correspondingly reduce delegation. Finally, compared to the variable prize model, turf wars appear at lower values of $\theta_1$ because originators can guarantee themselves a substantial prize even if their output is low.

## 5.2 Multiple agents and synergies

We next consider a version of the fixed prize model, which we generalize in two ways. First, we allow $n \geq 2$ agents. Second, we use the more general CES production function for determining output $x = (\sum_i \theta_i^\rho)^{1/\rho}$, where $\sum_i \theta_i = 1$ and $\rho > 0$. If $\rho = 1$ then abilities are perfect substitutes. For $\rho < 1$ there are synergies in working together (the total ability is larger than the sum of the abilities), and conversely for $\rho > 1$. For simplicity, we work out the model without moral hazard (i.e., the case where $k = 0$), which implies that agents automatically exert effort and the only possible outcomes are turf war and collaboration.

To start, consider the case where the sole originator, A1, can share with either all other agents or none. If there are synergies, namely for $\rho < 1$, we show that there is a cutoff value of $\theta_1$ above which the originator shares. Moreover, the greater the synergy, the more inclined the originator will be to share. For $\rho > 1$, however, the pattern is reversed: there is another cutoff value of $\theta_1$ *below* which the originator shares.[19]

Next, let us consider what would happen if the originator could choose the agents she shares with. In particular, suppose that A1 can share jurisdiction with one additional agent. As above, we find that, as $\theta_1$ increases, sharing with a given agent becomes easier if $\rho < 1$, but may become harder if $\rho > 1$. The latter happens because the contribution of sharing toward the collective outcome becomes smaller, while the probability of winning the prize remains the same. We also show that the originator picks the strongest available partner when $\rho > 1$, as the expected loss in the prize is always offset by productivity gains. However, when $\rho < 1$, partner choice depends on the originator's productivity. Specifically, A1 prefers the strongest partner if she is stronger than the originator, but this preference may be reversed if the strongest potential partner is weaker than the originator.[20]

In summary, although not directly comparable, the results for $\rho < 1$ are consistent with the basic model in that the most productive originators share. However, the results for $\rho > 1$ show that the pattern of collaboration can be very different in the absence of production synergies.

### 5.3 Incomplete information

We now discuss a version of the game in which each agent is uncertain of the other's productivity. We retain the fixed reward, but make three simplifying modifications. First, we do not consider referrals. Second, A1 is assumed to always work. Third, uncertainty over productivity eliminates the need for $\epsilon$ in the basic model; thus, we assume A$i$ wins the prize if $x_i > x_{-i}$.

[19] In the linear case, $\rho = 1$, the propensity to share does not depend on $\theta_1$, and depends only on the size of the prize $\beta$ relative to the policy motivation $m$.

[20] We also consider a second case where the originator can choose $t$ identical agents (i.e., with $\theta_i = \theta$) to partner with. This objective is simpler than that with heterogeneous agents, and so it is straightforward to show that there is less sharing as the prize becomes relatively more important. Somewhat more interestingly, there is never an interior solution, and so the originator will share with either no agents or all agents.

The model might therefore describe a situation in which the originator is required to work on a project, but still decides whether to share jurisdiction or not. In this environment, the originator's sharing decision serves a signal of the originator's productivity.

In the perfect Bayesian equilibrium of this game, sufficiently productive originators share and sufficiently productive partners work. The prize $\beta$ plays a role similar to that in the basic model. Low values of $\beta$ are undesirable because they provide A2 with too little incentive to work, but high values are also undesirable as they decrease A1's propensity to share jurisdiction. As in the fixed-prize model, for a given $\beta$, less productive originators are the ones responsible for turf wars.[21]

## 6 Discussion

The goal of this paper is largely positive: we attempt to formalize the popular notion of turf wars in organizations. As we argue, the minimal necessary components of a turf war are joint production, competition, and property rights over jurisdiction. From this starting point, our model produces a unique equilibrium in which high-productivity originators share and high-productivity partners exert effort. One implication is that turf battles hurt most when collaboration is most needed; that is, when originators have moderate productivity. Perhaps most prominently, it shows that the reward from competition, $\beta$, can both help and hurt collaboration. While competition always mitigates moral hazard and free riding by inducing effort, high levels of competition can encourage originators to "go it alone."

Despite their ubiquity, turf wars are difficult to observe directly. In fact, inefficient lack of cooperation is present and most prominent precisely when the failure to share a task is hard to monitor and hence discipline directly. Our experiment therefore sought to test the model's predictions about originator sharing behavior when there is an able partner willing to work. Consistent with a host of previous results, subjects cooperated somewhat more often than predicted by the model. Yet the main predictions about the role of competitive versus policy-motivated incentives are supported, and in particular there is support for the non-monotonic effects of competitive rewards on collaboration.

[21]Note that in the incomplete information model whether sharing (keeping) results in collaboration (a turf war) depends on the drawn value of $\theta_2$. That is, except in the limiting case where full sharing occurs and $k \to 0$, there is a set A2s with sufficiently productivity who do not find it optimal to provide effort.

While we view our basic model as capturing a necessary and sufficient condition for turf wars, other factors may also matter. Agents are limited by being unable to strike bargains to divide the surplus with either each other or the principal. We also do not consider organizational solutions such as the selection of agent types, or incentives provided through oversight or contracts. Yet, the model allows us to speculate on some possible remedies. For example, a principal could use a performance cutoff below which $\beta$ is not awarded to any agent. This scheme might correspond to an organization's implicit threat to fill a higher position with an outsider rather than promoting from within. This might produce collaboration by reducing the payoff from autarchy, but it may also reduce the incentive of certain agent types to work.

Another important question concerns the way in which effort is aggregated. In our game theoretic model, outputs are perfect substitutes. However, our decision theoretic extension suggests the possibility that returns to scale and complementarities might affect sharing patterns in a way that our other extensions did not. In an environment with rapidly diminishing returns to collaborative effort, a hypothetical principal might actually want autarchy.

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# Appendices (for online publication)

## A Proofs

### Proof of Lemma 1

We can rewrite

$$\theta^H \equiv \frac{-\left(m+\frac{\beta}{2}\right)+\sqrt{\left(m+\frac{3}{2}\beta\right)^2+2\beta\left(k-(m+\beta)\right)}}{\beta}$$

It is then easily verified that $k = m + \beta$ iff $\theta^L = \theta^H = 1$, and $k = 0$ iff $\theta^L = \theta^H = 0$. The rest is straightforward, as squaring both sides we obtain.

$$\begin{aligned}
\theta^H \equiv \frac{-\left(m+\frac{\beta}{2}\right)+\sqrt{(m+\frac{\beta}{2})^2+2\beta k}}{\beta} &> \frac{k}{m+\beta} \equiv \overline{\theta} \\
\sqrt{\left(m+\frac{\beta}{2}\right)^2+2\beta k} &> \frac{k\beta}{m+\beta}+\left(m+\frac{\beta}{2}\right) \\
1 &> \frac{k}{m+\beta}
\end{aligned}$$

Since $k < m + \beta$, we have $0 < \theta^L < \theta^H < 1$ ■

### Proof of Proposition 1

(i) and (ii) are derived in the text. For (iii), A2 always works as $\theta_2 \in (\theta^H, 1)$, so we have three cases.

1. For $\theta_1 \in (0, \theta^L)$, A1 does not work. Since A2 works if she has jurisdiction, A1 receives zero from keeping and strictly positive utility from sharing. Thus the outcome is delegation.
2. For $\theta_1 \in (\theta^H, 1)$ A1 always works and prefers keep (resulting in autarchy) over share (resulting in collaboration) if

$$m(\theta_1+\theta_2)+\beta(\theta_1+\theta_2)\,\omega_1(\theta_1,\theta_2)-k \quad < \quad (m+\beta)\theta_1-k \tag{A1}$$

$$\beta\theta_1^2-\beta\theta_1+\beta\theta_2(1-\theta_2)+2m\theta_2 \quad < \quad 0 \tag{A2}$$

   The solutions ($\theta^-$, $\theta^+$) to (A2) for $\theta_1$ are given by (6). Hence, if $\theta_1 < \theta^-$ or $\theta_1 > \theta^+$, then A1 shares. If $\theta_1 \in (\theta^-, \theta^+)$ then A1 keeps. If $\theta^-$ and $\theta^+$ are not real-valued, then A1 shares.

3. For $\theta_1 \in (\theta^L, \theta^H)$, A1 prefers share (resulting in delegation) to keep (resulting in autarchy) if

$$\begin{aligned} m\theta_2 + \beta\theta_2\,\omega_1(0,\theta_2) &\geq (m+\beta)\theta_1 - k \\ \theta_1 &\leq \tilde{\theta} \equiv \frac{m\theta_2 + \beta\theta_2\frac{1-\theta_2}{2} + k}{m+\beta} \end{aligned} \tag{A3}$$

Since $\tilde{\theta} > \theta^L$ always, this case breaks into two subcases:

3a. $\tilde{\theta} > \theta^H$, so $\tilde{\theta}$ is irrelevant: A1 delegates always in this region, hence at $\theta_1 = \theta^H$ A1, by definition indifferent between collaboration and delegation, prefers either over autarchy. If either $\theta^-$ and $\theta^+$ are not real-valued, or $\theta^+ < \theta^H$, then A1 does not choose keep for any $\theta_1 > \theta^H$. Combining the previous cases, the outcomes are

$$\begin{cases} \text{delegation} & \text{if } \theta_1 \in \left(0, \theta^L\right) \\ \text{delegation} & \text{if } \theta_1 \in \left(\theta^L, \theta^H\right) \\ \text{collaboration} & \text{if } \theta_1 \in \left(\theta^H, 1\right). \end{cases}$$

And when $\theta^-$ and $\theta^+$ are real-valued and $\theta^+ > \theta^H$ we have

$$\begin{cases} \text{delegation} & \text{if } \theta_1 \in \left(0, \theta^L\right) \\ \text{delegation} & \text{if } \theta_1 \in \left(\theta^L, \theta^H\right) \\ \text{collaboration} & \text{if } \theta_1 \in \left(\theta^H, \theta^-\right) \\ \text{autarchy (turf war)} & \text{if } \theta_1 \in (\theta^-, \theta^+) \\ \text{collaboration} & \text{if } \theta_1 \in (\theta^+, 1). \end{cases}$$

The region $(\theta^H, \theta^-)$ is possibly empty, in which case the autarchy region is $(\theta^H, \theta^+)$. Combining outcomes yields the result.

