# Business-Science Research Collaboration under Moral-Hazard*

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**Abstract**

I analyze, in the context of business and science research collaboration, how the characteristics of partnership agreements are the result of an optimal contract between partners. The final outcome depends on the structure governing the partnership, and on the informational problems towards the efforts involved. The positive effect that the effort of each party has on the success of the other party, makes collaboration a preferred solution. Divergence in research goals may, however, create conflicts between partners. This paper shows how two different structures of partnership governance (a centralized, and a decentralized ones) may optimally use the type of project to motivate the supply of non-contractible efforts. Decentralized structure, however, always choose a project closer to its own preferences. Incentives may also come from monetary transfers, either from partners sharing each other benefits, or from public funds. I derive conditions under which public intervention is optimal.

*JEL Classification*: L21, L24, L31, L33, O31, O32.

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# 1 Introduction

Why do profit firms collaborate with universities in less applied research projects? Why do universities collaborate with firms in less basic research projects? Firms and universities belong to different institutional settings, with different approaches and objectives when conducting research (Dasgupta & David, 1994). Through research, firms aim to obtain profitable discoveries that increase the quality of their goods and services or their productivity, or that reduce their production costs (European Commission, 2004). For universities, however, research is the mean to fulfill their "commitment to society to create and sustain knowledge" (Argyres & Liebeskind, 1998). Despite these divergences in research goals, recent trends in partnerships show an increasing importance of research collaborations between firms and universities (NSF, 2006; Caloghirou *et al.*, 2001).[1] The main reason for such trend relies on the recognition of mutual benefits from this type of interaction. To my knowledge, the type of research projects that may arise under collaboration of institutionally different parties, however, has not received a satisfactory explanation in the literature.[2] The present paper contributes with a new possible answer to this puzzling question, by showing that the outcome of a partnership agreement may optimally derive from a contract between the partners. The main point of the argument is that the characteristics of a collaborative research can act as an incentive tool for non-contractible *resources* (hereafter named *efforts*). The choice of a research project closer to the interests of one of the parties, motivates a higher allocation of effort from that party, thus increasing the expected benefit of collaborating. The analysis also emphasizes how the collaboration outcome depends on the structure of partnership governance, by comparing a *centralized* decision making process, to a *decentralized* one. Besides expanding the study of business and science links, the theory developed in this paper contributes to a deeper understanding of the organization of research activities.

In the most recent decades, special attention has been dedicated to collaborative research between firms and universities. The reason for this special interest lays in the recognition of potential benefits and costs from this interaction.

Several empirical studies document the benefits accruing to firms that have universities as research partners (e.g., Lee, 2000; Caloghirou *et al.,* 2001; Schartinger *et al.,* 2001; Belderbos *et al.*, 2004; Veugelers & Cassiman, 2005). The common factor in these studies is the recognition that cooperation with universities represents the access to a pool of highly qual-

[1] Refering to US alliances registered at the US Department of Justice, the Cooperative Research (CORE) database recorded a significative increase of RJVs having at least one university as a partner (NSF, 2006): 6% in 1985 (3 RJVs in a total of 50), towards 15% in 2003 (133 RJVs in a total of 913). In Europe, under the first four Framework Programmes of the European Union, the percentage of RJVs with at least one university as partner, increased from 56% in 1983, 5 RJVs out of 9, towards 67% in 1996, 938 out of 1401 (Caloghirou *et al.*, 2001).

[2] Some possible explanations, maybe complementaries of mine, can be found in Rosenberg (1990).

ified scientists, in a wide range of disciplines. These portfolios of knowledge and technology become especially relevant to firms, as societies become more developed and consumers more demanding. The need to accomplish with sophistication of the markets as a way to maintain performance is, in fact, one of the most plausible causes for the recent trends in the research strategy of the firms.[3]

From the universities perspective, it is also possible to capitalize benefits from cooperating with firms. First, companies provide an extra source of monetary funds for universities. With the outrunning of public available resources for the universities, the importance of this funding component increases (Rosenberg, 2003; and Nowotny *et al.,* 2003). Second, the access to companies' data, equipment, and market experience also benefits academics' own research. Firms' skills and resources are excellent tools to test existing theories, or to have insights for the development of new theories (Lee, 2000).

From a more general perspective, several empirical evidence register a higher probability of achieving valuable outcomes from research, when entrepreneurs and academics work together (e.g., Lambert, 2003; Zucker & Darby, 1995; Cockburn & Henderson, 1998; Balconi & Laboranti, 2006).

Advantages of collaboration, however, come at a cost, which often hinders the relation between firms and universities. As Dasgupta & David (1994) remark, firms (belonging to the *Realm of Technology*) and universities (belonging to the *Republic of Science*) have different cultures, goals, norms of behavior and reward systems. Distinct socioeconomic rules lead to different approaches and objectives when conducting research. On the one hand, universities' primary concern is to contribute for the advancement of knowledge. Activities of research developed with this goal, define what is known in the literature as *basic research* (OECD, 2002). On the other hand, the purpose of firms when doing research is to find concrete solutions for practical problems, thus pursuing what is identified as *applied research* (OECD, 2002). According to existing empirical evidence (e.g., Hall *et al.,* 2001; Siegel, 1999; Hall, 1999; Brainard, 1999; Schartinger *et al.*, 2001), these distinct institutional settings and, especially, the distinct objectives towards research, are a natural source of obstacles for the interaction of business and science.

The framework in this paper builds on the two phenomena just described: collaboration between firms and universities is beneficial, since it increases the probability of obtaining a valuable research outcome for both partners; but divergence in research goals may raise tensions in the agreement. Under these premises, I analyze how the characteristics of col-

[3]From the beginning of the last century until 1980s, the most successful innovative firms were making (all) their in-house research at their (big) corporate laboratories, (e.g. General Electrics, AT&T, Kodak, Xerox, IBM). In the past two decades, however, the tendency has been towards an increased cooperation with other institutions, in particularly, with universities (Lambert, 2003; Audretsch *et al.*, 2002; Hall *et al.*, 2001).

laboration change in two dimensions: the structure of the partnership governance, and the informational constraints of who has the authority over the decision making process. In terms of partnership governance, I compare two structures, a *centralized* one and a *decentralized* one. Under a centralized structure, an entity representing the aggregate interests of both collaborators, the *Consortium*, is responsible for deciding the characteristics of the common project, and the amount of resources that each party shall employ. Under a decentralized structure, one of the parties is empowered to make those decisions. For each of these two structures of governance, I consider alternative informational scenarios that differ with respect to the verifiability of efforts, thus creating or not a moral-hazard problem. I start with a benchmark where both partners contribute with verifiable efforts (no moral-hazard). I then analyze how the characteristics of the common project change, when efforts become non-verifiable to the decision-maker (moral-hazard from one or both partners).

The main results of this paper show that, although a decentralized decision-maker always prefers a project closer to its own interests (comparing with the choice of a Consortium), both types of governance may use the type of research as an incentive tool for effort. This incentive mechanism means that, when the effort of one of the parties, say, the University is non-verifiable, the other party, the Firm, may find optimal to collaborate in a less applied project. With such less applied research, scientists of the University are willing to exert higher effort in the joint project. This higher involvement makes a success more likely, increasing the expected benefit also of the Firm. Nevertheless, the use of the type of project as an incentive mechanism must satisfy two requirements. First, a successful project should have a sufficiently high market value for the Firm, when comparing with the scientific value that a success brings to the University. Second, the effort of the University should be sufficiently relevant for the success of the project. By a similar reasoning, when the Firm contributes to the joint project with non-verifiable effort, it may also be optimal for the University to collaborate in a more applied research project.

This incentive argument offers an alternative explanation for the evidence that firms and universities tend to collaborate in more basic research projects (Caloghirou, 2001; Veugelers & Cassiman, 2005). Some authors, e.g., Rosenberg (1990), justify the involvement of firms in collaborative projects of basic research, as an long-term investment to acquire complementary knowledge. Ultimately, they argue, this investment would bring some insights on how to better conduct and evaluate firms' own research. The present paper shows another possible justification for the interest of firms in collaborative basic research: it is a tool to motivate the supply of effort of the universities, whenever this effort is sufficiently important to obtain a successful valuable outcome.

The predictions of my model also offer insights with managerial and policy relevant implications. From the perspective of management, this paper emphasizes the importance of committing to a project that aligns the interests of the parties involved in the collaboration.

The ex-ante commitment on the project is specially valuable, whenever they can not commit on the resources to employ. By choosing a project whose characteristics are closer to the interest of the parties, their motivation to collaborate is higher and, thus, is more likely to obtain a successful result.

At the level of the internal organization of research, in firms, it is also possible to derive some managerial implications of my results. In order to motivate highly qualified scientists for the Firm's projects, the Firm may give to those scientists the possibility to continue publishing and to use the results of research in their own scientific agenda. This argument is consistent with the results of Cockburn & Henderson (1998), who find evidence that rewarding researchers in firms, on the basis of their standing in the public rank hierarchy, is associated with firms being more productive than their rivals.

From a policy perspective, this paper stresses the benefits of promoting both a centralized partnership governance, and verifiability of the resources involved in the common project. When the moral-hazard problem from at least one of the partners is the reason for a less efficient collaboration, it may be socially desirable to increase the reward of a successful project, using public funds. The conditions for the optimality of such policy intervention rely, on the one hand, on a high expected gain from the partnership and a high relevance of the non-contractible resources to realize such gain, and on the other hand, on the low cost of the public funds.

The theory of this paper relates to three main branches of literature. First, my results have some features of research partnership literature that shows the efficiency gains of co-operation in R&D, in the presence of spillovers and low degree of competition (e.g., Spence, 1984; Katz, 1986; D'Aspremont & Jacquemin, 1988; Kamien *et al.*, 1992; De Bondt, 1996). Classifying as a *spillover* the positive externality of the effort of a partner on the expected benefit of the other partner, my results are aligned with this literature. In fact, I emphasize, first, that collaborating is preferred to developing research alone, and second, that a centralized structure of governance delivers a more efficient outcome than a decentralized one. In contrast with this stream of work, I consider that there exists only one phase of interaction between partners, and that all benefits from collaboration accrue to the partners. Furthermore, I take into account the peculiarities of firms and universities interaction, namely differences in research goals, and the tensions that can arise due to these divergences.

Second, my paper relates to the literature of moral-hazard problems in teams (e.g., Holmstrom, 1982). As in this literature, I emphasize the inefficiency in the allocation of resources, when individually decided by team members. Nevertheless, we differentiate on the main suggestion to reduce the moral-hazard impact. This branch of literature emphasizes the role of the principal and a non-balanced budget, to ensure that agents' decisions are aligned with the efficient ones. In the present paper, I use the capacity to commit on the characteristics of project, as the mechanism to motivate agents for a higher effort (closer, but not necessarily equal, to the efficient level). Macho-Stadler & Perez-Castrillo (1993) also analyze a moral-hazard problem, considering a principal-agent model with several agents. As in my setting, the structure of incentives aims to elicit cooperation between agents, since it yields more efficient outcomes. Nevertheless, we differ on the main incentive mechanism used to reduce moral-hazard inefficiencies. Their focus is on how the capacity of the group to commit on non-verifiable variables, such as effort and mutual help, can motivate agents to a higher involvement. My focus is on how the proximity of the qualitative characteristics of the activity towards the interests of the agents (the partners) can be the mechanism enhancing the efforts. Moreover, while in Macho-Stadler & Perez-Castrillo (1993) the interest of the agents are aligned, in mine they are divergent, thus creating a trade-off when the decision-maker faces double moral-hazard.