3b. $\tilde{\theta} < \theta^H$, so $\tilde{\theta}$ is relevant: A1 delegates for $\theta_1 < \tilde{\theta}$ and keeps otherwise. Hence at $\theta_1 = \theta^H$ A1, by definition indifferent between collaboration and delegation, prefers keep over either. It is straightforward to verify that $\theta^+$ and $\theta^-$ are always real-valued in this case. Combining the previous cases, the outcomes are

$$\begin{cases} \text{delegation} & \text{if } \theta_1 \in (0, \theta^L) \\ \text{delegation} & \text{if } \theta_1 \in (\theta^L, \tilde{\theta}) \\ \text{autarchy (turf war)} & \text{if } \theta_1 \in (\tilde{\theta}, \theta^H) \\ \text{autarchy (turf war)} & \text{if } \theta_1 \in (\theta^H, \theta^+) \\ \text{collaboration} & \text{if } \theta_1 \in (\theta^+, 1) \end{cases}$$

The region $(\theta^H, \theta^+)$ is possibly empty, in which case there can be no autarchy for any $\theta_1 > \theta^H$, so the autarchy region is $(\tilde{\theta}, \theta^H)$ and the collaboration region is $(\theta^H, 1)$. Combining outcomes yields the result ■

**Proof of Proposition 2**

Rewriting the thresholds so that $2m + \beta = W$ yields

$$
\begin{aligned}
\theta^L &= \frac{k}{m+\beta} = \frac{2k}{W+\beta} \\
\theta^H &= \frac{2k}{\left(m+\frac{\beta}{2}\right) + \sqrt{(m+\frac{\beta}{2})^2 + 2\beta k}} = \frac{2k}{W/2 + \sqrt{(W/2)^2 + 2\beta k}} \\
\tilde{\theta} &= \frac{m\theta_2 + \beta\theta_2(1-\theta_2)/2 + k}{m+\beta} = \theta_2^2\left(-1 + W\frac{1+1/\theta_2}{W+\beta}\right) + \frac{2k}{W+\beta} \\
\theta^- &= \frac{1}{2} - \sqrt{\frac{1}{4} - \theta_2\left(\frac{W}{\beta} - \theta_2\right)} \\
\theta^+ &= \frac{1}{2} + \sqrt{\frac{1}{4} - \theta_2\left(\frac{W}{\beta} - \theta_2\right)}
\end{aligned}
$$

From these expressions it is clear that $\theta^L$, $\theta^H$, $\tilde{\theta}$, and $\theta^-$ are decreasing in $\beta$, while $\theta^+$ is increasing in $\beta$. Additionally, $\theta^L$, $\theta^H$, and $\tilde{\theta}$ are increasing in $k$, while $\theta^-$ are $\theta^+$ are constant in $k$. The results on the regions follow from these relationships ■

# B Extensions

In this section, we describe and solve the variations of our basic game that are discussed in the main body of the paper. All proofs are provided at the end of each extension.

## B.1 Fixed prize

The model with a fixed prize is identical to the basic model, with the exception that the prize for victory is simply $\beta$ instead of $\beta(x_1 + x_2)$. We retain the assumption that no prize is given when neither agent exerts effort.

In the second period, the effort decision is qualitatively similar to the one obtained in the variable prize case. Following A1's choice to share, A$i$ works when her counterpart works if $m(\theta_1 + \theta_2) + \beta\,\omega_i(\theta_i, \theta_{-i}) - k \geq m\theta_{-i} + \beta\,\omega_i(0, \theta_{-i})$. Likewise, A$i$ works when her partner does not work if $m\theta_i + \beta\,\omega_i(\theta_i, 0) - k \geq 0$. As in the basic model, both of these expressions evaluate to the same threshold value for $\theta_i$, which we define as follows

$$\theta_i \geq \theta_f^H \equiv \frac{k}{m + \frac{\beta}{2}}. \tag{B4}$$

It is also straightforward to verify that when A$i$'s partner does not work, then A$i$ will work if $\theta_i$ exceeds the following threshold.

$$\theta_i \geq \theta_f^L \equiv \frac{k-\beta}{m}. \tag{B5}$$

The thresholds $\theta_f^H$ and $\theta_f^L$ work analogously to the thresholds $\theta^H$ and $\theta^L$ in the basic model. For $\theta_i < \theta_f^L$, A$i$ exerts no effort, and for $\theta_i > \theta_f^H$, A$i$ always exerts effort. For $\theta_i \in (\theta_f^L, \theta_f^H)$, A$i$ works only if she has sole jurisdiction. Again, each agent is more inclined to work when she has sole jurisdiction as opposed to shared jurisdiction, since the latter entails a positive probability of losing $\beta$ even when the partner exerts no effort.

A1's first period strategy anticipates A2's effort response. The next proposition summarizes outcomes and comparative statics for all combinations of $\theta_1$ and $\theta_2$. The result makes use of the following notation. For $\theta_1 \in (\theta_f^L, \theta_f^H)$, A1 is indifferent between keeping and sharing at the following threshold for $\theta_1$:

$$\theta_f^- \equiv \frac{k-\frac{\beta}{2}}{m} + \theta_2\left(1-\frac{\beta}{2m}\right). \tag{B6}$$

It is straightforward to verify that $\theta_f^- > \theta_f^L$. Next, for $\theta_1 > \theta_f^H$, A1 is indifferent between keeping and sharing at the following threshold for $\theta_1$:

$$\theta_f^+ \equiv 1 + \theta_2\left(1-\frac{2m}{\beta}\right). \tag{B7}$$

**Proposition B1 (Outcomes under fixed prize)**

*(i) If* $\theta_2 \in (0, \theta_f^L)$ *then*

$$\begin{cases} \textit{indifference} & \textit{if } \theta_1 < \theta_f^L \\ \textit{autarchy} & \textit{if } \theta_1 > \theta_f^L. \end{cases}$$

*(ii) If* $\theta_2 \in (\theta_f^L, \theta_f^H)$ *then*

$$\begin{cases} \textit{referral} & \textit{if } \theta_1 < \left(\theta_2 + \theta_f^L\right) \\ \textit{autarchy}^* & \textit{if } \theta_1 > \left(\theta_2 + \theta_f^L\right). \end{cases}$$

*(iii) If* $\theta_2 \in (\theta_f^H, 1)$ *then*

$$\begin{cases} \textit{delegation}^* & \textit{if } \theta_1 < \min\{\theta_f^-, \theta_f^H\} \\ \textit{turf war}^* & \textit{if } \theta_1 \in \left(\min\{\theta_f^-, \theta_f^H\}, \min\{\max\{\theta_f^+, \theta_f^H\}, 1\}\right) \\ \textit{collaboration}^* & \textit{if } \theta_1 > \max\{\theta_f^+, \theta_f^H\}, \end{cases}$$

*where (*) denotes regions that may be empty.*

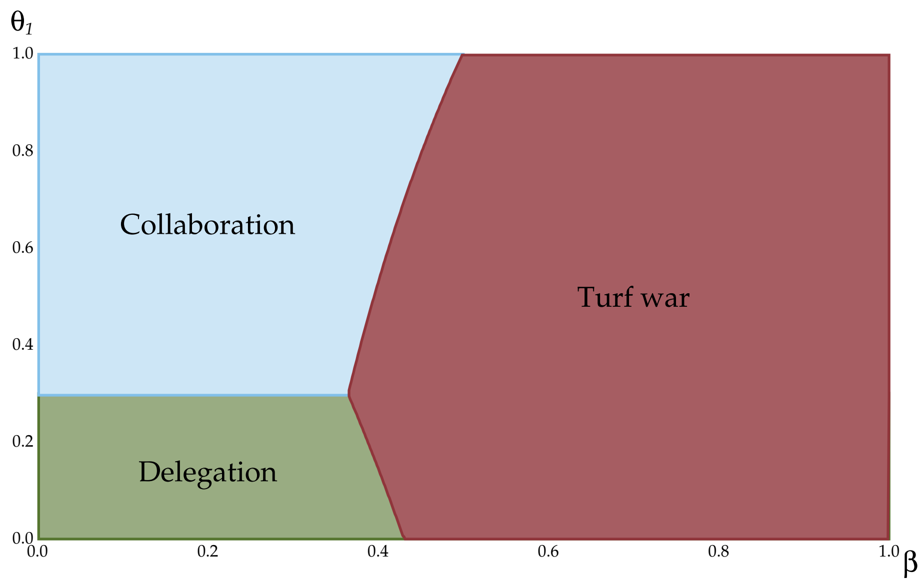



**Figure B1. Fixed prize outcomes as a function of $\beta$ and $\theta_1$**

*Note:* Here $2m + \beta = 1$, $k = 0.15$, and $\theta_2 = 0.95$, which ensures that A2 always works when given jurisdiction. Compared to the variable-prize model, the independence of the size of the reward on collaboration increases the range of parameters under which turf wars occur.

The main findings are analogous to those of the basic model. For $\theta_2 < \theta_f^H$, A1s with high productivity prefer autarchy, while those with low productivity prefer indifference or, when A2 is willing to work under sole jurisdiction, referral. Sharing occurs only if $\theta_2 > \theta_f^H$, in which case turf wars occur for "intermediate" values of $\theta_1$: the originator chooses to keep jurisdiction because sharing would greatly reduce her chances of receiving the prize to a high-ability partner. By contrast, when the originator's productivity is low enough to make her either unwilling to exert effort or unlikely to win, the result is delegation. Finally, when the originator's productivity level guarantees a sufficiently high probability of winning the prize, the result is collaboration.

The comparative statics on outcomes behave in an intuitive manner, and resemble those of the basic model. When the value of the prize is high relative to the common value payoff (i.e., $\beta > 2m$), there is no collaboration. Higher values of $\beta$ enlarge the set of $\theta_1$ values for which there is a turf war and correspondingly reduce delegation. For $\beta < 2m$ there is collaboration, and collaboration is increasingly desirable to the originator as $\theta_2$ decreases. Finally, as $k$ increases, the set of $\theta_1$ values resulting in delegation expands. Figure B1 illustrates some of these relationships, using the same parameters as in Figure 1.

We note finally that in the special case where effort is costless ($k = 0$), the fixed prize model produces a simpler equilibrium than the basic model. In both models, both agents work when they have jurisdiction, and thus the only possible results are collaboration and autarchy. With a fixed prize, low productivity originators will keep (resulting in autarchy), while high productivity originators will share (resulting in collaboration). By contrast, in the basic model, Proposition 1(ii) shows that the lowest-type originators share as well. Intuitively, the prize being fixed means it is guaranteed in autarchy even to low ability types who, unlike what happened in the basic model, now no longer have to use the work of higher ability collaborators to successfully complete the project.

**Proof of Proposition B1**

Second period strategies are characterized above. In the first period:

(i) When $\theta_2 \in (0, \theta_f^L)$, A1 anticipates no effort from A2. A1 therefore works if $\theta_1 > \theta_f^L$ (resulting in indifference), and does not work otherwise (resulting in autarchy).

(ii) When $\theta_2 \in (\theta_f^L, \theta_f^H)$, sharing results in no effort by A2. Thus, A1 keeps if she prefers to work herself, and refers if she prefers that A2 work alone, or $m\theta_1 + \beta - k > m\theta_2$. This reduces to $\theta_1 > \theta_2 + \theta_f^L$. Thus, higher values of $\theta_1$ result in autarchy and lower values result in referral.

(iii) When $\theta_2 > \theta_f^H$, since A2 is guaranteed to work, delegation yields a higher payoff than referral. A1 therefore effectively decides over turf war, delegation, and collaboration, as follows. For $\theta_1 < \theta_f^L$, A1 exerts no effort and delegation is clearly her most preferred outcome; thus, she shares. For $\theta_1 \in (\theta_f^L, \theta_f^H)$, A1 exerts no effort when sharing. She then prefers keeping to sharing when $m\theta_1 + \beta - k > m\theta_2 + \beta\omega(0, \theta_2)$, or $\theta_1 > \theta_f^-$. Combining the subcases where $\theta_1 < \theta_f^H$, A1 shares for all $\theta_1 < \min\{\theta_f^-, \theta_f^H\}$, and keeps otherwise. Finally, for $\theta_1 > \theta_f^H$, A1 exerts effort when sharing. She the prefers sharing to keeping when $m(\theta_1 + \theta_2) + \beta\omega(\theta_1, \theta_2) - k > m\theta_1 + \beta - k$, or $\theta_1 > \theta_f^+$. Combining the outcomes from these regions produces the result ■

## B.2 Multiple agents and synergies

We next consider a version of the fixed prize model without moral hazard, namely in which agents automatically exert effort, as in the $k = 0$ case of the previous models. We generalize the model in two ways. First, we allow $n \geq 2$ agents, each with corresponding productivity $\theta_i \in (0, 1)$. To do this in a simple way we let $\sum \theta_i = 1$ and also let each A$i$'s probability of winning the prize $\beta$ be $\theta_i$ when all agents have jurisdiction. A1 remains the originator, and she can share with either all other agents or none. Second, we use the more general CES production function for determining output.