Third, a more recent branch of literature focuses on business and science interaction, emphasizing their institutional differences, Aghion *et al.* (2005) and Lacetera (2006). As in my paper, Lacetera (2006) focuses on the distinct goals of each institution: firms seek economic profits, while universities are interested in scientifically valuable knowledge. Similarly to my result, a higher level of effort translates in a larger probability of a successful outcome. Nevertheless, Lacetera (2006) does neither consider a collaborative scenario where both, firm and university, interact, nor does he consider the existence of informational problems in the interaction. Instead, he analyzes the outsourcing of a project to academia as a commitment of the firm not to terminate a project before its completion. That commitment motivates scientists' effort. Aghion *et al.* (2005) also discuss the best allocation of a project between academia and the private sector, based on their institutional differences. Their main argument emphasizes the control rights over research decisions, with scientists praising their freedom in research, and the directness of private sector conveying a disutility for researchers. As a result, academia should develop projects with smaller market value. My main question differs from these two previous works. Considering business and science as different institutions with their own established features, I analyze the characteristics of a simultaneous interaction. Rather than studying *who* develops a project, I ask *what kind of* project is developed by both.

The paper is organized as follows. In the next section, I present the theoretical setting of the model, with the objective functions of both Firm and University, and the characteristics of the collaboration. In Section 3, I explain the collaboration equilibrium outcomes under a centralized partnership governance as well as under a decentralized one, and I compare the outcomes of these two structures. In Section 4, I discuss a policy intervention to support the collaboration through subsidies. In Section 5, I interpret the results of the model and I address their managerial and policy implications. Conclusion remarks are in Section 6. All the proofs are in the Appendix.

# 2 The Model

Firms and universities have different organizational settings and goals towards the production of knowledge. Consider a representative member of each community, namely one university (identified as the $U$niversity) and one firm (identified as the $F$irm). When developing a project, the University seeks to contribute for the existent stock of knowledge. Following the literature, *basic research* is defined as the set of theoretical and experimental research activities aiming to advance knowledge (OECD, 2002). For the Firm, however, the interest of research relies on the potential applications that can be derived from the new discoveries. Let *applied research* be the production of knowledge with the purpose of meeting a specific recognized need. Stressing the difference between these two research approaches, I represent them as opposite extremes of a line, as Figure 1a shows.


Figure 1a: Applied Research and Basic Research.

A research project is identified by a point in this line, representing a combination of both goals. The outcome of a project is either a success or a failure. For the Firm, a successful project translates into an invention with *market value*, $V_F$. The Firm receives all the benefits from the market value of the new discovery. For the University, a success represents a scientific publication with a certain *scientific value*, $V_U$. The scientific value of the discovery, hence of the publication, determines the reward of the University. Both values, $V_F$ and $V_U$, depend on how applied (or symmetrically, how basic) is the research.

For simplicity, I consider the preferences of the two parties, Firm and University, towards the type of project, as single-peaked. Considering the two most preferred projects (one for each party), I normalize the distance between them to one. I then identify each party with its most preferred project, respectively, at 0 and 1. Figure 1b represents the normalization.

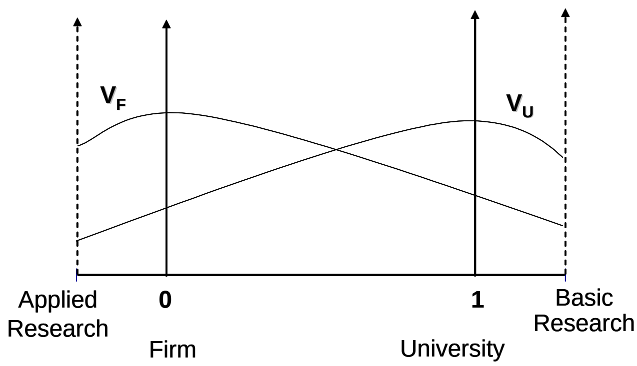


Figure 1b: Normalization of the values of a successful project.

Since, in reality, Firm's interests are closer to applied research and University's to basic research, these new extremes of the line are the most applied and most basic projects that are now relevant. Figure 1c represents the new project domain.

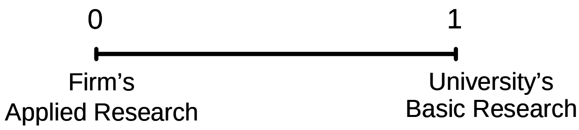


Figure 1c: Relevant range of research projects.

A point $x \in [0, 1]$ in this new (shorter) line describes the type of a research project. $x$ represents the relative importance of the basic research features of the project, and $(1 - x)$ the relative importance of its applied characteristics. Since, by definition of the line, the highest possible benefit for the Firm comes from project $x = 0$, and for the University from project $x = 1$, it is possible to define the market and the scientific values of all the projects in the range as follows:

$$V_F(x) = B_f - m_f x, \tag{1}$$
$$V_U(x) = B_u - m_u (1 - x), \tag{2}$$

where $B_i$ represents the highest possible value of a success, for party $i$ $(i = f, u)$, and the slope $m_i$ indicates the *marginal loss* that $i$ incurs when developing a research project that is farther from its most preferred option. I consider $1 \leq B_i < \infty$ and $m_i \in (0, 1)$. The value of $m_i$ can also reflect the distance between the research goals of the Firm and the University. The closer the interests, the smaller the value of $m_i$. Thus, a smaller $m_f$ is associated with more science-base industries, and a smaller $m_u$ with academic departments whose interests are more applied.

As expressions (1) and (2) make explicit, the source of conflict between the two parts lies on how applied is the research, in comparison with what is individually preferred. The type of project, $x$, then becomes an important decision variable, and the results depend on the relative value of $m_f$ in comparison with $m_u$. For the sake of simplicity, I consider $m_u < m_f$, and discuss how results change for the remaining cases ($m_u = m_f$, and $m_u > m_f$). Also for questions of simplicity in notation, $M_0 = \frac{B_f}{B_u - m_u}$ represents the ratio of market-scientific values at $x = 0$, and $S_1 = \frac{B_u}{B_f - m_f}$ the ratio of scientific-market values at $x = 1$.

The market value $V_F$, and the scientific value $V_U$ are, however, achievable only in the case of a *successful* outcome for the research project. In the alternative scenario of a *failure*, the project brings no value for the partners. The probability of each outcome depends on the efforts exerted by the partners. Through collaboration, each party benefits from the effort exerted by the other party. Assume $p$ is the probability of a success, while $(1 - p)$ the probability of a failure, where $p$ depends positively on the efforts that both collaborators exert:

$$p = ke_f + (1-k)e_u. \tag{3}$$

The variable $e_i$ denote the effort exerted by party $i$, while the parameter $k$ represents the substitution rate of $e_f$ by $e_u$. I consider $e_i \in (0,1)$, and $k \in (0,1)$.

Each institution $i$ bears a cost $C_i$ associated to a certain effort level $e_i$, given by:

$$C_F = \frac{c_f}{2}e_f^2, \tag{4}$$

$$C_U = \frac{c_u}{2}e_u^2. \tag{5}$$

The cost coefficients $c_i \in \mathbb{R}^+$ are such that $c_f > k(B_f + B_u - \tilde{m})$ and $c_u > (1-k)(B_f + B_u - \tilde{m})$, with $\tilde{m} = \min(m_f, m_u)$.[4]

For simplicity of notation, consider $R_U = \frac{(1-k)^2 c_f}{k^2 c_u}$ the benefit-cost ratio of the University's effort relative to the Firm's effort, while $R_F = \frac{1}{R_U}$.

Using (1), (3), and (4), the Firm's expected gain from developing a research project together with the University, $E\Pi_F$, is described by:

$$E\Pi_F = pV_F(x) - C_F. \tag{6}$$

Using (2), (3), and (5), the University's expected reward from collaborating is:

$$E\Pi_U = pV_U(x) - C_U. \tag{7}$$

As far as the structures for governing the partnership are concerned, I consider two possible alternatives: a centralized, and a decentralized ones. The main difference between these two structures of governance relies on who decides over the main characteristics of the collaboration (type of project, efforts): either one of the parties, *decentralized* structure; or a third entity, which considers the aggregate interest of the two partners, *centralized* structure.

Under the *centralized* structure, the Firm and the University (after agreeing to collaborate) create a separate entity, the *Consortium*, to manage the collaboration. The Consortium chooses the best joint project $x$, and if possible also the amount of effort that each partner should exert in the project $(e_f, e_u)$. Both, type of the project and resources, are settled by contract. Nevertheless, informational constraints may prevent the contractibility of the efforts of the partners. I consider different scenarios, regarding the verifiability of efforts: both $(e_f, e_u)$ are verifiable, only one is, none is.

Consortium's objective is to maximize the joint expected net benefit of the collaboration, $EW = E\Pi_F + E\Pi_U$. As explicit in this objective, I assume the Consortium gives equal weight to each of the partners.

[4] In this domain for $c_i$ we guarantee that $e_f$ and $e_u$ always lay in the interval $(0,1)$.

The sequence of the actions under centralized structure is: first, the Consortium decides over the collaboration characteristics; second, partners exert effort; third, Nature plays, deciding whether the project is successful or not, and finally each partner receives its revenues from the research.

Under the alternative *decentralized* structure, the relation is promoted by one of the parties. Instead of a common manager, it is now one of the collaborators who chooses the project to be jointly developed, and presents it to the other party. For simplicity of the analysis, I consider the effort exerted by the party promoting the collaboration is always verifiable. However, the effort that the other party devotes to the common project may be contractible or not. I then consider two alternative scenarios: first, when the effort of the other party is verifiable, and second when it is not. In the former scenario, the promoter of the collaboration designs a contract defining the project type, $x$, and the efforts. In the later scenario, the promoter only decides $x$ and its own effort. Once the collaboration proposal is accepted, each partner allocates its resources to the common project. Finally, Nature plays, deciding whether the project is successful or not, and each partner receives its revenues from research.

Table 1 presents the summary of the several contexts, as well as the notation used afterwards to identify each different situation.

| INFORMATION / MANAGEMENT | Consortium | Firm's initiative | University's initiative |
|---|---|---|---|
| Both $(e_f, e_u)$ verifiable | $*$ | $1FG$ | $1UG$ |
| Only $e_f$ verifiable | $AU$ | $2FG$ | $non-applicable$ |
| Only $e_u$ verifiable | $AF$ | $non-applicable$ | $2UG$ |
| Both $(e_f, e_u)$ non-verifiable | $AUF$ | $non-applicable$ | $non-applicable$ |

Table 1: Different contexts to analyze.

Under the management of the Consortium, four alternative contexts are taken into account, namely situations $*$ (first-best), $AU$, $AF$, $AUF$. When the Firm governs the collaboration, its effort $e_f$ is always assumed verifiable, and the only informational change relates with the verifiability of $e_u$. As a consequence, under Firm's initiative there is only two relevant contexts: $1FG$ and $2FG$. Similarly, when is the University governing the collaboration, the two contexts to take into consideration are $1UG$ and $2UG$.

**Outside option** Instead of collaborating, each party has the possibility to develop the research by its own, alone.[5] Research alone, however, translates in a small probability of

[5] In a more general setup, we could just consider as alternative for collaboration, a (general) action for each party, that would yield a payoff of $\bar{u}_i$ (also general). By considering the specific case of *doing research alone*, we not only endogenize results, but also gain some insights on the comparison of the two research scenarios (alone and with collaboration).

success, or a higher cost, or both.

When the Firm develops research alone, its choice solves the following problem:

$$\max_{\{x,e_f\}} E\Pi_F = p_F V_F(x) - C_F, \tag{8}$$

where $p_F = ke_f$ is the probability of a successful outcome. In the optimal solution, the Firm develops the project type $x = 0$, exerts an effort $e_{f,alone} = \frac{kB_f}{c_f}$, and obtains an expected profit of $E\Pi_{F,alone} = \frac{k^2 B_f^2}{2c_f}$.

Similarly, when the University performs research without collaboration, it succeeds with probability $p_U = (1-k)\,e_u$. The best solution is to exert an effort of $e_{u,alone} = \frac{(1-k)B_u}{c_u}$ for the project type $x = 1$. This yields an expected benefit of $E\Pi_{U,alone} = \frac{(1-k)^2 B_u^2}{2c_u}$.

Comparing (8) and (6), the University's effort has a positive externality over Firm's expected gain (and vice-versa). Departing from a situation of doing research alone, collaboration represents an increase in the total expected gain, for a given project type $x$. The issue, however, is the opposite interests of the parties towards $x$. As a result, the decision of whether to collaborate or to develop research alone involves a trade-off: on the one hand, doing research alone enables to select the most preferred project; on the other hand, under collaboration, the partner contributes to the success of the project. When the benefit-cost ratio of the University's effort ($R_U$) is high, academics contribution to the success is relatively high. In this case, we expect the Firm to be more willing to collaborate. Conversely, the University prefers collaboration when the effort of the Firm is relatively important for a success, that is, when $R_F$ is high. The calculus confirm this intuition.

The aim of this paper, however, is to focus in the role of *incentives* on the outcome of collaboration. Therefore, and for the sake of simplicity, I postpone the presentation and discussion of the exact participation constraints to the Appendix.

In the next section, I present the collaboration outcomes, once adopting Sub-game Perfect Nash Equilibrium as the solution concept.

# 3 Collaboration Outcomes

## 3.1 Consortium Governance

The outcome of the Consortium governance depends on the verifiability, hence contractibility, of the resources that each partner devotes to the joint project.

### 3.1.1 First-best: both efforts are verifiable

In the first-best scenario, the Consortium verifies the effort of both partners and, therefore, includes them in the collaboration contract. Knowing the impact that the resources of each partner has on the expected revenue of the project, the Consortium asks effort levels that equate their marginal cost to their marginal revenue. Proposition 3.1 presents the optimal joint project.

**Proposition 3.1** *When the effort of both partners is verifiable, their optimal level depends on the total value of a successful project:*

$$\begin{aligned} e_f^* &= \frac{k}{c_f}\left[V_F(x) + V_U(x)\right], \\ e_u^* &= \frac{1-k}{c_u}\left[V_F(x) + V_U(x)\right]. \end{aligned}$$

*In this situation, the maximum joint expected gain from collaboration is*

$$EW^* = \frac{1}{2}\left[\frac{k^2}{c_f} + \frac{(1-k)^2}{c_u}\right]\left[B_f + B_u - m_u - (m_f - m_u)x\right]^2. \tag{9}$$

*Considering $m_f > m_u$, the best project is the one with the highest market value, that is, the most applied research.*

At the optimal level of efforts, the maximum joint expected gain from collaboration is convex in the type of project $x$, and therefore the optimal joint project is located at one of the extremes of the line, $x = 0$ or $x = 1$. When $m_f > m_u$, the stakes of the Firm are higher than of the University, meaning that the Firm looses more from a less applied project, than the University looses when deviating from its most preferred basic research. As a result, the sum of the expected gains is maximized when the Consortium decides to implement the most applied project. Figure 2 represents the situation.

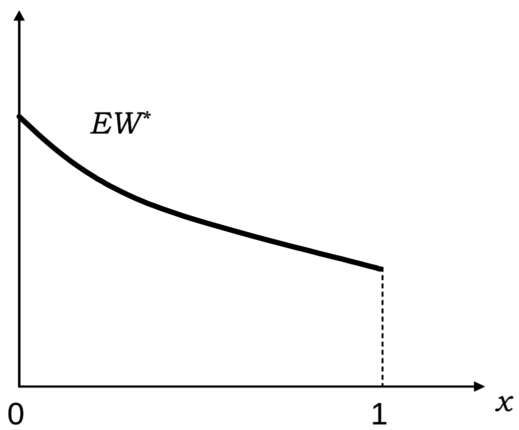


Figure 2: Joint expected gain with verifiable efforts, when $m_f > m_u$.

In the opposite case, when $m_f < m_u$, the loss in the scientific value from a less basic project would be the largest, and the best choice would be at $x = 1$. In a third (alternative) case of $m_f = m_u$, any project in the interval $[0, 1]$ would be equally preferred by the Consortium.

The next corollary presents comparative statics results for the first-best scenario.

**Corollary 3.1** *In the first-best collaborative scenario (Consortium, and verifiability of both efforts):*

1. *the optimal research project does not change with the parameters $k$, $c_i$, or $B_i$ (for $i = f, u$). As long as $m_f > m_u$, the optimal project is always the one with the highest market value;*

2. *the maximum joint expected gain from collaboration increases with: i) a greater relative importance of the Firm's effort for the success of the project, $k$, as long as $k > \frac{c_f}{c_f + c_u}$; ii) a smaller cost coefficients, $c_i$; iii) a higher market or scientific values, $B_i$; and iv) a smaller marginal loss in the scientific value due to a less basic project, $m_u$.*

When the efforts of the partners are contractible, the Consortium's decision internalizes the positive effect that the effort of each partner has on the expected gain of the other. The optimal decision for the efforts, then, depends on the sum of both market and scientific values. This implies that the optimal type of project $x$ only depends on how it affects that sum of values, that is, on the relation between $m_f$ and $m_u$. A change in the remaining parameters does not affect this reasoning.

When $k$ increases, the Firm's effort becomes relatively more important for the success of the project and, therefore, the optimal $e_f$ increases. Since an increase in $k$ is equivalent to a decrease in $(1 - k)$, for the University the opposite holds, that is, the optimal $e_u$ decreases. Considering the increase in Firm's effort, it has both a positive impact on the probability of success, and a negative impact of enhancing the costs. The decrease in the University's effort has opposite effects. When $k > \frac{c_f}{c_f + c_u} \iff 1 - k < \frac{c_u}{c_f + c_u}$, the positive effects of the changes in the efforts dominate and, as a consequence, $EW^*$ increases.

When one of the cost coefficients $c_i$ increases, the optimal level of $e_i$ decreases. This translates into a smaller probability of a success, and hence in a reduction of $EW^*$. Also, when $B_i$ increases, a successful project brings a larger benefit, hence a larger expected gain $EW^*$.

Finally, a University with more applied interests, characterized by a smaller $m_u$, gets a higher scientific value at the first-best research project $x = 0$. As a result, the maximum possible $EW^*$ is higher.

### 3.1.2 At least one effort is non-verifiable

When the effort exerted by one or both of the parties is non-verifiable, its choice of effort dedicated to the common project depends on its individual interest. At the first stage, the Consortium takes into account those interests of the partners, when choosing the type of project to be jointly developed. Considering the following pairs of regions of parameters, the next proposition states the result:

**Region $1^{AU}$:** $M_0 > \frac{m_f}{m_u} - 1$ and $R_U > \frac{(m_f - m_u)(M_0+1)}{m_u M_0 - (m_f - m_u)}$;

**Region $2^{AU}$:** otherwise.

**Region $1^{AUF}$:** $M_0 > \frac{m_f}{m_u} - 1$ and $R_U > \frac{(m_f - m_u)M_0 + m_f}{m_u M_0 - (m_f - m_u)}$;

**Region $2^{AUF}$:** otherwise.

**Proposition 3.2** *The level of effort that each party $i$ exerts depends on its verifiability:*

$$\begin{aligned} \text{if } e_i \text{ is verifiable, } e_i &= \frac{k_i}{c_i}\left[V_F(x) + V_U(x)\right], \\ \text{if } e_i \text{ is non-verifiable, } e_i &= \frac{k_i}{c_i} V_i(x), \end{aligned}$$

*where $k_i = k$ for $i = F$, or $k_i = 1 - k$ for $i = U$.*

*The best joint collaborative project chosen by the Consortium also depends on the (non) verifiability of the efforts, according to the following rule:*

| | *Optimal* | *project* |
|---|---|---|
| *Non-verifiable effort* | $x > 0$ | $x = 0$ |
| *only* $e_u$ | *Region* $1^{AU}$ | *Region* $2^{AU}$ |
| *only* $e_f$ | *never* | *always* |
| *both* $e_u, e_f$ | *Region* $1^{AUF}$ | *Region* $2^{AUF}$ |

*Furthermore, in Region $1^{AUF}$ we have $0 < x^{AUF} < x^{AU}$.*

Figure 3 plots the results related with the choice of the project:

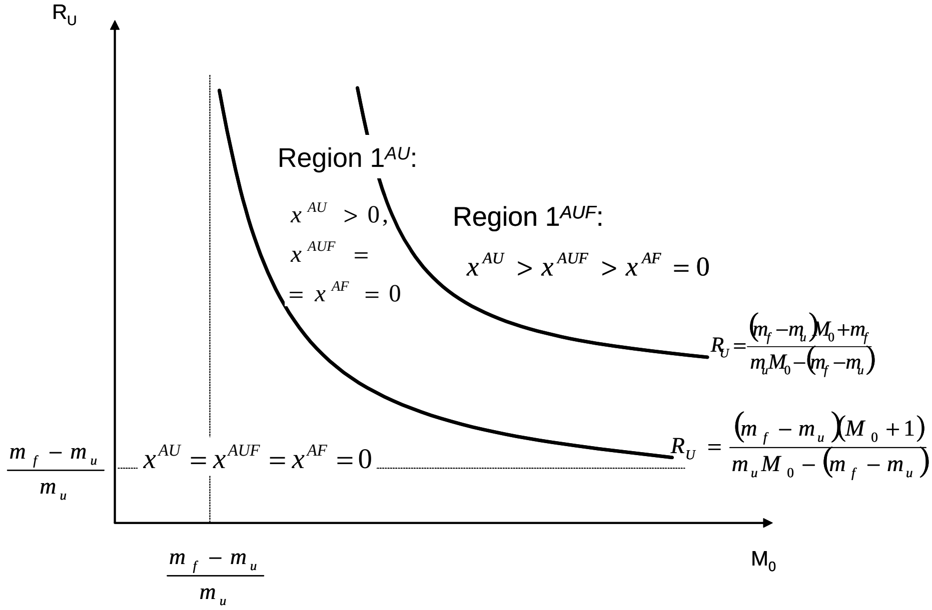


Figure 3: Consortium's optimal project with $e_u$ non-verifiable $(AU)$, with $e_f$ non-verifiable $(AF)$, and with both $e_u$ and $e_f$ non-verifiable $(AUF)$.