Since there is no effort choice, the problem reduces to A1's sharing decision and the only possible outcomes are turf war and collaboration (i.e., not sharing is obviously inefficient). Given sharing by A1, agent A$i$'s expected utility can be written as

$$u_i = m\left(\sum \theta_i^\rho\right)^{1/\rho} + \beta\theta_i.$$

Here $\rho > 0$ is the substitutability or complementarity of abilities. For example, if $\rho = 1$ then abilities are perfect substitutes, for $\rho < 1$ there are synergies in working together (the total ability is larger than the sum of the abilities), and conversely for $\rho > 1$. As in the basic fixed prize, zero effort cost game, the originator's utility from not sharing is simply $m\theta_1 + \beta$.

A1 shares if and only if

$$m\left(\left(\sum_{i=1}^{n}\theta_i^\rho\right)^{1/\rho} - \theta_1\right) > \beta\left(1-\theta_1\right).$$

It will then be convenient to express the condition for sharing as

$$A(\theta_1) \equiv \frac{\left(\sum_{i=1}^{n}\theta_i^\rho\right)^{1/\rho} - \theta_1}{1-\theta_1} > \frac{\beta}{m}.$$

$A(\theta_1)$ can be understood as a measure of the A1's net gain from sharing.

As in the preceding analysis, we are mainly interested in seeing how the originator's productivity affects the propensity to share. Since productivity levels sum to a constant, the results depend on how changes in $\theta_1$ affect $\theta_i$ for $i \neq 1$. One simple way to do this is to assign non-negative linear "weights" to each player's productivity parameter, of the following form:

$$\theta_i = \pi_i(1-\theta_1).$$

It is straightforward to derive each $\pi_i$. Note that $\theta_1 = 1 - \theta_i/\pi_i$ for each $i \neq 1$, which implies that $\theta_i/\pi_i$ is constant for all $i \neq 1$. Furthermore, to ensure that $\sum_i \theta_i = 1$, the weights $\pi_i$ must satisfy $\sum_{i\neq j}\pi_i = 1$. This implies that for each $i \neq 1$,

$$\sum_{k\neq j}\pi_k = \sum_{k\neq j}\frac{\theta_k}{\theta_i}\pi_i = 1,$$

and therefore we have the following unique weights for each pair

$$\pi_i = \frac{\theta_i}{\sum_{k\neq 1}\theta_k}.$$

This is simply agent $i$'s relative weight among the set of A2s. These weights imply that as $\theta_1$ increases, the remaining $\theta_i$'s must all shrink in proportion with their relative size. The first result presents the basic comparative statics of the model.

**Proposition B2 (Sharing with multiple agents and synergies)**

*(i) For any* $\theta_1 \in [0,1)$, $\rho \lesseqgtr 1 \Longrightarrow \frac{dA}{d\theta_1} \gtreqless 0$.

*(ii) For any* $\theta_1 \in (0,1)$, $\rho \lesseqgtr 1 \Longrightarrow A(\theta_1) \gtreqless 1$, *and*

$$A(0) = \begin{cases} 1 & \text{if } n = 2 \\ \lesseqgtr 1 \text{ if } \rho \gtreqless 1 & \text{if } n > 2. \end{cases}$$

*(iii)* $\frac{dA}{d\rho} < 0$.

Part (i) of Proposition B2 shows how synergies and A1's type matter for A1's sharing decision, and is the main point of comparison with the basic model. For $\rho < 1$ and $\beta/m$ sufficiently high, there is a "cutoff" value of $\theta_1$ above which A1 shares. This is consistent with the basic model, where the most productive A1s share, conditional upon being willing to work. From a welfare perspective this is a bad result, as it would be better for lower productivity A1s to share. For $\rho > 1$ and $\beta/m$ sufficiently low, however, the pattern is reversed: there is another cutoff value of $\theta_1$ *below* which A1 shares. Low type A1s also shared in some cases of the basic model, but always along with high types. Interestingly, in the linear case ($\rho = 1$) the propensity to share does not depend on $\theta_1$, and depends only on the agents' relative policy motivation. Thus with the caveat that the results are not directly comparable with those of the basic model because the values of $\theta_i$ are not independent, the result shows that the pattern of collaboration can be at least somewhat sensitive to the presence of production synergies. Part (ii) shows how the critical value for $\beta/m$ depends on synergies. For $n > 2$, values of $\beta/m$ very close to 1 can make sharing either optimal for all $\theta$ ($\rho < 1$) or not optimal for all $\theta$ ($\rho > 1$). Part (iii) simply establishes the intuitive result that the benefit of sharing is decreasing in $\rho$ (i.e., increasing in synergy). Thus, the greater the synergy, the more inclined A1 will be to share.

We finally consider what would happen if the originator could choose the set of agents she shares with. There are two cases. First, suppose that A1 can share the task with only one additional agent. As the probability of victory conditional upon sharing with A$k$ is $\theta_1/(\theta_1 + \theta_k)$, A1 would be willing to add agent A$k$ if

$$\begin{aligned} m\left(\theta_1^\rho + \theta_k^\rho\right)^{1/\rho} + \beta\frac{\theta_1}{\theta_1 + \theta_k} &> m\theta_1 + \beta \\ \left(\theta_1^\rho + \theta_k^\rho\right)^{1/\rho} - \theta_1 &> \frac{\theta_k}{\theta_1 + \theta_k}\left(\frac{\beta}{m}\right). \end{aligned}$$

Note that this expression is identical to that of the two-agent case when $\theta_1 + \theta_k = 1$. There are two effects of increasing $\theta_k$: increasing the probability of a successful outcome, and decreasing the probability of winning the award. The preceding expression can be rewritten as follows:

$$A(\theta_1, \theta_k) = (\theta_1 + \theta_k)\left[\left(\left(\frac{\theta_1}{\theta_k}\right)^\rho + 1\right)^{1/\rho} - \frac{\theta_1}{\theta_k}\right] > \frac{\beta}{m}. \tag{B8}$$

This expression implies that holding $\theta_1/\theta_k$ constant, sharing becomes harder as $\theta_1 + \theta_k$ shrinks. This happens because the contribution of sharing toward the collective outcome becomes smaller, while the probability of winning the prize remains the same. Likewise, holding $\theta_1 + \theta_k$ constant, sharing becomes easier (harder) as $\theta_1$ increases if $\rho < (>)\, 1$. The next comment characterizes A1's choice of a single partner.

**Comment B1 (Optimal partner)**

*For potential partner Ak:*

*(i) If $\rho < 1$, $\frac{\partial A}{\partial \theta_1} > 0$. If $\rho > 1$, $\frac{\partial A}{\partial \theta_1} > 0$ if $\theta_1 \leq \theta_k$ and $\rho$ sufficiently large;* $\lim_{\rho \to \infty} \frac{\partial A}{\partial \theta_1} = 0$ *if $\theta_1 > \theta_k$.*

*(ii) If $\rho > 1$, $\frac{\partial A}{\partial \theta_k} > 0$. If $\rho < 1$, $\frac{\partial A}{\partial \theta_k} > 0$ if $\theta_1 \leq \theta_k$;* $\lim_{\rho \to \infty} \frac{\partial A}{\partial \theta_k} < 0$ *if $\theta_1 > \theta_k$.*

Part (i) considers A1's productivity. When $\rho < 1$ (i.e., there are synergies), high productivity A1s will be more inclined to share with a given partner. The results are weaker when $\rho > 1$ but A1s with high productivity will often do better in a partnership than those with low productivity. Part (ii) considers the more interesting question of whom A1 would choose. Often more productive partners are preferred. Interestingly, when $\rho > 1$ A1 prefers partners with high productivity because the expected loss in the victory bonus is now offset by productivity gains. This is also true when $\rho < 1$ and potential partners are more productive than A1. The relationship may be reversed if potential partners are less productive than A1.

Next, consider a second case where the originator can choose $t$ agents to partner with, but all agents are identical ($\theta_i = \theta$). Thus, the originator's objective is

$$L(t) \equiv m\left(t\left(\frac{1}{n}\right)^\rho\right)^{1/\rho} + \frac{\beta}{t}. \tag{B9}$$

where $t \in \{1, \ldots, n\}$.

This objective is considerably simpler than that with heterogeneous agents, and so it is straightforward to derive the following comment.

**Comment B2 (Optimal number of homogeneous partners)**

*If $\frac{\beta}{m} \geq \frac{n^{1/\rho}-1}{n-1}$, then $t^* = 1$; otherwise, $t^* = n$.*

As intuition would suggest, when the bonus from victory is relatively important, then there is less sharing. Somewhat more interestingly, there is never an interior solution, and so the originator will share with either no agents or all agents.

**Proof of Proposition B2**

(i) Letting $k_1 = \theta_1/(1-\theta_1)$, this gives us:

$$\begin{aligned} A(\theta_1) &= \frac{\left(\theta_1^\rho + \sum_{i\neq 1}(\pi_i(1-\theta_1))^\rho\right)^{1/\rho} - \theta_1}{1-\theta_1} \\ &= \left(k_1^\rho + \sum_{i\neq 1}(\pi_i)^\rho\right)^{1/\rho} - k_1. \end{aligned}$$

$A(\theta_1)$ has the same sign as $\frac{dA}{dk_1}$. The derivative with respect to $k_1$ is

$$\begin{aligned} \frac{dA}{dk_1} &= \left(k_1^\rho + \sum_{i\neq 1}(\pi_i)^\rho\right)^{\frac{1-\rho}{\rho}} k_1^{\rho-1} - 1 \\ &= \left(1 + k_1^{-\rho}\sum_{i\neq 1}(\pi_i)^\rho\right)^{\frac{1-\rho}{\rho}} - 1, \end{aligned}$$

which is positive (zero) (negative) if

$$\frac{1-\rho}{\rho}\ln\left(1 + k_1^{-\rho}\sum_{i\neq 1}(\pi_i)^\rho\right) > (=)(<)\, 0.$$

Since the term in parentheses is greater than 1, $\frac{dA}{dk_1} > (=)(<)\, 0$ if $\rho < (=)(<)\, 1$.

(ii) Note first that

$$A(0) = \left(\sum_{i\neq 1}(\pi_i)^\rho\right)^{1/\rho}.$$

For $n = 2$, there is only one term in the summation, and $\pi_i = 1$, so $A(0) = 1$. For $n > 2$, since $\sum_{i\neq 1}\pi_i = 1$, it is clear that $A(0) > (=)(<)\, 1$ if $\rho < (=)(>)\, 1$. Finally, since $A'(\theta_1) > (=)(<)\, 0$ for $\rho < (=)(>)\, 1$, we have $A(\theta_1) > (=)(<)\, 1$ when $\rho < (=)(>)\, 1$ for $\theta_1 > 0$.