When resources are non-contractible, the Consortium knows that the more benefit a partner obtains from a project, the larger is the amount of resources it is willing to allocate to that project. When the non-contractible resources of a partner are specially important for the expected joint benefit of the collaboration, the Consortium's best option is to deviate from its first-best project and to approach the interests of that partner. The increase in the probability of success compensates the decrease in the total value of a successful outcome, and hence the expected benefit increases. More specifically:

- when $e_u$ is non-verifiable, the University is not willing to devote as much resources for an applied project as it would be jointly preferred. In Region $1^{AU}$, the relative market value of the invention $M_0$ is sufficiently high, meaning that a successful project brings a relatively high market value. Also in Region $1^{AU}$, the benefit-cost of the University's effort $R_U$ is sufficiently high, meaning that the University's resources are important for the success of the collaborative research. Both conditions ensure that the Consortium is sensible to academics' preferences. Since a research project closer to the University's interests acts as an incentive for its effort, the Consortium prefers to select a less applied (more basic) project than in the first-best solution;

- when the Firm contributes with non-contractible effort for the joint project, it does not consider the positive externality that its effort has on the University's expected gain. As a result, the Firm chooses to exert less effort than it is jointly desirable. In order to reduce as much as possible the impact of such individualistic approach, the Consortium prefers a project closer to the Firm's interests. Given $m_f > m_u$, the first-best project is already the most preferred of the Firm, thus no further distortion can be made. This means that, under $m_f > m_u$ and verifiability of University's effort, the best joint project is exactly the same as in the first-best scenario;

- in the presence of a double moral-hazard, the divergence of preferences creates an ambiguity on how to use the type of project as an incentive mechanism. The result depends on whose effort is more important for the success of the project and how valuable is such success. In Region $1^{AUF}$, a successful result brings a sufficiently high relative market value (high $M_0$), and the University is relatively important for such outcome (high $R_U$). Therefore, in Region $1^{AUF}$, University's interests dominate and $x$ is more basic than in first-best.

  In the case of double moral-hazard, the effort of the Firm is also non-contractible. In order to motivate it, the Consortium chooses a more applied project than in the case where only University's effort is non-verifiable.

Figure 4 depicts the comparison of best projects for the Consortium as well as the expected joint benefit, under the different informational contexts, for parameters in Region $1^{AUF}$.

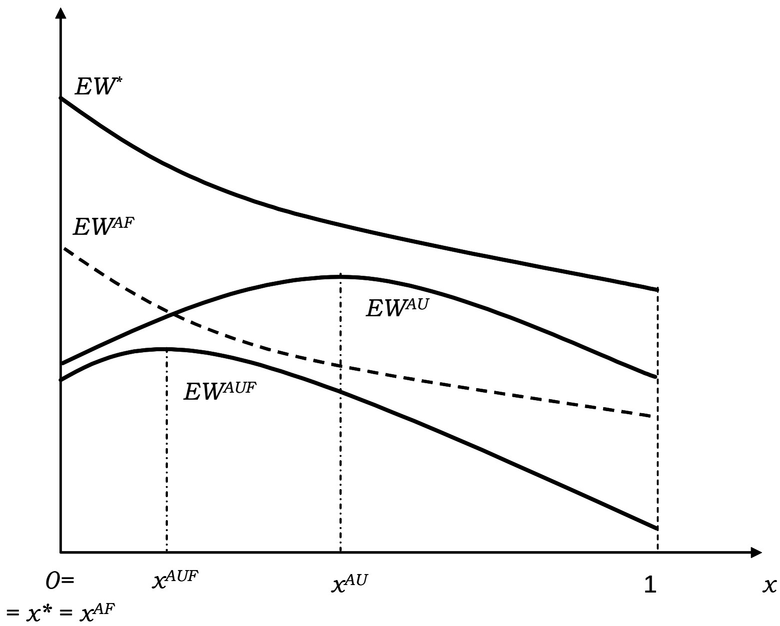


Figure 4: Optimal joint expected gain under first-best ($EW^*$), moral hazard from one of the partners (Firm, $EW^{AF}$; University, $EW^{AU}$), and double moral-hazard ($EW^{AUF}$).

I now present some comparative statics results for the collaboration outcome, when University's effort is non-contractible.

**Corollary 3.2** *Under non-verifiability of University's effort, the best collaborative project in Region 1$^{AU}$ becomes closer to the University's interests when: i) $B_f$ increases, thus increasing the market value of the invention; ii) $B_u$ decreases, thus decreasing the scientific value of the publication; iii) the importance of the Firm's effort for the success, $k$, decreases; iv) the Firm's effort becomes more costly, higher $c_f$; v) the University's effort becomes less costly, smaller $c_u$; vi) the loss in the market value of a less applied invention, $m_f$, decreases; vii) the loss in the scientific value of a less basic publication, $m_u$, increases.*

A higher market value, $B_f$, increases the importance of the University's involvement in the research, to ensure a larger probability of success. The Consortium selects a project closer to University's interest, as an incentive mechanism for $e_u$. Conversely, when $B_u$ increases, the higher scientific value of the research already acts as a motivation for the University. The optimal collaborative project can be more applied, closer to the first-best.

When $k$ decreases, the Firm's effort becomes relatively less important for the success of the project, whereas for the University the opposite holds. In order to induce a higher $e_u$, the Consortium chooses a less applied project.

With a higher coefficient cost $c_f$, the optimal level of Firm's effort decreases. A smaller $e_f$ means a smaller probability of success. This reduction may, however, be partially compensated by increasing the University's effort. In order to induce such larger involvement of the University, the project becomes more basic research, that is, $x$ increases. The inverse happens, $x$ becomes more applied, when the University's effort is more costly, through a higher $c_u$.

A smaller marginal loss $m_i$ means that partner $i$ experiments a smaller loss, when the project is different from its most preferred. When $m_f$ is smaller, the impact on the market value of the invention due to a less applied project is smaller and, therefore, Consortium may afford to choose a project closer to the University's interests. Conversely, a smaller $m_u$ is linked with a smaller loss in the scientific value whenever the project is more applied. In this case, the Consortium prefers a more applied project.

When it is possible to establish transfers between partners, the incentive for the involvement of a partner in the joint project may also come through a share in the revenue of the other partner. The next proposition formalizes this result, for the case when only the University's effort is non-verifiable, and academics receive a share $t_f \in [0, 1)$ of the market value of a successful invention. We consider the two following regions of parameters:

**Region 1$^{AUT}$:** $M_0 > \frac{m_f - m_u}{m_u - m_f(2-t_f)t_f}$ and $R_U > \frac{(m_f - m_u)(M_0+1)}{[m_u - m_f(2-t_f)t_f]M_0 - (m_f - m_u)}$;

**Region 2$^{AUT}$** : otherwise.

**Proposition 3.3** *With non-verifiability of the University's effort, if the University receives a share of the market value from a successful project, the joint optimal project is closer to the first-best. In particular, in Region $1^{AUT}$, the joint preferred type of project is between the first-best and the one chosen when no share is given. In Region $2^{AUT}$, the project is exactly the first-best.*

When $e_u$ is non-verifiable, denote by $x^{AUT}$ the best project when the University receives a share $t_f$, and by $x^{AU}$ the best project when $t_f = 0$. Figure 5 presents the proposition, in Region $1^{AUT}$.

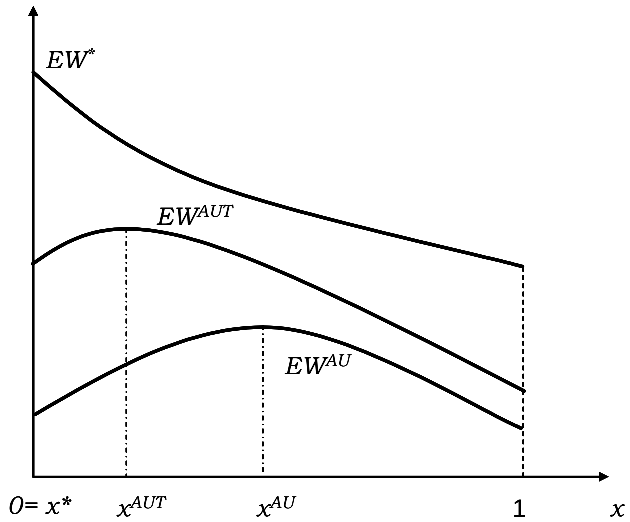


Figure 5: Joint expected gain in the first-best ($EW^{*}$), and under University's moral-hazard (with transfer, $EW^{AUT}$; without transfer, $EW^{AU}$).

*Region* $1^{AUT}$ emphasizes the high market value of a successful research (high $M_0$), as well as the relative importance of the University for such success (high $R_U$). Under this region, the Consortium selects a less applied project than in the first-best, in order to motivate academics' effort. Making the University also a beneficiary of a successful invention is an alternative way of motivating its scientists. As a result, the higher is $t_f$, the closer is the research to the first-best. Nevertheless, the higher is $t_f$, the lower is the remaining share for the Firm. The boundary level of Firm's expected gain that still makes it willing to collaborate dictates the optimum value of $t_f$.

An alternative way of comparing both situations, with and without transfer, is to analyze both regions $1^{AUT}$ and $1^{AU}$. Since *Region* $1^{AUT} \subset$*Region* $1^{AU}$, the conditions ensuring $x^{AUT} > 0$ are more restrictive than the ones for $x^{AU} > 0$.[6]

Similarly, when only the Firm's effort is non-verifiable, it is jointly beneficial to transfer a share of the University's revenue to the Firm. This transfer would not change the optimal

[6] Figure 9, in the Appendix, represents these two regions.

project chosen by the Consortium (since it is already the first-best $x = 0$), but it increases the amount of effort that the Firm is willing to exert in the collaboration. As such, it enhances the joint expected gain.

## 3.2 Decentralized Governance

Under a decentralized governance structure, one of the parties involved, the Firm or the University, proposes to the other the joint development of a research project. The governing party designs a contract with the characteristics of the relation, which the other party can accept or reject. Apart from defining the type of the common project and the effort of the party in governance, the contract may also specify the amount of resources that the second party should devote to it. This specification of effort may or not be possible, depending on their verifiability. I analyze both cases: when the effort of the other party is verifiable, and when it is not.[7]

### 3.2.1 Firm's governance

**When $e_u$ is verifiable,** the Firm proposes to the University a contract that specifies the type of project and the amount of effort that the academics must exert. The freedom of the Firm in designing the contract is, however, limited by the outside option of the University. The following proposition states the result, considering two regions of parameters:

**Region 1$P_U$:** $R_F > \frac{m_u^2[m_f^2(2B_u - m_u) + m_u B_f^2]}{2m_f^2(B_u - m_u)[m_f(B_u - m_u) + m_u B_f]}$;

**Region 2$P_U$:** otherwise.

**Proposition 3.4** *When University's effort is verifiable and the Firm designs the collaborative contract, the University earns as much as in its outside option of developing research alone. In Region 1$P_U$, the Firm proposes its most preferred project $x = 0$. In Region 2$P_U$, the Firm proposes a more basic project, $x > 0$.*

Due to divergences in the preferences and the existence of an outside option for the University, the Firm may face some constraints in selecting its most preferred project under collaboration. As long as its contribution for the success is relatively more important than the University's contribution (high benefit-cost ratio of the Firm $R_F$, or equivalently, low $R_U$), the Firm selects $x = 0$. This is the case in Region 1$P_U$. There, the damage that an

[7] Under the decentralized governance, the effort of the party in governance is considered verifiable. Introducing non-verifiability of this effort, would induce an additional incentives contraint. Since this increase in complexity of qualitative results would not have a qualitative impact, the verifiability assumption is kept.

applied project causes to the University is completely compensated by the increase in the probability of success when collaborating with the Firm.[8]

**When $e_u$ is non-verifiable,** the Firm's best contract takes into consideration not only the participation constraint of its partner, but also the role of incentives of a more basic project towards inducing a higher $e_u$. Considering the two following regions, the next proposition states the result:

**Region $1^{FG}$:** $M_0 > \frac{m_f}{m_u}$ and $R_U > \frac{m_f M_0}{m_u M_0 - m_f}$;

**Region $2^{FG}$:** otherwise.

**Proposition 3.5** *Under non-verifiability of University's effort, the Firm may propose a less applied project than its most preferred one, to increase University's involvement. This is the case in Region $1^{FG}$, where $x > 0$. In Region $2^{FG}$, the Firm chooses exactly its most-preferred project, $x = 0$.*

In Region $1^{FG}$, a successful research brings a sufficiently high relative market value (high $M_0$), and the relative contribution of the University for such success is significantly high (high $R_U$). Under such conditions, the Firm chooses a less applied project than its most preferred, that is, $x > 0$, to motivate University's effort.

### 3.2.2 University's governance

**When $e_f$ is verifiable,** the collaboration contract that the University designs is only constrained by the willingness of the Firm to participate in such joint project. When the relative importance of the Firm to have a successful project is high (high $R_F$), its participation constraint induces the University to choose a less basic project than its most preferred. Otherwise, the University proposes the joint development of $x = 1$, and a level for $e_f$ that makes the Firm (almost) indifferent between collaboration and its outside option.

**When $e_f$ is non-verifiable,** the choice of the project becomes an instrument to motivate Firm's involvement in the common project. Considering the two following regions, the next proposition states the result.

**Region $1^{UG}$:** $S_1 > \frac{m_u}{m_f}$ and $R_F > \frac{m_u S_1}{m_f S_1 - m_u}$;

[8] As stated in the *Model* section, in this paper the focus is the role of incentives for the outcome of collaboration. As Proposition 3.4 shows, however, participation constraints can also affect the outcome of collaboration. Future work may enlarge this discussion.

**Region $2^{UG}$:** otherwise.

**Proposition 3.6** *When the University governs the collaboration and Firm's effort is non-verifiable, the chosen project may not be the University's most preferred, as a way to motivate Firm's effort. In Region $1^{UG}$ the project is more applied than the University's most-preferred, $x < 1$. In Region $2^{UG}$, the University chooses $x = 1$.*

In Region $1^{UG}$, the relative scientific value of a discovery ($S_1$), as well as the Firm's importance for such success ($R_F$) are high enough to make the University sensible to Firm's interests. As a result, the best option for the academics is to propose the joint development of a less basic project than its most-preferred. By doing so, the University gives an incentive to a higher effort of the Firm and, hence, increases its own expected gain.

## 3.3 Comparison of outcomes: Centralized *vs* Decentralized governance

From the previous analysis, we may conclude that the type of research under collaboration can be used as an incentive tool, both under centralized and decentralized structures of governance. Nevertheless, the optimal project is not always the same for both structures. In fact, when the Firm governs the collaboration and selects a less applied project than its most-preferred (and first-best), it is also true that a Consortium facing moral-hazard from the University also prefers $x > 0$. Taking into account the conditions that ensure $x > 0$ for the centralized context with either moral-hazard from the University (situation $AU$) or double moral-hazard (situation $AUF$), and for the decentralized context with Firm's initiative (situation $F$), we conclude that: Region $1^{FG}$ $\subset$Region $1^{AUF}$ $\subset$Region $1^{AU}$. Furthermore, the following corollary holds:

**Corollary 3.3** *In the Region $1^{FG}$, it is possible to establish the following comparison between optimal research projects:* $0 < x^F < x^{AUF} < x^{AU}$.

Figure 6 below presents this corollary as well as the expected joint gain for the different scenarios, considering parameters in Region $1^{FG}$.

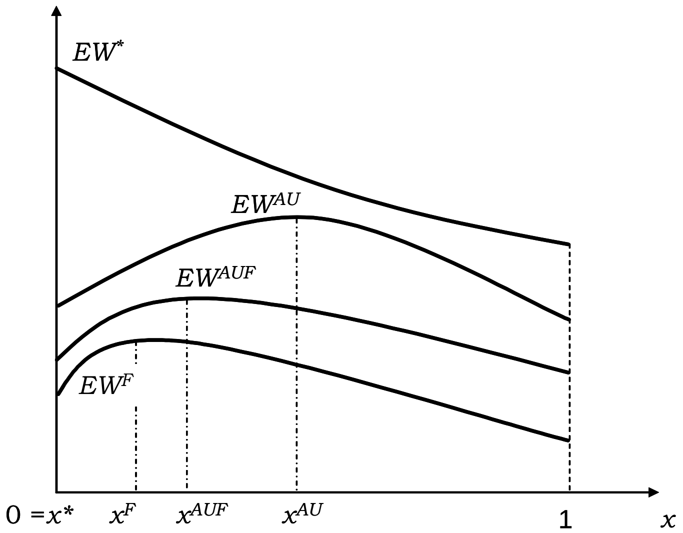

Figure 6: Joint expected gain under Consortium ($EW^*$, $EW^{AU}$, $EW^{AUF}$), and under Firm's governance with non-verifiable $e_u$ ($EW^F$).

A similar reasoning can be developed for $x = 1$. Comparing University and Consortium governance, having the University choosing a less basic project than individually it would prefer, is a sufficient condition for all the remaining projects being also smaller than 1.

# 4 Policy Intervention: Prize

From the previous section, it is clear that informational asymmetries on the amount of effort that each partner decides to allocate to the common project, affect the outcome of such collaboration. In order to reduce the negative impact of a moral-hazard problem, the governor of the relationship (either the Consortium or one of the partners) may decide to deviate from its most preferred project. An additional way to reduce inefficiencies arising from the moral-hazard problem is to allow a monetary transfer between partners. In this section, I analyze a third mechanism to motivate the partners to dedicate more resources for the collaboration: through (public) prizes.

Given that raising public funds is costly, society is only willing to give an extra-reward for the collaborative research, when the associated benefits more than compensate.[9] In the case of a research project, these benefits can be several. In the framework of the present paper, all the benefits are already considered in the values of the project. Nevertheless, society may still be interested in promoting a more efficient outcome by increasing the reward of a

[9] As explicit in the model and common in the literature, the cost of public funds relates not only to the decrease of resources somewhere else, but also to distortions that such decrease creates (Laffont & Tirole, 1993).

successful project developed under collaboration, that is, by giving a *prize*. The conditions presented here under which this public intervention is optimal, may then be consider as a *lower boundary* for those cases where other benefits for society may exist.

The previous analysis of collaboration outcome considers two alternative governance structures: centralized and decentralized. It has been shown that the centralized structure allows to obtain a higher joint expected gain and, hence, leads to a more efficient outcome. The conditions under which society prefers to give an extra-reward for the collaboration with centralized governance, are then sufficient to ensure that society also prefers to intervene under a decentralized structure. Therefore, I only focus on giving an extra-reward (prize) for research collaboration with Consortium governance.

Let $z \geq 0$ represent the prize for the research that is already collaborative, and $\lambda \in \mathbb{R}^+$ be the cost of such public funds. Considering that both market and scientific values reflect all the benefits from a research project, a Social Planner's objective function is represented by:

$$\begin{aligned} ES &= p\left(V_F + V_U + z\right) - C_F - C_U - (1+\lambda)\, zp \\ &= p\left(V_F + V_U - \lambda z\right) - C_F - C_U. \end{aligned}$$

The probability of success $p$, the market and scientific values of a successful outcome, $V_F$ and $V_U$, and the cost of resources involved, $C_F$ and $C_U$, are the same as defined in the Section 2 (expressions (3), (1), (2), (4), and (5), respectively).

Let us consider the case where the Social Planner has the capability to define both the total amount of the prize, $z$, and the fraction that each party receives: $\alpha \in [0, 1]$ is the fraction for the Firm, whereas $(1 - \alpha)$ the fraction for the University. After observing the Social Planner's decision, the Consortium decides on the type of project to develop, and on the amount of resources to allocate, in a similar way as before.

The objective functions for the Firm, the University, and the Consortium are now, respectively:

$$E\Pi_F = p\left(V_F + \alpha z\right) - C_F,$$

$$E\Pi_U = p\left[V_U + (1-\alpha)\, z\right] - C_U,$$

$$EW = E\Pi_F + E\Pi_U.$$

When both efforts are verifiable and, hence, contractible, the Consortium chooses the project $x = 0$, whether there is or not a prize. Since the Consortium's decision does not consider the cost of the public funds, $\lambda$, the possibility of having a prize leads to excessive levels of effort, from the social point of view. Therefore, in the symmetric information case, the best social solution is not to give a prize to collaboration.

When the involvement of at least one the collaborators is non-contractible, however, it may be optimal to give a prize for such partner. The prize not only motivates the non-contractible effort, but also allows to choose a project that is closer to the first-best. Next proposition states the result.

**Proposition 4.1** *When the effort of at least one of the partners is non-verifiable, its effort is sufficiently important for the success of the project, the success of the project is sufficiently valuable, and the cost of public funds is not very high, it is optimal to give a prize to such partner.*[10]

*In case of a double moral-hazard, either* $\alpha = 0$ *or* $\alpha = 1$, *that is, it is never socially optimal to simultaneously give a prize to both partners.*

*Furthermore, with a prize, the optimal project comes closer to the first-best.*

When only University's effort is non-verifiable, the Consortium may motivate the University for a higher involvement by choosing a project closer to its most-preferred, as seen in the previous section. Under such scenario, the prize has the double impact of increasing the resources involved in the research, and of approximating the project type to the first-best ($x = 0$). When the cost of collecting public funds is not very high, the socially optimal solution is to attribute a prize to the University, which acts as an incentive substitute of a more basic research.

When only Firm's effort is non-verifiable, the Consortium chooses the most applied research, independently of the existence or not of a prize. When the cost of public funds is not very high, however, it may be socially desirable to attribute a prize to the Firm. Such intervention increases the involvement of the Firm in the collaborative research to an amount closer to the first best, thus improving the probability of a successful outcome.

When the efforts of both partners are non-verifiable, the previous arguments justify the allocation of a prize for their involvement on the collaborative project. Nevertheless, only one of the two partners should receive the extra-reward. When $R_U$ is high, the University effort is relatively more important for a successful outcome. Giving a prize to academics increases the amount of resources that they are willing to devote for the collaboration project and, hence, the expectation of a joint gain enlarges. Conversely, when $R_F$ is high, the prize should be given to the Firm.

[10]In the Appendix, the proof of the proposition makes explicit the upper boundary of $\lambda$ compatible with the prize of each partner.

# 5 Generalization

In this section, I show that the results of the previous Sections 3 and 4 are robust to more general specification of the model.

As before, let us consider one University and one Firm, with single-peaked preferences over the type of research projects. The two most preferred projects (one for each party) are the two extremes of a line of unitary measure. A point $x \in [0,1]$ in this line identifies a research project.

In case of a successful outcome, a project developed under collaboration translates in an invention for the Firm and in a scientific publication for the University. The invention has a market value $V_F(x)$, and the scientific publication has a scientific value $V_U(x)$. $V_F$ is a decreasing function of $x$, while $V_U$ is an increasing function of $x$, and each of these functions $V_i$ is non-convex on $x$, i.e., $\frac{\partial V_F}{\partial x} < 0$, $\frac{\partial V_U}{\partial x} > 0$, $\frac{\partial^2 V_i}{\partial x^2} \leq 0$ for $i = F, U$.

In case of a failure, the projects brings no value for any of the two parties. The probability of success depends on the effort that each party exerts to the project, $p(e_f, e_u)$, increasing and non-convex in each of the arguments: $\frac{\partial p}{\partial e_i} > 0$, $\frac{\partial^2 p}{\partial e_i^2} \leq 0$.

For exerting an effort $e_i$, party $i$ has a cost $C_i(e_f, e_u)$, where $\frac{\partial C_i}{\partial e_i} \leq 0$, $\frac{\partial^2 C_i}{\partial e_i^2} \geq 0$.