(iii) Let $\tilde{A}(\rho) = \left(k_1^\rho + \sum_{i\neq 1}(\pi_i)^\rho\right)^{1/\rho}$, which has the same derivative as $A(\cdot)$ with respect to $\rho$. Differentiating $\tilde{A}(\theta_1)$ with respect to $\rho$, we obtain

$$\frac{1}{\tilde{A}}\frac{d\tilde{A}}{d\rho} = \frac{1}{\rho}\frac{k_1^\rho \ln k_1 + \sum_{i\neq 1}(\pi_i)^\rho \ln \pi_i}{k_1^\rho + \sum_{i\neq 1}(\pi_i)^\rho} - \frac{1}{\rho^2}\ln\left(k_1^\rho + \sum_{i\neq 1}(\pi_i)^\rho\right).$$

Observe that $\tilde{A}(\rho) > 0$ for all $\rho$, and therefore $\frac{d\tilde{A}}{d\rho}$ is negative if

$$\frac{k_1^\rho \ln k_1 + \sum_{i\neq 1}(\pi_i)^\rho \ln \pi_i}{k_1^\rho + \sum_{i\neq 1}(\pi_i)^\rho} < \frac{1}{\rho} \ln \left( k_1^\rho + \sum_{i\neq 1} (\pi_i)^\rho \right).$$

Since $\pi_i > 0$ for all $i$ and $\ln \pi_i < 0$, the left-hand side of the expression above is strictly less than $\ln k_1$. And since $\pi_i > 0$ for all $i$, the right-hand side is strictly greater than $\ln k_1$, thus establishing the result ■

**Proof of Comment B1**

(i) As derived in the proof of Proposition B2, the bracketed expression in (B8) is positive and increasing in $\theta_1$ if $\rho < 1$. It follows that $A(\theta_1, \theta_k)$ is increasing in $\theta_1$ if $\rho \leq 1$. For $\rho > 1$, we differentiate with respect to $\theta_1$, and so $\frac{\partial A}{\partial \theta_1} < (>)\, 0$ if

$$(\theta_1 + \theta_k) \left[ \left( \left( \frac{\theta_1}{\theta_k} \right)^\rho + 1 \right)^{1/\rho - 1} \left( \frac{\theta_1}{\theta_k} \right)^{\rho - 1} \frac{1}{\theta_k} - \frac{1}{\theta_k} \right] + \left( \left( \frac{\theta_1}{\theta_k} \right)^\rho + 1 \right)^{1/\rho} - \frac{\theta_1}{\theta_k} \quad < (>) \quad 0.$$

Following the proof of Proposition B2, the bracketed expression is negative for $\rho > 1$, while $\left( \left( \frac{\theta_1}{\theta_k} \right)^\rho + 1 \right)^{1/\rho} - \frac{\theta_1}{\theta_k}$ is positive. Letting $k = \theta_1/\theta_k$ and simplifying, we have $\frac{\partial A}{\partial \theta_1} < (>)\, 0$ if

$$\frac{1}{(k^\rho + 1)^{1 - 1/\rho}} - \frac{2k + 1}{2k^\rho + k^{\rho - 1} + 1} < (>)\, 0.$$

There are two cases. First, suppose $k \leq 1$ (i.e., $\theta_1 < \theta_k$). Since $(k^\rho + 1)^{1/\rho - 1} \leq 1$, it follows that $\frac{dA}{d\theta_1} < 0$ if: $2k^\rho + k^{\rho-1} < 2k$, or $k^{\rho - 1} < 2k/(2k + 1)$. This is clearly satisfied for $\rho$ sufficiently large. Second, suppose $k > 1$. The limits of both fractions in the above expression as $\rho \to \infty$ are clearly 0. Thus $\lim_{\rho \to \infty} \frac{\partial A}{\partial \theta_1} = 0$.

(ii) As derived in the proof of Proposition B2, the bracketed expression in (B8) is positive and increasing in $\theta_k$ if $\rho > 1$. It follows that $A(\theta_1, \theta_k)$ is increasing in $\theta_k$ if $\rho \geq 1$. For $\rho < 1$, we differentiate with respect to $\theta_k$ and substitute $k = \theta_1/\theta_k$:, which gives

$$\begin{aligned} \frac{\partial A}{\partial \theta_k} &= (\theta_1 + \theta_k) \left[ - \left( \left( \frac{\theta_1}{\theta_k} \right)^\rho + 1 \right)^{1/\rho - 1} \left( \frac{\theta_1^\rho}{\theta_k^{\rho+1}} \right) + \frac{\theta_1}{\theta_k^2} \right] + \\ &\quad \left( \left( \frac{\theta_1}{\theta_k} \right)^\rho + 1 \right)^{1/\rho} - \frac{\theta_1}{\theta_k} \\ &= k^2 - (k^\rho + 1)^{1/\rho - 1} k^\rho (k + 1) + (k^\rho + 1)^{1/\rho}. \end{aligned}$$

Thus $\frac{\partial A}{\partial \theta_k} > (<)\, 0$ if

$$k^2 > (<)\, (k^\rho + 1)^{1/\rho} \left[ \frac{k^\rho (k+1)}{k^\rho + 1} - 1 \right].$$

There are two cases. First, suppose $k \leq 1$. Then $\frac{\partial A}{\partial \theta_k} > 0$ if $k^\rho(k+1) \leq k^\rho + 1$, or $k^{\rho+1} \leq 1$, which holds for any $\rho > 0$. Second, suppose $k > 1$. Since $\lim_{\rho \to \infty}(k^\rho + 1)^{1/\rho} = k$, we have $\lim_{\rho \to \infty} \frac{\partial A}{\partial \theta_k} < 0$ if $\lim_{\rho \to \infty} \frac{k^\rho(k+1)}{k^\rho+1} > k+1$. Applying L'Hopital's Rule yields $\lim_{\rho \to \infty} \frac{k^\rho(k+1)}{k^\rho+1} = \frac{(k+1)k^\rho \ln k + k^\rho}{k^\rho \ln k} = k + 1 + \frac{1}{\ln k}$, thus proving the result ■

**Proof of Comment B2**

We first give the condition under which A1 prefers 1 partner to $n$ partners. This is the case if

$$\begin{aligned} \frac{m}{n} + \beta &\geq mn^{1/\rho - 1} + \frac{\beta}{n} \\ \frac{\beta}{m} &\geq \frac{n^{1/\rho} - 1}{n - 1}. \end{aligned} \tag{B10}$$

Next we derive conditions under which A1's objective is either strictly increasing or decreasing. Differentiating the objective $L(t)$ (see (B9)) yields $L'(t) = mt^{1/\rho - 1}/(n\rho) - \beta t^{-2}$. This implies that $L'(1) = m/(n\rho) - \beta$, which is positive if $\beta/m < 1/(n\rho)$. Note also that $L'(t) > 0$ for all $t \in [1, n]$ if $mt^{1/\rho+1}/(n\rho) - \beta > 0$. Since this expression is increasing in $t$, it follows that $L'(t) > 0$ for all $t \in [1, n]$ iff $L'(1) > 0$. Likewise, $L'(n) < 0$ if $\beta/m > n^{1/\rho}/\rho$, and $L'(t) < 0$ for all $t \in [1, n]$ iff $L'(n) < 0$.

Thus, there can only be a corner solution (B10) if $\beta/m \notin [1/(n\rho), n^{1/\rho}/\rho]$. Moreover, for $\beta/m$ in this interval, $L'(1) < 0$ and $L'(n) > 0$. By the continuity of $L(\cdot)$, this implies that there cannot be a local interior maximum if there is a unique $t$ for which $L'(t) = 0$. Manipulating $L'(t)$, we have $L'(t) = 0$ if

$$t^{1/\rho + 1} = \frac{\beta \rho n}{m},$$

which implies a unique $t$. Hence the maximum must be at a corner, which again implies that the solution is characterized by condition (B10) ■

## B.3 Incomplete Information

We now discuss a version of the game in which each agent is uncertain of the other's productivity. Specifically, suppose that $\theta_i \sim U[0, 1]$ for agent A$i$. In this environment, the originator's sharing decision serves a signal of the originator's productivity.

We retain the fixed reward and make three other modifications to further simplify the analysis. First, we do not consider referrals. Second, A1 is assumed always to work, with her effort level denoted simply by $e$. Conditional upon A$i$ having jurisdiction, output $x_i$ is then

$$\begin{aligned} x_1 &= \theta_1 \sim U[0,1] \\ x_2 &= \begin{cases} \theta_2 \sim U[0,1] & \text{if } e = 1 \\ 0 & \text{if } e = 0. \end{cases} \end{aligned}$$

Third, uncertainty over productivity eliminates the need for $\epsilon$ in the basic model; thus, agent A$i$ wins the prize $\beta$ if $x_i > x_{-i}$. The model might therefore describe a situation in which A1 is formally required to work on a project, but might still share jurisdiction.

We characterize a perfect Bayesian equilibrium of this game. As the subsequent derivations show, there is essentially a unique equilibrium. Formally, strategies consist of A1's sharing choice $s \in \{\text{share}, \text{keep}\}$ and A2's effort level $e \in \{0,1\}$ conditional upon having jurisdiction. A2 also has posterior beliefs over $\theta_1$ given A1's sharing decision, denoted $\rho : \{\text{share}, \text{keep}\} \to \mathcal{P}$, where $\mathcal{P}$ is the set of measurable subsets of $[0,1]$. These beliefs are consistent with Bayes' rule along the equilibrium path. An out of equilibrium information set can only be encountered if A1 shares when she was not expected to do so. In these cases, we simply assume that A2's beliefs are concentrated on $\theta_1 = 1$. Although the equilibrium does not require such extreme beliefs, this designates the type that would benefit most from sharing, since she would win with probability one.

We begin by considering the subgame following A1's choice to share, where agent A2 has posterior beliefs about A1's productivity that are uniformly distributed on the interval $(\underline{\theta}, \overline{\theta}]$. While this is not a fully general treatment of A2's possible beliefs, we will subsequently argue that A1's sharing strategies are monotonic and therefore must take this form in equilibrium.

A2 works if

$$m\,(E[\theta_1|\,\text{share}] + \theta_2) - k + \beta\,\omega(\underline{\theta}, \overline{\theta}, \theta_2, e) > mE[\theta_1|\,\text{share}]. \tag{B11}$$

Here $\omega(\underline{\theta}, \overline{\theta}, \theta_2, e)$ represents the probability that A2 wins. The uniform distribution implies that

$$\omega(\underline{\theta}, \overline{\theta}, \theta_2, 1) = \begin{cases} 0 & \text{if } \theta_2 < \underline{\theta} \\ \frac{\theta_2 - \underline{\theta}}{\overline{\theta} - \underline{\theta}} & \text{if } \theta_2 \in [\underline{\theta}, \overline{\theta}] \\ 1 & \text{if } \theta_2 > \overline{\theta}, \end{cases}$$

and expression (B11) simplifies to

$$m\theta_2 + \beta\,\omega(\underline{\theta}, \overline{\theta}, \theta_2, e) > k.$$

As intuition would suggest, working becomes more attractive to A2 as $m$, $\theta_2$ and $\beta$ increase, and less attractive as $k$ increases. The expression implies that for any $(\underline{\theta}, \overline{\theta}]$, there is a unique type $\hat{\theta}_2$ such that higher productivity types work and lower productivity types shirk. This type is given by

$$\hat{\theta}_2 = \begin{cases} \frac{k}{m} & \text{if } \underline{\theta} \geq \frac{k}{m} \\ \min\left\{1, \frac{k(\overline{\theta}-\underline{\theta})+\beta\underline{\theta}}{m(\overline{\theta}-\underline{\theta})+\beta}\right\} & \text{if } \underline{\theta} < \frac{k}{m}. \end{cases} \tag{B12}$$

The first line of (B12) gives a corner case where A2 is indifferent between working and not even though she expects to lose $\beta$ with certainty. Thus, strong policy motivations alone can induce some types to work even when they expect to lose with certainty. The second line gives the interior case where the indifferent A2 expects to win with some probability. Because this set of types necessarily hits a corner at 1, this threshold must be weakly increasing in $\underline{\theta}$. Reducing the set of sharing originator types (i.e., increasing $\underline{\theta}$) therefore does not expand the set of partner types willing to work.

Given $\hat{\theta}_2$, the probability that A2 will work given $(\underline{\theta}, \overline{\theta}]$ is

$$\phi(\underline{\theta}, \overline{\theta}) = 1 - \hat{\theta}_2. \tag{B13}$$

And given $\theta_1$, the probability that A2 wins conditional upon working is

$$\xi(\theta_1) = \begin{cases} 1 & \text{if } \theta_1 \leq \hat{\theta}_2 \\ \frac{1-\theta_1}{1-\hat{\theta}_2} & \text{if } \theta_1 \geq \hat{\theta}_2. \end{cases} \tag{B14}$$

Note that if $\theta_1 < \hat{\theta}_2$, then the probability of A1 winning is zero.