As far as second-order effects are concerned, let us consider three alternative cases:[11]

1. complementarity of efforts, both in the probability of success and in the costs: $\frac{\partial^2 p}{\partial e_i \partial e_j} > 0$, $\frac{\partial^2 C_i}{\partial e_i \partial e_j} < 0$;

2. substitutability of efforts: $\frac{\partial^2 p}{\partial e_i \partial e_j} < 0$, $\frac{\partial^2 C_i}{\partial e_i \partial e_j} > 0$;

3. independence of efforts: $\frac{\partial^2 p}{\partial e_i \partial e_j} = 0$, $\frac{\partial^2 C_i}{\partial e_i \partial e_j} = 0$.

The remain structure of the model, namely in terms of governance and verifiability of efforts, is the same as before.

Consider, first, a centralized structure of governance. When both efforts are verifiable, the decision problem of the Consortium is:

$$\max_{\{x, e_f, e_u\}} EW = p(e_f, e_u)\left[V_F(x) + V_U(x)\right] - C_F(e_f, e_u) - C_U(e_f, e_u),$$

[11] The two initial alternatives (complementarity, and substitutability) are defined in strict sense (with strict inequality). The results for the weak complementarity and weak substitutability (with weak inequality) can, afterwards, be easily deduced.

subject to the participation constraints of both parties. When such constraints are satisfied, collaboration is preferred to a situation where both parties do research alone. The solutions for the Consortium problem follow as:

$$e_i^* \quad : \quad \frac{\partial p}{\partial e_i}(e_f, e_u)\left[V_F(x) + V_U(x)\right] = \frac{\partial C_i}{\partial e_i}(e_f, e_u) + \frac{\partial C_j}{\partial e_i}(e_f, e_u), \tag{10}$$

$$x^* \quad : \quad p(e_f, e_u)\left[\frac{\partial V_F}{\partial x} + \frac{\partial V_U}{\partial x}\right] = 0, \tag{11}$$

where $i, j = F, U$, and $i \neq j$.

With the specific functional forms of Section 2, namely assuming linearity of the values $V_i$ towards the type of project $x$, the best research is either a corner solution or undetermined. Nevertheless, as condition (11) emphasizes, once we leave the linearity assumption, it may also appear interior solutions $x^* \in (0, 1)$.

When the effort of one of the parties is non-contractible, its level is individually decided by that party:

$$e_i^{Ai} : \frac{\partial p}{\partial e_i}(e_f, e_u) V_i(x) = \frac{\partial C_i}{\partial e_i}(e_f, e_u).$$

The optimal decision of the Consortium becomes:

$$\begin{aligned} e_j^{Ai} \quad &: \quad \frac{\partial p}{\partial e_j}(e_f, e_u)\left[V_F(x) + V_U(x)\right] + \frac{\partial p}{\partial e_i}\frac{\partial e_i}{\partial e_j}(e_f, e_u) V_j(x) \\ &= \quad \frac{\partial C_j}{\partial e_j}(e_f, e_u) + \frac{\partial C_i}{\partial e_j}(e_f, e_u), \end{aligned} \tag{12}$$

$$x^{Ai} \quad : \quad p(e_f, e_u)\left[\frac{\partial V_F}{\partial x} + \frac{\partial V_U}{\partial x}\right] + \frac{\partial p}{\partial e_i}\frac{\partial e_i}{\partial x}(e_f, e_u) V_j(x) = 0. \tag{13}$$

Comparing (12) and (13) with the previous (10) and (11), respectively, is visible the existence of a new term (hereafter, called *external effect*), due to the influence of the choices of the Consortium on the non-contractible effort of party $i$. The following proposition then holds:

**Proposition 5.1** *Assume the effort of party $i$ is non-contractible. When the external effect of $e_i$ in the choice of project is strong enough, the Consortium distorts its first-best decision towards the most preferred project of party $i$.*

*When both efforts are non-verifiable (double-moral-hazard), the distortion of the project is towards the preferences of the party causing the higher external effect.*

*In terms of efforts, if only effort $i$ is non-contractible, the Consortium chooses an effort for $j$ that is:*

- *higher than in first-best, when efforts are complementary,*
- *smaller than in first-best, when efforts are substitutes,*
- *equal to the first-best, when efforts are independent.*

Consider now the decentralized structure of governance. Party $j$ is responsible to define the characteristics of the research collaboration and its own effort $e_j$, but the effort of party $i$ is non-contractible. The optimal decision of party $j$ is given by:

$$
\begin{aligned}
e_j^{jG} \quad &: \quad \frac{\partial p}{\partial e_j}\left(e_f, e_u\right) V_j\left(x\right) + \frac{\partial p}{\partial e_i}\frac{\partial e_i}{\partial e_j}\left(e_f, e_u\right) V_j\left(x\right) \\
&= \quad \frac{\partial C_j}{\partial e_j}\left(e_f, e_u\right), \qquad (14)
\end{aligned}
$$

$$
x^{jG} \quad : \quad p\left(e_f, e_u\right)\frac{\partial V_j}{\partial x} + \frac{\partial p}{\partial e_i}\frac{\partial e_i}{\partial x}\left(e_f, e_u\right) V_j\left(x\right) = 0. \qquad (15)
$$

When the decentralized governance faces moral-hazard from its partner, the external effect is present. Nevertheless, since under decentralized governance the decisions are individually taken, the value of the external effects are smaller than with Consortium's governance. This implies the following result.

**Proposition 5.2** *Assume that the effort of party $i$ is non-contractible. When the external effect of $e_i$ in the choice of project is strong enough, party $j$'s governance may distort its first-best decision towards the most preferred project of party $i$. Nevertheless, comparing with a Consortium governance, the decentralized governance of $j$ always choose a project closer to $j'$s preferences.*

# 6 Discussion and Implications of the Results

Research collaboration between firms and universities brings mutual gains through enhancing the probability of achieving discoveries valuable for both partners. Cultural and goals divergences may, however, become obstacles for the interaction of the two parties. The results in the present paper help to predict the sustainability and outcomes of collaboration, in the presence of those divergences. These results focus on four main ideas.

First, when the resources of a partner are non-contractible, choosing a project closer to the interests of this partner is a way of inducing it to exert a higher effort for the common project. With more resources being devoted to the project, a successful outcome is more probable. Although the initial distortion of the characteristics of the project could affect negatively the value of the outcome, the increase in the probability of a success may compensate that. As a result, the expected return of the project may be higher. My analysis shows that distortion of the characteristics of the project is worth when two conditions are satisfied: first, when the impact of non-verifiable effort is relatively more important for obtaining a success than the effort of the other partner; second, when the value of a successful outcome is sufficiently large, in particular for the partner whose interests are damaged due to the change in project.

Second, changing the characteristics of a project is an incentive mechanism that may enhance the expected gain of the collaboration, both under a centralized and a decentralized structure of governance. Nevertheless, under a decentralized structure, the outcome is always closer to the interests of the partner promoting the collaboration. As a consequence, under decentralization, the collaboration holds a smaller expected gain than in the case of centralization.

Third, besides changing the characteristics of the project, an alternative mechanism of motivating the supply of effort can be the establishment of a transfer between the partners. In particular, when the partner whose resources are non-contractible receives a share of the revenue of the other partner, the negative impact of the moral-hazard decreases. As a result, the type of the project can be closer to the first-best.

Fourth, society may be interested in giving an extra-reward to the collaboration, in order to reduce the inefficiency caused by moral-hazard. This is the case when the non-contractible resources of one of the partners are relevant to obtain a successful result, and when the value of a successful project is sufficiently high to justify policy intervention.

My claims support the empirical evidence that universities and firms tend to collaborate in more fundamental, general-purpose research (e.g., Veugelers & Cassiman, 2005; Caloghirou *et al.*, 2001). Scientists' dedication and effort to research is usually difficult to verify (Cockburn & Henderson, 1998), and therefore a university may be unable to commit on the resources that it allocates for collaboration. The university's involvement may, however, be highly relevant for the success of a project. As such, my results show that it may be optimal to develop a project whose characteristics are closer to academics' interests. This incentive mechanism is particularly suitable when the goals of the two partners are more aligned (smaller marginal losses $m_i$, in the language of the model). When that is the case, the smaller is the reduction in the value of one partner by changing the characteristics of a project towards the other's interests, the smaller is the conflict of interests in the partnership. For example, in the research agreement started in 1994 between the Massachusetts Institute of Technology (MIT) and the pharmaceutical firm Amgen, this alignment of interests is perceived as the main reason for the viability of the relation. Initial doubts on how different institutions would be able to jointly develop a project that would be beneficial for both partners, were not materialized due to the proximity of interests. In 2002, however, the reverse happened. The shift in the goals of the firm towards a greater emphasis on marketing, raised serious concerns on the collaboration persistence (Lawler, 2003; Lacetera, 2006).

In my framework, I consider that the outcome of a successful research renders both market and scientific values, respectively for a firm and a university. The analysis does not directly deal with the problems that partners may face in appropriating those values. The main justifications for taking such approach is twofold. First, my aim is to focus on how informational problems can affect the outcome of a collaborative research between two different institutions. Second, there is no clear pattern on how intellectual property rights affect collaboration between firms and universities. Some authors find no evidence that concerns about appropriating the benefits of new knowledge are an obstacle to the relationship (e.g., Veugelers & Cassiman, 2005), while other authors find that those concerns may be a barrier to collaboration (e.g., Hall *et al.*, 2001). Nevertheless, this issue can be addressed in my framework. In the model, the variable $x$ represents the basic research features of a project that is valuable for the University. Academics' knowledge production is by nature open to society, with no rivalry in its use, and often non-excludable (the "intellectual commons" concept of Argyres & Liebeskind, 1998). Therefore, an additional interpretation for $x$ is to consider it a measure of how non-excludable is new knowledge of the project. As $x$ becomes smaller than one, the knowledge produced becomes more excludable (so further from University's main goal), but with higher valuable commercial applications. As Argyres & Liebeskind (1998) mention, biotechnology is an example of such type of research, where excludability increases the private value of the knowledge, while decreasing the amount of knowledge publicly available.

Considering this alternative interpretation for $x$, my results are also consistent with the findings of Zucker & Darby (1995). Analyzing cooperation between star bioscientists and biotechnology enterprises, they find evidence that as the expected commercial value of the research increases and scientists receive a share from that value, they decrease the diffusion of the discoveries to other scientists. In the language of my model, this corresponds to the result of Proposition 3.3: when University receives a share of the market value of the outcome, the optimal type of project is closer to Firm's interests (optimal $x$ decreases).

## 6.1 Managerial Implications

The results of this paper bring concrete management insights for the collaboration between firms and universities.

First, when a partner cannot commit on the amount of resources it dedicates to a common project, it may be optimal to change for a type of research closer to the interests of that partner. This is particularly so, when its involvement is relatively important to obtain a successful outcome and the successful outcome brings a sufficiently high value, in particular for the partner feeling the external effect.