We can now characterize A1's sharing decision. Suppose that in equilibrium, the set of sharing originators is $(\underline{\theta}, \overline{\theta}]$. Then A1 shares if

$$m\left(\theta_1 + \phi(\underline{\theta}, \overline{\theta})\frac{\hat{\theta}_2 + 1}{2}\right) + (1 - \phi(\underline{\theta}, \overline{\theta})\xi(\theta_1))\beta > m\theta_1 + \beta \tag{B15}$$

Simplifying, A1 shares if $\phi(\underline{\theta}, \overline{\theta}) > 0$ and

$$\frac{m(\hat{\theta}_2 + 1)}{2} - \xi(\theta_1)\beta > 0 \tag{B16}$$

There are two notable facts about this expression. First, it is independent of $\phi(\cdot)$ when $\phi(\cdot) \neq 0$. Second, it does not depend on the functional form of $\xi(\cdot)$; i.e., it applies to any measurable sharing strategy on $[0, 1]$. This implies an important monotonicity feature of sharing in equilibrium. If any type $\theta_1'$ shares in equilibrium, then all higher types will also be willing to share. To see why, suppose that some type $\theta_1'' > \theta_1'$ does not share. By sharing out of equilibrium, she would not affect A2's strategy, and so would only affect A2's chances of winning. Thus, type $\theta_1''$ would automatically satisfy (B16) if type $\theta_1'$ does.

The immediate consequence of the monotonicity of sharing incentives is that when sharing occurs, the set of sharing types is simply $(\underline{\theta}, 1]$. The final step in deriving the equilibrium is then to characterize $\underline{\theta}$. At an interior solution, this is the (unique) value of $\theta_1$ that satisfies (B16) with equality. Higher values of $\underline{\theta}$ imply lower levels of sharing. There are also corner solutions, where either no types or all types share.

Our next result describes the outcomes of the incomplete information game. Note that a difference between these results and those of preceding versions of the game is that collaboration and turf wars can only be probabilistic as they depend on the specific realization of $\theta_2$. That is, a set of sufficiently low types of A2 will find the utility gains from working to not warrant the effort. Thus, except in the limiting case where full sharing occurs and $k \to 0$, there is no equilibrium in which A2 always works. We therefore label outcomes where A1 shares and A2 works with positive probability as "possible collaboration" and those where A1 does not share but A2 would work with positive probability as a "possible turf war."

**Proposition B3 (Outcomes under incomplete information)**

*(i) (Indifference) If $\beta \leq k - m$, then the outcome is indifference.*

*(ii) (Possible turf war) If $\beta > k - m$ and $m < \min\{k, \beta\}$, then A1 keeps for all $\theta_1$.*

*(iii) (Possible collaboration) If $\beta \in \left(k - m, \frac{-m+\sqrt{m^2+8m(k+m)}}{4}\right)$, then A1 shares for all $\theta_1$.*

*(iv) (Possible collaboration and turf war) If the conditions of parts (i)-(iii) are not met, then the set of sharing types is $(\underline{\theta}^*, 1]$, where*

$$\underline{\theta}^* = \begin{cases} \frac{m(k-\beta+m)-2\beta^2}{m(k-3\beta+m)} & \text{if } m \leq k \text{ and } m \geq \beta, \text{ or } m > k \text{ and } \frac{k+m}{2} > \beta \\ 1 - \frac{m(1-(k/m)^2)}{2\beta} & \text{otherwise.} \end{cases}$$

Proposition B3 provides some basic intuitions about the effects of turf battles on sharing. Part (i) shows that the conditions generating indifference—low $\beta$, high $k$, and low $m$—are similar to those in Proposition 1. Parts (ii) and (iii) are the corner cases; in the former, autarchy is always the result because all A1 types play keep because $\beta$ is sufficiently high. In the latter, all types of A1 share because $\beta$ is moderate and $m$ is high. Finally, part (iv) is the interior solution, where autarchy results for low values of $\theta_1$ and possible collaboration for higher values.

The role of $\beta$ in the incomplete information game resembles that of the basic game. Clearly, extreme values of $\beta$ are undesirable from the perspective of maximizing joint production; very low values provide too little incentive to work, and very high values provide too little incentive to share. Focusing on intermediate values (i.e., parts (iii) and (iv) of Proposition B3), increasing $\beta$ limits A1's propensity to share. For low values of $\beta$ in this region there is full sharing. The following comment establishes that the set of types that share contracts as $\beta$ increases.

**Comment B3 (Comparative Statics)**
*$\underline{\theta}^*$ is increasing in $\beta$.*

These results show that despite numerous differences across models, two main intuitions carry over from the basic model. First, high levels of competition will inhibit sharing and collaboration. Second, conditional upon being willing to work, the highest type originators will share in equilibrium. This prediction is also consistent with the "synergies" case ($\rho < 1$) case of the no-effort model. As with the other models, equilibrium sharing behavior is in some sense undesirable, as a hypothetical principal or society would prefer that lower types share.

**Proof of Proposition B3**

We characterize $\underline{\theta}^*$ by solving (where possible) for the A1 type that is indifferent between sharing and not sharing, given that all types $(\underline{\theta}, 1]$ share.

We first establish some properties of the cutoff $\hat{\theta}_2$ for which all types $\theta_2 < (>)\ \hat{\theta}_2$ do not work (work). Let $\psi(\underline{\theta})$ denote the interior value of $\hat{\theta}_2$ from (B12), holding $\overline{\theta} = 1$. Note that $\psi(x) = x$ only for $x = 1$ and $x = k/m$. Differentiating $\psi(\cdot)$, we obtain

$$\frac{d\psi}{d\underline{\theta}} \leq 0 \quad \Leftrightarrow \quad (\beta - k)[m(1-\underline{\theta}) + \beta] + m[k(1-\underline{\theta}) + \beta\underline{\theta}] \leq 0. \tag{B17}$$

Simplifying (B17) yields $\frac{d\psi}{d\underline{\theta}} \leq 0$ iff $\beta \leq k-m$. Since $\psi(1) = 1$, this condition implies $\psi(\underline{\theta}) \geq 1$ for all $\underline{\theta} \in [0,1]$ if $\beta \leq k-m$, and $\psi(\underline{\theta}) < 1$ otherwise.

(i) Suppose $\beta \leq k-m$. Expressions (B12) and (B13) then imply that $\hat{\theta}_2 = 1$ and $\phi(\underline{\theta}, 1) = 0$ for all $\underline{\theta} \in [0,1]$, respectively. Applying (B15), A1 is indifferent between share and keep.

(ii) Now suppose $\beta > k-m$. Expressions (B12) and (B17) then imply that $\hat{\theta}_2$ is weakly increasing in $\underline{\theta}$ and $\hat{\theta}_2 \in (0,1)$ for $\underline{\theta} \in [0,1)$. We establish some useful features of the sharing condition (B16) when evaluated at some $\theta_1 = \underline{\theta}$. Define $\sigma(\underline{\theta}) = m(\hat{\theta}_2 + 1)/2 - \xi(\underline{\theta})\beta$ as the left-hand side of (B16), evaluated at $\theta_1 = \underline{\theta}$. It is easily verified that $\sigma(\underline{\theta})$ is single-valued and continuous on $[0,1]$. Next, we show that $\sigma(\underline{\theta})$ is strictly increasing on $[0,1]$. Since $\beta > k-m$, $\psi(\underline{\theta})$ is strictly increasing and $\hat{\theta}_2$ is weakly increasing. Thus $\sigma(\underline{\theta})$ is strictly increasing if $\hat{\theta}_2$ is non-decreasing and $\xi(\underline{\theta})$ is non-increasing, with one relationship strict. There are two cases.

a. Suppose that $k/m \leq 1$. Observe that for $\underline{\theta} \leq k/m$, $\hat{\theta}_2 = \psi(\underline{\theta}) \geq \underline{\theta}$, and when $\underline{\theta} > k/m$, $\hat{\theta}_2 = k/m < \underline{\theta}$. Thus by (B14), when $\underline{\theta} \leq k/m$, $\xi(\underline{\theta}) = 1$ (i.e., A2 always wins conditional upon working). Since $\frac{d\psi}{d\underline{\theta}} > 0$, $\sigma(\underline{\theta})$ is strictly increasing. When $\underline{\theta} > k/m$, $\xi(\underline{\theta}) = (1-\underline{\theta})/(1-k/m)$ is obviously strictly decreasing in $\underline{\theta}$. Since $\hat{\theta}_2$ is weakly increasing, $\sigma(\underline{\theta})$ is again strictly increasing.

b. Suppose that $k/m > 1$. Now for all $\underline{\theta}$, $\hat{\theta}_2 = \psi(\underline{\theta}) \geq \underline{\theta}$; thus by the argument for $k/m \leq 1$ and $\underline{\theta} \leq k/m$, $\xi(\underline{\theta}) = 1$ and $\sigma(\underline{\theta})$ is strictly increasing. Since $\sigma(\underline{\theta})$ is increasing, A1 does not share if $\lim_{\underline{\theta}\to 1} \sigma(\underline{\theta}) \leq 0$. There are two subcases. First, let $k/m \leq 1$. Note that $\hat{\theta}_2 = k/m$ at $\underline{\theta} = 1$ and $\xi(1) = 0$, so substituting into $\sigma(\cdot)$ the condition for no sharing becomes:

$$\frac{m}{2}\left(\frac{k}{m} + 1\right) < 0. \tag{B18}$$

This condition is obviously impossible to satisfy, and so $\sigma(1) \geq 0$ and A1 does not choose keep for all $\theta_1$. Second, let $k/m > 1$. By (B12), $\hat{\theta}_2 = 1$ at $\underline{\theta} = 1$ and $\xi(\underline{\theta}) = 1$, so substituting into $\sigma(\cdot)$ the condition for no sharing simplifies to $m < \beta$. Thus A1 keeps for all $\theta_1$ when $m < \min\{k, \beta\}$.

(iii) Full sharing occurs in equilibrium if and only if $\sigma(0) \geq 0$. Note that $\xi(0) = 1$, so substituting into $\sigma(\cdot)$ the condition for full sharing becomes

$$\begin{aligned} \frac{m}{2}\left(\frac{k}{m+\beta} + 1\right) - \beta &> 0 \\ \frac{m}{2}(k+m) - \frac{m}{2}\beta - \beta^2 &> 0. \end{aligned} \tag{B19}$$

It is easily shown that the last expression has only one positive root, and so all types share if

$$\beta < \frac{-m + \sqrt{m^2 + 8m(k+m)}}{4}.$$

(iv) There are two cases.

a. Suppose that $k/m < 1$. If sharing for all $\theta_1$ is not possible, then the analogous case in part (ii) implies that there exists some interior $\underline{\theta}^*$ such that $\sigma(\underline{\theta}) = 0$. Since $\underline{\theta}^*$ depends on $\hat{\theta}_2$ and $\hat{\theta}_2$ is at a corner at $\underline{\theta} = k/m$, we consider conditions under which $\underline{\theta}^*$ will lie on either side of $k/m$. As $\sigma(\underline{\theta})$ is increasing, $\underline{\theta}^* < k/m$ iff $\sigma(k/m) > 0$, or

$$\frac{k+m}{2} > \beta. \tag{B20}$$

If (B20) holds, then since $\underline{\theta}^* < k/m$ implies $\hat{\theta}_2 < k/m$, $\underline{\theta}^*$ is characterized by substituting $\psi(\underline{\theta})$ and $\xi(\underline{\theta}) = 1$ into (B16):

$$\frac{m}{2}\left[\frac{k(1-\underline{\theta}) + \beta\underline{\theta}}{m(1-\underline{\theta}) + \beta} + 1\right] - \beta = 0. \tag{B21}$$

The solution to (B21) is then easily derived:

$$\underline{\theta}^* = \frac{m(k-\beta+m) - 2\beta^2}{m(k-3\beta+m)} \tag{B22}$$

If (B20) does not hold, then since $\underline{\theta}^* \geq k/m$ implies $\hat{\theta}_2 = k/m$, $\underline{\theta}^*$ is characterized by substituting $\hat{\theta}_2$ and $\xi(\underline{\theta}) = (1-\underline{\theta})/(1-k/m)$ into (B16):

$$\frac{m}{2}\left(\frac{k}{m} + 1\right) - \frac{1-\underline{\theta}}{1-k/m}\beta = 0. \tag{B23}$$

The solution to (B23) is then easily derived:

$$\underline{\theta}^* = 1 - \frac{m(1-(k/m)^2)}{2\beta}.$$

b. Suppose that $k/m \geq 1$. From part (ii), $m < \beta$ implies that A1 always keeps, so we restrict attention to $m \geq \beta$. We have $\sigma(1) \geq 0$ and $\hat{\theta}_2 = \psi(\underline{\theta}) > \underline{\theta}$ for all $\underline{\theta} \in [0, 1)$. Thus, $\hat{\theta}_2$ is interior for all values of $\underline{\theta}$ and $\underline{\theta}^*$ is characterized by the the value of $\underline{\theta}$ such that $\sigma(\underline{\theta}) = 0$, as given by (B22).