Second, in case the change in the characteristics of the project is too costly and partners do not agree on it, but still find it worth to collaborate, the problem of non-commitment of resources can be reduced by a higher interaction between the partners. This means that, rather than considering the verifiability of effort, we may refer to the capacity of commitment on a certain level of effort. This is also the conclusion of the head of the pharmaceutical firm Amgen, Gordon Binder, whose experience of successful collaboration with MIT was based on regular joint research between Amgen's researchers and MIT's scientists: "What doesn't work is to give a university a ton of money and then sit back to wait for useful returns" (Lawler, 2003, page 331). Despite other benefits that team work may have, when academic scientists and the researchers of the firm work regularly together, it may be possible to reduce the informational problems on the resources employed. Developing research in a team environment, increases the possibilities of each partner to monitor the amount of resources that the other partner devotes to the common project. When such higher accountability is combined with a higher bargaining power of the partner whose interests are harmed with the non-verifiability of resources, then team work increases the expected gains of the collaboration. This reasoning may explain the recent trend in companies' collaboration strategy, when moving from large-scale agreements to contracts with individual scientists (Lawler, 2003).

From the point of view of the Firm, the research collaboration with individual scientists may also be interpreted as a way to adopt a decentralized management strategy, under the Firm's initiative. As the results of the model show, in this scenario, the Firm is able to implement a project closer to its interests.

Three more examples of research collaboration between a firm and a university reinforce the relevance and application of my framework (the first two examples are also discussed by Lacetera, 2006).

Example 1, Novartis and Berkeley University:

In November 1998, the Swiss pharmaceutical Novartis established an agreement with Berkeley University, California, under which the company paid $25 million over 5 years to the university. In exchange, the company had access to university's plant and microbial biology department labs and to scientific discoveries coming from the university. In terms of my framework, this corresponds to a collaborative relation where the effort of the firm is verifiable (money), but the resources of the university are not. In fact, there was no explicit commitment from the university to devote its resources for a common project, first and above all, because there was no exact definition of a common project, in particular there was no exact goal that the university should fulfill. In this scenario, it is natural to deduce that academic researchers would be work on projects closer to their own research interests, rather than to the interests of the firm. In case of divergence of objectives between the two partners, we could expect the outcome of the cooperation would be more valuable to the university than to the firm. The reality confirmed those expectations. According to several comments both from Berkeley University and from outsiders, the arrangement was a "terrific (good) deal for the university" (Robert Price, Berkeley's associate vice chancellor for research, *in* Lawler, 2003) and "a bad deal" for the company (Lawrence Busch, Michigan State University in East Lansing).

Example 2, DuPont and MIT Alliance, DMA:

In 2000, the American company DuPont and MIT established an agreement in the areas of materials, chemical and biological sciences. The initial agreement of five years involved an investment of $35 million to develop new materials and processes at bioelectronics, biosensors, biomimetic materials, and alternative energy sources. The success of this first interaction justified its renewal in 2005 for additional five years and to new areas as nanocomposites, nanoelectronic materials, and alternative energy technologies. Two main reasons for the success of such collaboration were given: on the one hand, the proximity of interests between the two partners (what in the model is considered as a small value of the marginal loss $m_i$); on the other hand, the working methodology where both MIT faculty and DuPont colleagues define together research opportunities (a Consortium management, which as the model shows maximizes the aggregate benefits of the project).

Example 3, Rolls-Royce and Pusan National University (PNU):

The power systems provider firm Rolls-Royce established a research collaboration agreement in January 2006 with PNU, to develop ultra-light weight heat exchangers. The goal is to, jointly, develop technologies that will be applied to Rolls-Royce's engines for the aviation, marine and energy sectors. The most important headquarters of the joint research are the existing Rolls-Royce University Technology Centres (UTCs), and the firm expects the activity of PNU to be aligned with the one at the UTCs (Rolls-Royce, 2006). In the language of my framework, this corresponds to a decentralized governance, under the initiative of the firm. As expected, the purpose of the project is closer to the interests of the firm. Nevertheless, the proximity of interests of the two parties (small $m_i$), and a work methodology based on teams formed by researchers from both partners are key ingredients for the success of this project.

Besides the insights on the management of collaboration between firms and universities, the reasoning of my framework can also be applicable towards a better understanding of the *internal organization* of research in the Firm. When developing research in-house, the

Firm recruits scientists specialized in the field. Nevertheless, the most qualified scientists are often not very motivated to work in private firms, where they may face restrictions on publishing and difficulties to pursue their academic research paths (Aghion *et al.*, 2005). An incentive mechanism to involve these scientists in the projects of the Firm, may then allow them to continue publishing and use the Firm's research results (at least partially) for the development of their own academic agenda. In the language of the model, this corresponds to a project whose characteristics are closer to academic scientists' interests (higher $x$). As a result, the smaller value of the outcome for the Firm (higher $x$ implies smaller market value $V_F$), may be compensated by an increase in the probability of success, due to a higher involvement of the scientists (higher $e_u$).

## 6.2 Policy Implications

From the policy point of view, my analysis delivers some implications. First, in the presence of non-verifiable resources in the collaboration between firms and universities, the negative impact of the moral-hazard can be reduced by giving a prize to the collaborative research. This is an optimal strategy when the cost of public funds is small as compared with the expected benefits of the project.

Second, as discussed, working in teams may increase the monitoring of partners' effort. Policy measures promoting the interaction of researchers from both institutions (or enhancing their mobility between firms and universities) may then have a positive impact on the expected gains of collaborative research.

Third, the aggregate expected gain from collaboration is maximized under a centralized governance, rather than a decentralized one. Policy measures that give incentives to the former have a clear benefit for society.

# 7 Conclusion

This paper studies how institutional differences between business and academia affect the outcome of their collaboration in research. Distinct research goals is a source of disagreement on the type of project to be jointly developed. When the amount of resources that one of the parties shall employ is non-verifiable, it may be optimal for the other party to agree on a research that is not its most preferred type. The party with non-verifiable resources is willing to enhance its contribution, when collaboration is on a project closer to its interests. The optimality of this incentive mechanism is conditional on two requisites. First, a sufficiently high value of a successful outcome for the party feeling the externality effect. Second, a relatively high importance of the non-contractible effort for the success. In comparative statics terms, the model predicts that when collaboration involves a more scientific-base firm, the best joint project becomes closer to the most preferred of the university. Conversely, when a university has more applied interests, the optimal research is less basic.

In the presence of a moral-hazard problem from at least one of the partners, incentives may also come by means of monetary transfers. Without policy intervention, the collaborator with non-verifiable effort should receive a share of the reward of the other party. This is the best option, when the non-verifiable resources are sufficiently important for the success of the project. When the payment of transfers between collaborators is not possible, a policy intervention may be in the interest of society. A prize to the non-contractible involvement is welfare improving when the cost of public funds is not too large. Public intervention has two positive effects for collaboration: it increases partners' effort, and it approaches the type of project to the first-best. By increasing the expected benefit of collaboration, the intervention reduces the negative impact of a moral-hazard situation.

The benefits from basic research may have a long-term horizon. In my static model, possible future gains from research are already taken into account, when we interpret both market and scientific values of a successful outcome as the present value of a stream of gains. An interesting extension of this analysis would be to consider a dynamic framework with several periods of time, and myopic partners interacting in each period of time. If the type of project today influences the outcome tomorrow, there would be intertemporal effects probably not internalized by partners. The design of policy would then be particularly important for the achievement of socially desirable result.

The present paper focus on incentives issues for a collaborative relation, that is already formed. Further developments may bring interesting insights for a previous stage, when partners select with whom they will develop such collaboration.

Empirically, also some work is still to be done. First, in terms of the predictions of the current model. The general setting used enables the discussion of the characteristics of the collaboration, in the presence of informational problems between partners who have different interests. The direction of the predictions depends, however, on the value of the parameters. Data on specific industries and on the profile of academics departments would allow to concretize the results for particular cases. Second, on the role that the type and frequency of interaction between partners may have on the outcome of the relationship. In fact, the results of the present paper stress the role of the verifiability of the efforts in obtaining a higher expected gain. Following the basic fundaments of contract theory, verifiability (and hence, contractibility) of efforts is essential to guarantee their enforcement, during the period of interaction. In everyday's life, however, enforcement of efforts may also be related with the capacity of the parties to commit on that level of efforts. Under such premises, a higher and more frequent interaction between partners may favor this commitment capacity, thus reducing the impact of a moral-hazard problem.

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# 8 Appendix

**Proof of Proposition 3.1.** When the efforts of both collaborators are verifiable, the Consortium decides over $x$, $e_f$, and $e_u$ in order to maximize the joint benefit of the research project, $EW$. The solution for the efforts is:

$$\begin{aligned} e_f^* &= \frac{k}{c_f}\left(V_F+V_U\right)=\frac{k}{c_f}\left[B_f+B_u-m_u-\left(m_f-m_u\right)x\right], \\ e_u^* &= \frac{1-k}{c_u}\left(V_F+V_U\right)=\frac{1-k}{c_u}\left[B_f+B_u-m_u-\left(m_f-m_u\right)x\right]. \end{aligned}$$

These optimal level of efforts make $EW^*$ a convex function of $x$ and, as a consequence, the best joint project is at one of the extremes, 0 or 1. By $m_f > m_u$, the best choice is $x^* = 0$, the Firm's most preferred project.

This solution yields an expected gain for each collaborator of:

$$\begin{aligned} E\Pi_F^* &= \frac{\left(B_f+B_u-m_u\right)\left[c_u k^2\left(B_f-B_u+m_u\right)+2c_f\left(1-k\right)^2 B_f\right]}{2c_u c_f}, \\ E\Pi_U^* &= \frac{\left(B_f+B_u-m_u\right)\left[2c_u k^2\left(B_u-m_u\right)+c_f\left(1-k\right)^2\left(B_u-m_u-B_f\right)\right]}{2c_u c_f}. \end{aligned}$$

The Firm's participation constraint is satisfied when $R_U$ is sufficiently high:

$$E\Pi_F^* \geq E\Pi_{F,alone} \Leftrightarrow R_U \geq \frac{c_u (B_u - m_u)^2}{2c_f B_f (B_f - B_u + m_u)}.$$

That is, when the role of the University's effort for the success of the project is sufficiently important, the Firm prefers to collaborate rather then to develop research alone.

Conversely, the University's participation constraint is satisfied when:

$$E\Pi_U^* \geq E\Pi_{U,alone} \Leftrightarrow R_F \geq \frac{c_f \left[B_f^2 + m_u (2B_u - m_u)\right]}{2c_u (B_u - m_u)(B_f - B_u + m_u)}.$$

■

**Proof of Corollary 3.1.**

1. When both efforts are verifiable, the joint expected gain from the collaboration is convex on $x$. As a result, the corner solution that maximizes $EW$ only depends on the relation between $m_f$ and $m_u$. When $m_f > m_u$ holds, the first best choice is always $x^* = 0$, no matter how the parameters of the model change inside their domain.