Observe finally that given $\underline{\theta}^*$, according to (B15) no type higher (resp., lower) than $\underline{\theta}^*$ can strictly benefit from keeping (resp., sharing); thus each type of A1 will play the specified sharing strategy.

Summarizing all of the derivations yields the claimed result ■

**Proof of Comment B3**

We show that the two possible values of $\underline{\theta}^*$ are increasing in $\beta$. Differentiating $\frac{m(k-\beta+m)-2\beta^2}{m(k-3\beta+m)}$ with respect to $\beta$ yields the following condition:

$$\begin{aligned} \frac{2\left(3\beta^2 + k(m-2\beta) + m^2 - 2\beta m\right)}{m(k-3\beta+m)^2} &> 0 \\ \Leftrightarrow \quad (m-\beta)^2 + 2\beta(\beta - k) + km &> 0. \end{aligned} \tag{B24}$$

There are two possible subcases.

1. Suppose $k < m$. Expression (B24) is linear in $k$ and holds at $k = 0$. At $k = m$, (B24) evaluates to $2(m-\beta)^2 + \beta^2 > 0$, which clearly holds. Thus (B24) holds for all $k < m$.

2. If $k \geq m$, then it is sufficient to show that $2\beta(\beta - k) + km > 0$. Observe that this expression is linear in $m$, and for $m = k$, it evaluates to $\beta^2 + (\beta - k)^2 > 0$, which clearly holds. As established in the proof of (iv) in Proposition B3, $m \geq \beta$ when $k \geq m$, and so the expression evaluates to $2\beta^2 - k\beta > 0$ at $m = \beta$. This is true if $k < 2\beta$, which follows from straightforward manipulation of the fact that $\beta > \frac{-m+\sqrt{m^2+8m(k+m)}}{4}$ in any interior equilibrium. Next, differentiating $1 - \frac{m(1-(k/m)^2)}{2\beta}$ with respect to $\beta$ yields the following condition:

$$\frac{(1 - k^2/m^2)m}{2\beta^2} > 0.$$

Since $k/m < 1$ for the subcase in which this value of $\underline{\theta}^*$ applies, this expression clearly holds ■

# C Instructions

You are participating in a study on economic decision making and will be asked to make a number of decisions. For your participation, you will receive a show-up fee of \$5. Please read these instructions carefully as they describe how you can earn additional money.

All the interaction between you and other participants will take place through the computers. Please do not communicate with other participants. If you have a question, raise your hand and one of us will help you.

The study is **anonymous**. In other words, your identity will not be revealed to others and the identity of others will not be revealed to you.

During the study your earnings will be expressed in points. Points will be converted to dollars at the following rate: **100 points = \$10**. You will be paid your earnings in cash.

The study is divided into **60 periods**. At the end of the study, we will randomly select **one period** (each with equal probability). Your earnings today will equal the number of points you obtained in that randomly-selected period (plus the \$5 show-up fee).

The decisions to be made in each period are described below.

### Decisions in each period

In each period, you will interact with **one other participant**. Note that you will be randomly paired with a **different participant at the beginning of each period**. Moreover, decisions from past periods will not be revealed.

At the beginning of each period, both participants receive an endowment of 110 points. In addition, each participant will be randomly assigned to a role and a productivity level.

Specifically, one participant will be randomly assigned to the role of **Player A** and the other participant to the role of **Player B**. The participant in the role of Player A will be randomly assigned to a **Low**, **Intermediate**, or **High** productivity level (each being equally likely). The participant in the role of Player B is always assigned to the **High** productivity level.

Each period is divided into two subsequent stages: a **pre-investment stage**, which is then followed by an **investment stage**.

**Pre-investment stage**

In this stage, **Player A** receives an **investment opportunity**. Player A then decides whether Player B can take part in the investment opportunity. Specifically, Player A chooses between the following three options:

- Only A can invest
- Only B can invest
- Both A and B can invest

**Investment stage**

In this stage, players who can invest decide whether to **invest** or **not invest**. If a player does not invest, he/she does not incur any costs and does not produce income. If a player invests, he/she incurs a cost of 220 points and produces an amount of income that depends on the player's productivity according to Table I below.

**Table I. Total income produced depending on productivity**

| **Productivity of the investing player** | **Total income produced** |
|---|---|
| Low productivity | 210 points |
| Intermediate productivity | 285 points |
| High productivity | 360 points |

The total income produced is divided into two types of income and is distributed among the two players in the following way:

- **Constant income**: this type of the income is always distributed equally between Player A and Player B. Moreover, it is received irrespective of whether players could make an investment decision or not, and if they could, irrespective of whether the players invested or not.
- **Varying income**: this type of the income is distributed only among the players that could make an investment decision. In other words:

– If Player A chose "only A can invest" then Player A receives all the varying income.
– If Player A chose "only B can invest" then Player B receives all the varying income.
– If Player A chose "Both A and B can invest" then both players receive varying income. The amount each player receives depends on the total amount of income each player generates. Recall that a player generates income by investing; if he/she does not invest then he/she generates 0 points. The precise share received by each player is given by Table II.

**Table II. Varying income if Player A chose "both A and B can invest"**

| Productivity of | | Total income produced by | | Share of varying income for | |
|---|---|---|---|---|---|
| A | B | A | B | A | B |
| Low | High | 210 points | 360 points | 30% | 70% |
| Low | High | 210 points | 0 points | 78% | 22% |
| Low | High | 0 points | 360 points | 3% | 97% |
| Intermediate | High | 285 points | 360 points | 40% | 60% |
| Intermediate | High | 285 points | 0 points | 88% | 12% |
| Intermediate | High | 0 points | 360 points | 3% | 97% |
| High | High | 360 points | 360 points | 50% | 50% |
| High | High | 360 points | 0 points | 97% | 3% |
| High | High | 0 points | 360 points | 3% | 97% |

To familiarize you with the screen in which you will make decisions, look at the provided screenshot in which Player A makes the pre-investment choice. In this example, 50% of the total income is allocated to constant income and the remaining 50% is allocated varying income.

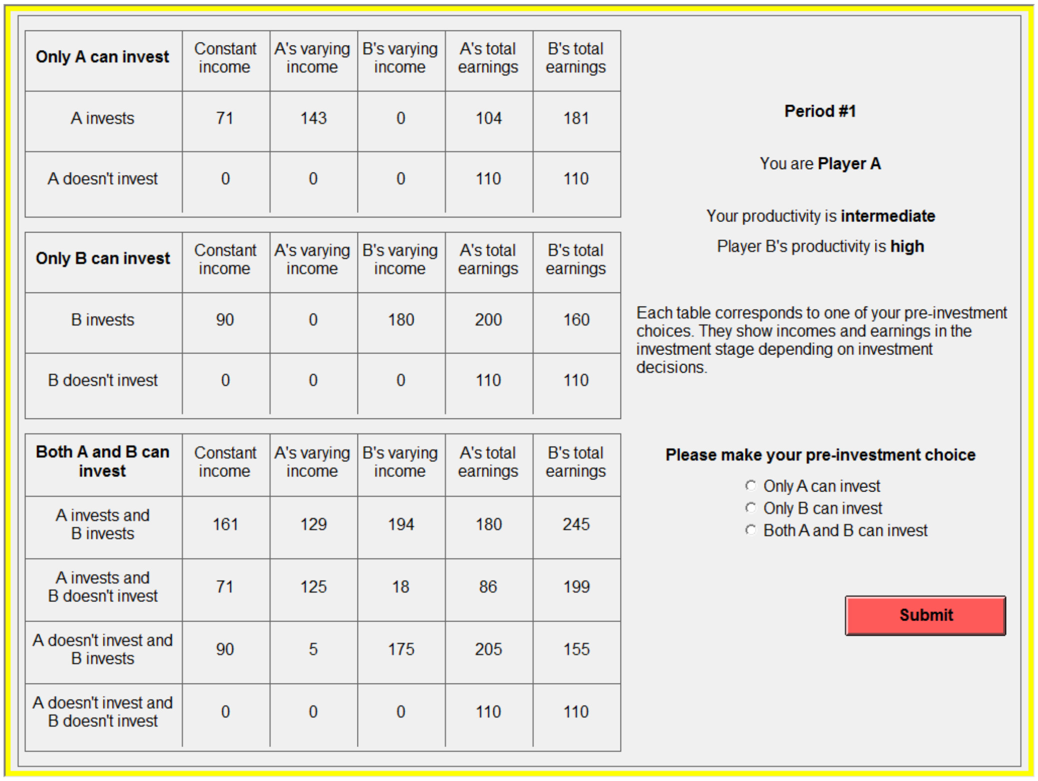
To help with the understanding of the way income and earnings are calculated, we will walk you through the calculations seen in the screenshot. Note that while you are making decisions these calculations are already made for you. We simply go through them here to illustrate how they are done.

I. As you can see, irrespective of Player A's pre-investment choice, if neither Player A nor Player B invests then both players earn their endowment: 110 points.

II. If only A can invest and he/she does invest then:

- The earnings of Player A equal: A's endowment (110 points)  the cost of investing

**Screenshot of Player A's pre-investment choice**



| Only A can invest | Constant income | A's varying income | B's varying income | A's total earnings | B's total earnings |
|---|---|---|---|---|---|
| A invests | 71 | 143 | 0 | 104 | 181 |
| A doesn't invest | 0 | 0 | 0 | 110 | 110 |

| Only B can invest | Constant income | A's varying income | B's varying income | A's total earnings | B's total earnings |
|---|---|---|---|---|---|
| B invests | 90 | 0 | 180 | 200 | 160 |
| B doesn't invest | 0 | 0 | 0 | 110 | 110 |

| Both A and B can invest | Constant income | A's varying income | B's varying income | A's total earnings | B's total earnings |
|---|---|---|---|---|---|
| A invests and B invests | 161 | 129 | 194 | 180 | 245 |
| A invests and B doesn't invest | 71 | 125 | 18 | 86 | 199 |
| A doesn't invest and B invests | 90 | 5 | 175 | 205 | 155 |
| A doesn't invest and B doesn't invest | 0 | 0 | 0 | 110 | 110 |

**Period #1**

You are **Player A**

Your productivity is **intermediate**

Player B's productivity is **high**

Each table corresponds to one of your pre-investment choices. They show incomes and earnings in the investment stage depending on investment decisions.

**Please make your pre-investment choice**

- Only A can invest
- Only B can invest
- Both A and B can invest

**Submit**

(220 points) + A's constant income (142 × 50% = 71 points) + all the varying income (143 points) = 104 points.

- The earnings of Player B equal: B's endowment (110 points) + B's constant income (142 × 50% = 71 points) = 181 points.

III. If only B can invest and he/she does invest then:

- The earnings of Player A equal: A's endowment (110 points) + A's constant income (180 × 50% = 90 points) = 200 points.
- The earnings of Player B equal: B's endowment (110 points)  the cost of investing (220 points) + B's constant income (180 × 50% = 90 points) + all the varying income (180 points) = 160 points.
- Note that, compared to case II, the constant and varying incomes are larger here because Player B is the one who invests and Player B has a higher productivity level than Player A.

IV. If both A and B can invest and both players invest then:

- The earnings of Player A equal: A's endowment (110 points)  the cost of investing

(220 points) + A’s constant income ($322 \times 50\% = 161$ points) + A’s share of the varying income ($323 \times 40\% = 129$ points) = 180 points.

- The earnings of Player B equal: B’s endowment (110 points)  the cost of investing (220 points) + B’s constant income ($322 \times 50\% = 161$ points) + B’s share of the varying income ($323 \times 60\% = 194$ points) = 245 points.
- Note that when both players invest, the constant and varying incomes are largest because both players generate income.

V. If both A and B can invest but only Player A invests then:

- The earnings of Player A equal: A’s endowment (110 points)  the cost of investing (220 points) + A’s constant income ($142 \times 50\% = 71$ points) + A’s share of the varying income ($143 \times 88\% = 125$ points) = 86 points.
- The earnings of Player B equal: B’s endowment (110 points) + B’s constant income ($142 \times 50\% = 71$ points) + B’s share of the varying income ($143 \times 12\% = 18$ points) = 199 points.
- Note that, as in case II, in this case Player A is the only one generating the constant and varying incomes. However, unlike in case II, Player A does not receive all the varying income, which is why Player A’s earnings are lower and Player B’s earnings are higher (compared to case II).

VI. If both A and B can invest but only Player B invests then:

- The earnings of Player A equal: A’s endowment (110 points) + A’s constant income ($180 \times 50\% = 90$ points) + A’s share of the varying income ($180 \times 3\% = 5$ points) = 205 points.
- The earnings of Player B equal: B’s endowment (110 points)  the cost of investing (220 points) + B’s constant income ($180 \times 50\% = 90$ points) + B’s share of the varying income ($180 \times 97\% = 175$ points) = 155 points.

The precise division of total income into constant income and varying income will change during the study. You will be told when such a change occurs.

This concludes the instructions. Please click on the red button on your screen. If you have any questions then raise your hand and we will be happy to assist.

# D Statistical analysis

In this section we describe in detail the statistical analysis supporting the experimental results.

### Regression analysis pooling on the theoretical predictions

Here we provide the regressions used to construct the 95% confidence intervals seen in Figure 3 in the main body of the paper. In all regressions, the only independent variables are dummy variables indicating each of the predicted outcomes (collaboration being the omitted outcome). Table D1 reports the marginal effects of the estimated coefficients and their respective standard errors.[D1] We cluster standard errors on the 24 matching groups.

Regression I in Table D1 corresponds to A1's first stage choice. We estimate the coefficients using a multinomial probit regression using A1's choice to either keep (column Ia), refer (column Ib), or share (column Ic) jurisdiction as the dependent variable. The next two regressions correspond to probit regressions where the dependent variable equals one if A1 exerted effort in the second stage. Regression II restricts the sample to periods in which A1 decided to keep jurisdiction and regression III to periods in which A1 decided to share jurisdiction. Similarly, regressions IV and V correspond to probit regressions where the dependent variable equals one if A2 exerted effort in the second stage. Regression IV restricts the sample to periods in which A1 decided to refer jurisdiction and regression V to periods in which A1 decided to share jurisdiction. Finally, regression VI is an OLS regression estimating the effect of the model's predictions on total welfare as a fraction of the maximum welfare (i.e., the sum of both players' payoffs when both have a high productivity, jurisdiction, and exert effort: $W(\theta_1 + \theta_2) - 2k = 0.74$).[D2]

The regressions from Table D1 can also be used to test whether there are statistically significant differences in behavior between equilibrium predictions. Since we are making multiple pairwise Wald tests for each variable, we determine statistical significance based on Bonferroni-adjusted $p$-values. Specifically, for the jurisdiction decision, we multiply $p$-values by 18 since we run one test per pairwise comparison for each of the three outcomes (keep, refer, and share). For the effort choices, we multiply $p$-values by 12 since we run one test per pairwise comparison for each jurisdiction choice (keep and share for A1, and refer

[D1] Marginal effects are estimated with respect to the case where all independent variables are zero. In other words, they indicate the mean change in behavior compared to the collaboration outcome.

[D2] Results are vary similar if instead of the probit regressions we use logit regressions with subject fixed effects and instead of an OLS we use a linear regression with subject fixed effects. The fixed-effects regressions are available upon request.

**Table D1. Regressing equilibrium outcomes on observed behavior**

| | Ia | Ib | Ic | II | III | IV | V | VI |
|---|---|---|---|---|---|---|---|---|
| Indifference | 0.00 | 0.12 | −0.12 | −0.87 | −0.74 | −0.83 | −0.73 | −0.70 |
| | (0.01) | (0.01) | (0.02) | (0.05) | (0.03) | (0.05) | (0.03) | (0.02) |
| Delegation | −0.03 | 0.34 | −0.31 | −0.79 | −0.95 | −0.03 | −0.07 | −0.43 |
| | (0.01) | (0.02) | (0.02) | (0.06) | (0.01) | (0.03) | (0.01) | (0.01) |
| Turf war | 0.78 | −0.01 | −0.77 | 0.07 | −0.01 | 0.03 | 0.01 | −0.58 |
| | (0.03) | (0.01) | (0.03) | (0.03) | (0.03) | (0.03) | (0.01) | (0.01) |
| No. obs. | | 5760 | | 643 | 4195 | 922 | 4195 | 5760 |

*Note:* Marginal effects and their respective standard errors in parenthesis.

and share for A2). Lastly, for welfare, we multiply $p$-values by 6 since we run one test per pairwise comparison. The results of these pairwise comparisons are presented in Table D2.

The pairwise comparisons from the regressions give very similar results as those from nonparametric tests (reported in Table 3 in the main body of the paper). There are only two differences between these results and those from the nonparametric tests. First, A2s effort after a referral is now significantly higher in a turf war compared to indifference, which is consistent with the theoretical predictions. Second, the small difference in A2s effort rate between delegation and turf war (6 percentage points) appears as statistically significant.

**Statistical analysis of individual treatments**

Here we provide the detailed statistical analysis of the subjects behavior in the individual treatments. Figure 4 in the main body of the paper presents the mean actions taken by A1s and A2s over all periods for each of the 12 combinations of $\beta$ and $\theta_1$. Going from the top-left to the bottom-right, the first three graphs show the mean fraction of times A1s choose to keep, refer, or share jurisdiction. The next four graphs show the mean fraction of times A1s/A2s exert effort (conditional on having jurisdiction, depending on whether they were sharing jurisdiction or not. Lastly, the eighth graph shows mean total welfare as a fraction of the maximum welfare.

To test whether the differences observed in Figure 3 are statistically significant, we ran both regressions and nonparametric tests. We start with the nonparametric analysis. Once again, we construct our independent observations by averaging the subjects' behavior within each matching group, which gives us 24 observations per treatment (all matching groups experienced all the parameter combinations). We then performed all pairwise treatment com-

**Table D2. Pairwise comparisons between equilibrium predictions**

| Agent | Action | Treatment comparisons | | | | | |
|---|---|---|---|---|---|---|---|
| | | Indif. vs. Deleg. | Indif. vs. Collab. | Indif. vs. Turf | Deleg. vs. Collab. | Deleg. vs. Turf | Collab. vs. Turf |
| A1 | Keep | | | ** | ** | ** | ** |
| | Refer | ** | ** | ** | ** | ** | |
| | Share | ** | ** | ** | ** | ** | ** |
| | Effort (after keep) | | ** | ** | ** | ** | |
| | Effort (after share) | ** | ** | ** | ** | ** | |
| A2 | Effort (after refer) | ** | ** | ** | | ** | |
| | Effort (after share) | ** | ** | ** | ** | ** | |
| Both | Welfare | ** | ** | ** | ** | ** | ** |

*Note:* Pairwise comparisons between equilibrium predictions based on the regressions in Table D1. ** and * indicate statistical significance at 1% and 5% according to Bonferroni-adjusted $p$-values.

parisons using Wilcoxon-signed-rank tests. We use Bonferroni-adjusted $p$-values to avoid false positives due to multiple comparisons. Specifically, for the jurisdiction choice, we multiply $p$-values by 198 since we run one test for each of the 66 pairwise comparisons for each of the three jurisdiction choices (i.e., for the keeping rate, the referral rate, and the sharing rate). For A1's effort rate, A2's effort rate, and welfare, we we multiply $p$-values by 66 since we run one test per pairwise comparison.[D3]

In Table D3 we present pairwise comparisons between treatments that have the same productivity for A1. In other words, these tests allow us to observe one of the most interesting predictions of the model, Namely, the non-monotonic effect of increasing the prize $\beta$ at the different productivity levels $\theta_1 \in \{0.55, 0.75, 0.95\}$. The other treatment comparisons are not reproduced here but can be obtained by rerunning our statistical analysis using provided do-file and dataset (we used the statistics software STATA version 13.1).

We start discussing the effort decision. Consistent with the theoretical predictions, we observe that increasing the prize clearly increases A2's likelihood of exerting effort (when $\beta$ increases from 0.15 to 0.50) and A1's likelihood of exerting effort when A1 is of intermediate productivity (when $\beta$ increases from 0.50 to 0.80) or high productivity (when $\beta$ increases from

[D3]In this analysis, we do not separate the effort rate depending on the jurisdiction choice because, if we do, there are too few independent observations for various treatment comparisons.

**Table D3. Treatments differences in behavior**

| | Keep | Refer | Share | A1's effort | A2's effort | Welfare |
|---|---|---|---|---|---|---|
| $\theta_{55}\beta_{15}$ vs. $\theta_{55}\beta_{50}$ | $0.07^{*}$ | $-0.38^{**}$ | $0.30^{**}$ | 0.02 | $-0.73^{**}$ | $-0.73^{**}$ |
| $\theta_{55}\beta_{15}$ vs. $\theta_{55}\beta_{80}$ | 0.06 | $-0.07$ | 0.01 | $0.08^{*}$ | $-0.81^{**}$ | $-0.80^{**}$ |
| $\theta_{55}\beta_{15}$ vs. $\theta_{55}\beta_{95}$ | $-0.01$ | 0.05 | $-0.04$ | $0.07^{*}$ | $-0.81^{**}$ | $-0.73^{**}$ |
| $\theta_{55}\beta_{50}$ vs. $\theta_{55}\beta_{80}$ | $-0.01$ | $0.31^{*}$ | $-0.29^{*}$ | 0.06 | $-0.08^{*}$ | $-0.07$ |
| $\theta_{55}\beta_{50}$ vs. $\theta_{55}\beta_{95}$ | $-0.08$ | $0.43^{**}$ | $-0.34^{**}$ | 0.05 | $-0.08$ | 0.00 |
| $\theta_{55}\beta_{80}$ vs. $\theta_{55}\beta_{95}$ | $-0.07$ | 0.12 | $-0.05$ | $-0.01$ | 0.00 | 0.07 |
| $\theta_{75}\beta_{15}$ vs. $\theta_{75}\beta_{50}$ | 0.04 | $-0.33^{**}$ | $0.29^{*}$ | 0.07 | $-0.69^{**}$ | $-0.45^{**}$ |
| $\theta_{75}\beta_{15}$ vs. $\theta_{75}\beta_{80}$ | $-0.03$ | 0.11 | $-0.08$ | $-0.78^{**}$ | $-0.79^{**}$ | $-0.74^{**}$ |
| $\theta_{75}\beta_{15}$ vs. $\theta_{75}\beta_{95}$ | $-0.79^{**}$ | $0.13^{**}$ | $0.66^{**}$ | $-0.84^{**}$ | $-0.79^{**}$ | $-0.24^{**}$ |
| $\theta_{75}\beta_{50}$ vs. $\theta_{75}\beta_{80}$ | $-0.07$ | $0.44^{**}$ | $-0.37^{**}$ | $-0.85^{**}$ | $-0.10^{*}$ | $-0.29^{**}$ |
| $\theta_{75}\beta_{50}$ vs. $\theta_{75}\beta_{95}$ | $-0.83^{**}$ | $0.46^{**}$ | $0.37^{**}$ | $-0.91^{**}$ | $-0.10^{*}$ | $0.21^{**}$ |
| $\theta_{75}\beta_{80}$ vs. $\theta_{75}\beta_{95}$ | $-0.76^{**}$ | 0.02 | $0.74^{**}$ | $-0.06^{*}$ | 0.00 | $0.50^{**}$ |
| $\theta_{95}\beta_{15}$ vs. $\theta_{95}\beta_{50}$ | 0.02 | 0.04 | $-0.07$ | $-0.53^{**}$ | $-0.59^{**}$ | $-0.56^{**}$ |
| $\theta_{95}\beta_{15}$ vs. $\theta_{95}\beta_{80}$ | $-0.02$ | $0.08^{*}$ | $-0.07^{*}$ | $-0.53^{**}$ | $-0.63^{**}$ | $-0.58^{**}$ |
| $\theta_{95}\beta_{15}$ vs. $\theta_{95}\beta_{95}$ | $-0.05$ | $0.08^{*}$ | $-0.04$ | $-0.54^{**}$ | $-0.63^{**}$ | $-0.56^{**}$ |
| $\theta_{95}\beta_{50}$ vs. $\theta_{95}\beta_{80}$ | $-0.04$ | 0.04 | 0.00 | 0.03 | $-0.04$ | $-0.02$ |
| $\theta_{95}\beta_{50}$ vs. $\theta_{95}\beta_{95}$ | $-0.07$ | 0.04 | 0.03 | $-0.01$ | $-0.04$ | 0.00 |
| $\theta_{95}\beta_{80}$ vs. $\theta_{95}\beta_{95}$ | $-0.03$ | 0.00 | 0.03 | $-0.01$ | 0.00 | 0.02 |

*Note:* Mean differences in observed behavior between treatments. ** and * indicate statistical significance at 1% and 5% according to Wilcoxon signed-ranks tests using matching-group means and Bonferroni-adjusted $p$-values.

0.15 to 0.50) but not when A1 is of low productivity. There are a few statistically significant differences that are not inline with the theoretical predictions. However, they tend to be small (at most 10 percentage points) and might occur because, as argued by Goeree and Holt (2001), mistakes are bound to be made more often when they are less costly. In this case, not exerting effort when one benefits from doing so is less costly for lower $\beta$s.

For the jurisdiction decision, we observe that, as predicted, increasing $\beta$ to 0.95 strongly increases the likelihood that A1 keeps jurisdiction when A1 is of intermediate productivity but not when A1 is of low or high productivity. The most obvious deviation from the model's prediction is the high propensity of A1 of intermediate productivity to refer jurisdiction instead of sharing it when $\beta = 0.50$. Once again, this can be explained by mistakes being made more often when they are less costly (e.g., referring instead of sharing implies a loss of 2% of A1s

**Table D4. Regressing treatments on observed behavior**

| | Ia | Ib | Ic | II | III | IV |
|---|---|---|---|---|---|---|
| $\theta_{55}\beta_{50}$ | −0.07 | 0.38 | −0.31 | −0.02 | 0.73 | 0.37 |
| | (0.03) | (0.18) | (0.15) | (0.03) | (0.03) | (0.02) |
| $\theta_{55}\beta_{80}$ | −0.06 | 0.07 | −0.01 | −0.08 | 0.81 | 0.40 |
| | (0.03) | (0.05) | (0.05) | (0.02) | (0.02) | (0.01) |
| $\theta_{55}\beta_{95}$ | 0.01 | −0.05 | 0.04 | −0.07 | 0.80 | 0.37 |
| | (0.03) | (0.04) | (0.03) | (0.02) | (0.02) | (0.02) |
| $\theta_{75}\beta_{15}$ | −0.03 | −0.04 | 0.07 | 0.06 | 0.05 | 0.06 |
| | (0.02) | (0.02) | (0.02) | (0.02) | (0.03) | (0.01) |
| $\theta_{75}\beta_{50}$ | −0.07 | 0.29 | −0.22 | 0.00 | 0.73 | 0.38 |
| | (0.03) | (0.15) | (0.12) | (0.03) | (0.03) | (0.01) |
| $\theta_{75}\beta_{80}$ | 0.00 | −0.15 | 0.15 | 0.85 | 0.83 | 0.60 |
| | (0.02) | (0.05) | (0.05) | (0.02) | (0.02) | (0.01) |
| $\theta_{75}\beta_{95}$ | 0.76 | −0.17 | −0.59 | 0.90 | 0.84 | 0.24 |
| | (0.03) | (0.11) | (0.11) | (0.02) | (0.02) | (0.01) |
| $\theta_{95}\beta_{15}$ | −0.03 | −0.10 | 0.13 | 0.36 | 0.21 | 0.32 |
| | (0.02) | (0.02) | (0.02) | (0.04) | (0.03) | (0.03) |
| $\theta_{95}\beta_{50}$ | −0.06 | −0.14 | 0.20 | 0.89 | 0.80 | 0.87 |
| | (0.02) | (0.06) | (0.04) | (0.02) | (0.03) | (0.02) |
| $\theta_{95}\beta_{80}$ | −0.02 | −0.18 | 0.20 | 0.90 | 0.84 | 0.89 |
| | (0.03) | (0.14) | (0.12) | (0.02) | (0.02) | (0.01) |
| $\theta_{95}\beta_{95}$ | 0.01 | −0.18 | 0.17 | 0.90 | 0.84 | 0.88 |
| | (0.02) | (0.11) | (0.10) | (0.02) | (0.02) | (0.01) |
| No. obs. | | 5760 | | 4838 | 5117 | 5760 |

*Note:* Marginal effects and their respective standard errors in parenthesis.

profits when $\beta = 0.50$ but a 9% of A1s profits when $\beta = 0.80$).

Lastly, we look at the treatment differences in welfare. In line with the theoretical predictions, when A1 is of intermediate productivity welfare significantly increases as $\beta$ increases from 0.15 to 0.50 and then to 0.80, but then significantly decreases as $\beta$ reaches 0.95. By contrast, when A1 is of low or high productivity, welfare significantly increases as $\beta$ increases from 0.15 to 0.50 but then does not decrease with further increases in $\beta$.

We also analysed the data using regressions. In all regressions, the independent variables correspond to dummy variables indicating each of the treatments (the omitted treatment is $\theta_{55}\beta_{15}$). We ran the same type of regressions as those reported in Table D1. Namely, regression

**Table D5. Pairwise comparisons between treatments**

| | Keep | Refer | Share | A1's effort | A2's effort | Welfare |
|---|---|---|---|---|---|---|
| $\theta_{55}\beta_{15}$ vs. $\theta_{55}\beta_{50}$ | | | | | ** | ** |
| $\theta_{55}\beta_{15}$ vs. $\theta_{55}\beta_{80}$ | | | | * | ** | ** |
| $\theta_{55}\beta_{15}$ vs. $\theta_{55}\beta_{95}$ | | | | * | ** | ** |
| $\theta_{55}\beta_{50}$ vs. $\theta_{55}\beta_{80}$ | | | | | ** | |
| $\theta_{55}\beta_{50}$ vs. $\theta_{55}\beta_{95}$ | | | | | * | |
| $\theta_{55}\beta_{80}$ vs. $\theta_{55}\beta_{95}$ | | | | | | |
| $\theta_{75}\beta_{15}$ vs. $\theta_{75}\beta_{50}$ | | | | | ** | ** |
| $\theta_{75}\beta_{15}$ vs. $\theta_{75}\beta_{80}$ | | | | ** | ** | ** |
| $\theta_{75}\beta_{15}$ vs. $\theta_{75}\beta_{95}$ | ** | | ** | ** | ** | ** |
| $\theta_{75}\beta_{50}$ vs. $\theta_{75}\beta_{80}$ | | | | ** | * | ** |
| $\theta_{75}\beta_{50}$ vs. $\theta_{75}\beta_{95}$ | ** | | | ** | ** | ** |
| $\theta_{75}\beta_{80}$ vs. $\theta_{75}\beta_{95}$ | ** | | ** | | ** | ** |
| $\theta_{95}\beta_{15}$ vs. $\theta_{95}\beta_{50}$ | | | | ** | ** | ** |
| $\theta_{95}\beta_{15}$ vs. $\theta_{95}\beta_{80}$ | | | | ** | ** | ** |
| $\theta_{95}\beta_{15}$ vs. $\theta_{95}\beta_{95}$ | | | | ** | ** | ** |
| $\theta_{95}\beta_{50}$ vs. $\theta_{95}\beta_{80}$ | | | | | ** | |
| $\theta_{95}\beta_{50}$ vs. $\theta_{95}\beta_{95}$ | | | | | ** | |
| $\theta_{95}\beta_{80}$ vs. $\theta_{95}\beta_{95}$ | | | | | | |

*Note:* Pairwise comparisons between treatments based on the regressions in Table D4. $^{**}$ and $^{*}$ indicate statistical significance at 1% and 5% according to Bonferroni-adjusted *p*-values.

I is a multinomial probit regression using A1's choice to either keep (column Ia), refer (column Ib), or share (column Ic) jurisdiction as the dependent variable. Regressions II and III are probit regressions where the dependent variable is A1's (regression II) or A2's (regression III) effort choice conditional on having jurisdiction. Lastly, regression IV is an OLS regression with total welfare as a fraction of the maximum welfare as the dependent variable. Table D4 reports the marginal effects of the estimated coefficients and their respective standard errors.[D4] Standard errors are clustered on the 24 matching groups.[D5]

[D4] As before, marginal effects are estimated for the case where all independent variables are zero.

[D5] Once again, the results are very similar if instead of the probit regressions we use logit regressions with subject fixed effects and instead of an OLS we use a linear regression with subject fixed effects. These regressions are available upon request.

Using the regressions reported in Table D4, we use Wald tests to evaluate whether there are statistically significant differences between treatments. To determine statistical significance, we adjust $p$-values using the same method as in the nonparametric analysis. Table D5 presents the significance of the same pairwise comparisons presented in Table D3.

By and large, the pairwise comparisons from the regressions give very similar results as those from non-parametric tests (reported in Table D3). On one hand, a few of the small treatment differences in the effort decision of A1 and A2 are now statistically significant at the 5% level. On the other hand, in the jurisdiction decision, the differences in the referral rate that are statistically significant with the nonparametric tests are not statistically significant with the regressions. However, both statistical approaches arrive to the same conclusion: A1's of intermediate productivity (but not A1's of low or high productivity) keep jurisdiction more when the prize is high, which produces an inverse U-shape relationship between the prize and welfare.