2. When both efforts are verifiable, the maximum joint expected gain from the collaboration is
$$EW^*(0) = \frac{1}{2}\left[\frac{k^2}{c_f} + \frac{(1-k)^2}{c_u}\right](B_f + B_u - m_u).$$
From this, we can verify that
$$\frac{\partial EW^*(0)}{\partial \kappa} = [k(c_f + c_u) - c_f]\frac{(B_f + B_u - m_u)^2}{c_f c_u},$$
which is positive when $k > \frac{c_f}{c_f + c_u}$;
$$\frac{\partial EW^*(0)}{\partial c_f} = -\frac{k^2}{2c_f^2}(B_f + B_u - m_u) < 0;$$
$$\frac{\partial EW^*(0)}{\partial c_u} = -\frac{(1-k)^2}{2c_u^2}(B_f + B_u - m_u) < 0;$$
$$\frac{\partial EW^*(0)}{\partial B_f} = \frac{\partial W^*(0)}{\partial B_u} = \frac{1}{2}\left[\frac{k^2}{c_f} + \frac{(1-k)^2}{c_u}\right] > 0;$$
$$\frac{\partial EW^*(0)}{\partial m_u} = -\frac{1}{2}\left[\frac{k^2}{c_f} + \frac{(1-k)^2}{c_u}\right] < 0.$$

■

**Proof of Proposition 3.2.** The proof is made for each informational context, in separate.

**Scenario 1:** Only $e_u$ is non-verifiable. When the Consortium cannot contract on $e_u$, the University's best choice is given by:

$$\max_{\{e_u\}} E\Pi_U = [ke_f + (1-k)\, e_u]\, V_U - C_U.$$

The solution to this maximization problem is $e_u^{AU} = \frac{1-k}{c_u} V_U = \frac{1-k}{c_u} (B_u - m_u + m_u x) < e_u^*$. Anticipating this decision, the Consortium maximizes the total collaboration gain by choosing:

$$\begin{aligned} e_f^* &= \frac{k}{c_f}(V_F + V_U) = \frac{k}{c_f}[B_f + B_u - m_u - (m_f - m_u)\, x], \\ x^{AU} &= \frac{c_u k^2 (m_f - m_u)(B_f + B_u - m_u) + c_f (1-k)^2 [(m_f - m_u)(B_u - m_u) - m_u B_f]}{c_u k^2 (m_f - m_u)^2 - c_f (1-k)^2 m_u (2m_f - m_u)}. \end{aligned}$$

The best research project in this context, $x^{AU}$, is positive (more basic than in the first-best) whenever $B_f > \left(\frac{m_f}{m_u} - 1\right)(B_u - m_u) \Longleftrightarrow M_0 > \frac{m_f}{m_u} - 1$ and $R_U > \frac{(m_f - m_u)(B_f + B_u - m_u)}{m_u B_f - (m_f - m_u)(B_u - m_u)} \Longleftrightarrow R_U > \frac{(m_f - m_u)(M_0 + 1)}{m_u M_0 - (m_f - m_u)}$. Furthermore, $R_U > \frac{(m_f - m_u)(M_0+1)}{m_u M_0 - (m_f - m_u)}$ is also sufficient for having $EW^{AU}$ concave on $x$, and therefore, the solution is a maximizer of $EW^{AU}$.

Figure 7 represents the situation.

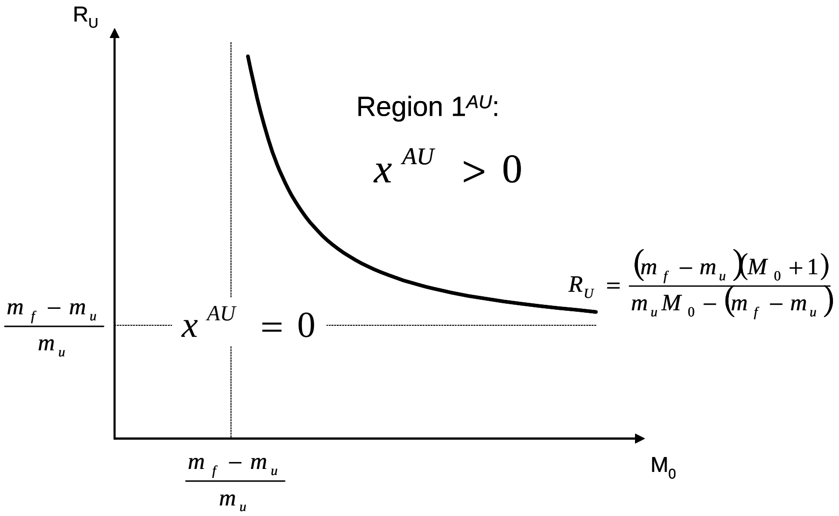


Figure 7: Consortium's optimal project when $e_U$ is non-verifiable, $x^{AU}$.

When $R_U < \frac{(m_f - m_u)(B_f + B_u - m_u)}{m_u (B_f - m_f) - (m_f - m_u) B_u}$, we additionally have $x^{AU}$ smaller than 1. This means that, although the optimal project is less applied than in the first-best, it does not go to the opposite extreme. The University is important to ensure the success of the research, but its contribution is not sufficiently strong to convince the Consortium to choose $x = 1$.

With the solution $\left(e_f^*, e_u^{AU}, x^{AU}\right)$, the collaborators reward is:

$$\begin{aligned} E\Pi_F^{AU} &= \frac{\left[m_u B_f + m_f \left(B_u - m_u\right)\right]^2 (1-k)^2}{2c_u \left[k^2 c_u \left(m_f - m_u\right)^2 - (1-k)^2 c_f m_u \left(2m_f - m_u\right)\right]^2} \left\{2k^4 c_u^2 \left(m_f - m_u\right) m_u + \right. \\ & \left. +2(1-k)^4 c_f^2 \left(m_f - m_u\right) m_u - (1-k)^2 k^2 c_f c_u \left(m_f - 2m_u\right)^2\right\}, \\ E\Pi_U^{AU} &= \frac{\left[m_u B_f + m_f \left(B_u - m_u\right)\right]^2 (1-k)^2}{2c_u \left[k^2 c_u \left(m_f - m_u\right)^2 - (1-k)^2 c_f m_u \left(2m_f - m_u\right)\right]^2} \cdot \\ & \cdot \left\{\left[(1-k)^2 c_f + k^2 c_u\right]^2 m_u^2 - k^4 c_u^2 m_f\right\}. \end{aligned}$$

The Firm's participation constraint is satisfied when

$$\begin{aligned} (1-k)^6 c_f^2 \left\{2\left(m_f - m_u\right) m_u \left[R_F + R_U\right] - \left(m_f - 2m_u\right)^2\right\} \geq \\ \geq \frac{B_f \left[k^2 c_u \left(m_f - m_u\right)^2 - (1-k)^2 c_f m_u \left(2m_f - m_u\right)\right]^2}{\left[m_u B_f + m_f \left(B_u - m_u\right)\right]^2}. \end{aligned}$$

This means that the Firm is more willing to collaborate when $k$ is smaller (University's contribution for the success is larger), and $B_f$ is smaller (the opportunity cost from not developing its most preferred project is not too large).

Conversely, the individual rationality constraint of the University is satisfied when

$$\left[R_U + 1\right]^2 m_u - m_f \geq \frac{B_u \left[k^2 c_u \left(m_f - m_u\right)^2 - (1-k)^2 c_f m_u \left(2m_f - m_u\right)\right]^2}{k^2 c_u \left[m_u B_f + m_f \left(B_u - m_u\right)\right]^2},$$

that is, for small $k$ (University's higher importance for the success makes the choice more favored to its own preferences), and for small $B_u$ (the opportunity cost from not developing University's most preferred project is not too large).

**Scenario 2:** Only $e_f$ is non-verifiable. At the second-stage, Firm's optimal choice is $e_f^{AF} = \frac{k}{c_f} V_F = \frac{k}{c_f}\left(B_f - m_f x\right)$.

At the first stage, the Consortium decides on University's effort $e_u^* = \frac{1-k}{c_u}\left(V_F + V_U\right) = \frac{1-k}{c_u}\left[B_f + B_u - m_u - \left(m_f - m_u\right) x\right]$. The joint expected gain becomes

$$EW^{AF} = \frac{k^2}{2c_f} V_F \left(V_F + 2V_U\right) + \frac{(1-k)^2}{2c_u}\left(V_F + V_U\right)^2.$$

Depending on the value of the parameters, $EW^{AF}$ can either be convex or concave. The two possible situations are:

1. if $m_f > 2m_u$ or $R_U > \frac{m_f(2m_u - m_f)}{(m_f - m_u)^2}$, $EW^{AF}$ is convex on $x$, and the best project chosen by the Consortium can only be one of the extremes. At $x = 0$ and $x = 1$, we have, respectively,

$$
\begin{aligned}
EW^{AF}(0) &= \frac{k^2}{2c_f} B_f \left[B_f + 2(B_u - m_u)\right] + \frac{(1-k)^2}{2c_u}(B_f + B_u - m_u)^2 \\
&= \left[\frac{k^2}{2c_f} + \frac{(1-k)^2}{2c_u}\right](B_f + B_u - m_u)^2 - \frac{k^2}{2c_f}(B_u - m_u)^2, \\
EW^{AF}(1) &= \frac{k^2}{2c_f}(B_f - m_f)(B_f - m_f + 2B_u) + \frac{(1-k)^2}{2c_u}(B_f - m_f + B_u)^2 \\
&= \left[\frac{k^2}{2c_f} + \frac{(1-k)^2}{2c_u}\right](B_f + B_u - m_f)^2 - \frac{k^2}{2c_f} B_u.
\end{aligned}
$$

Given $m_f > m_u$, the best research project is $x = 0$.

2. if $m_f < 2m_u$ and $R_U < \frac{m_f(2m_u - m_f)}{(m_f - m_u)^2}$, $EW^{AF}$ is concave on $x$. The type of project that maximizes $EW^{AF}$ is then $x = \frac{c_u k^2 \left[(m_f - m_u) B_f + m_f (B_u - m_u)\right] + c_f (1-k)^2 (m_f - m_u)(B_f + B_u - m_u)}{c_f (1-k)^2 (m_f - m_u)^2 - c_u k^2 m_f (2m_u - m_f)}$, which is negative and out of the decision domain. Comparing $EW^{AF}(0)$ with $EW^{AF}(1)$, we conclude that the best option is $x = 0$.

This means that, whether $EW^{AF}$ is convex or concave on $x$, the optimal project is always $x = 0$ (as long as $m_f > m_u$).

At $x = 0$, the expected gain of both parties is

$$
\begin{aligned}
E\Pi_F^{AF} &= \frac{k^2 B_f}{2c_f} + \frac{(1-k)^2 B_f (B_u - m_u)}{c_u}; \\
E\Pi_U^{AF} &= \frac{k^2 B_f (B_u - m_u)}{c_f} + \frac{(1-k)^2 (B_u - m_u)^2}{2c_u}.
\end{aligned}
$$

Since $E\Pi_F^{AF} > \frac{k^2 B_f}{2c_f}$, the participation constraint of the Firm is satisfied. For having the University willing to participate in the collaborative research project, it is necessary that $E\Pi_U^{AF} > \frac{(1-k)^2 B_u}{2c_u} \Leftrightarrow R_U < \frac{2(B_u - m_u)}{m_u(2B_u - m_u)}$.

**Scenario 3:** Both $e_u$ and $e_f$ are non-verifiable. At the second stage of this double moral-hazard situation, each partner chooses its most preferred effort: the Firm chooses $e_f^{AUF} = \frac{k}{c_f} V_F$, and the University $e_u^{AUF} = \frac{1-k}{c_u} V_U$. Given $m_f > m_u$, the joint expected gain $EW^{AUF}$ is concave on the type of the project for $R_U > \frac{m_f(m_f - 2m_u)}{m_u(2m_f - m_u)}$. In this range of parameters, the Consortium selects

$$x^{AUF} = \frac{1}{c_u k^2 m_f (m_f - 2m_u) - c_f (1-k)^2 m_u (2m_f - m_u)} \cdot \left\{ c_u k^2 [B_f (m_f - m_u) + m_f (B_u - m_u)] + c_f (1-k)^2 [(m_f - m_u)(B_u - m_u) - m_u B_f] \right\}.$$

When $R_U > \frac{(m_f - m_u)M_0 + m_f}{m_u M_0 - (m_f - m_u)}$ and $M_0 > \frac{m_f}{m_u} - 1$ (Region $1^{AUF}$), the project is more basic than in the first-best: $x^{AUF} > 0$. Figure 8 presents this result.

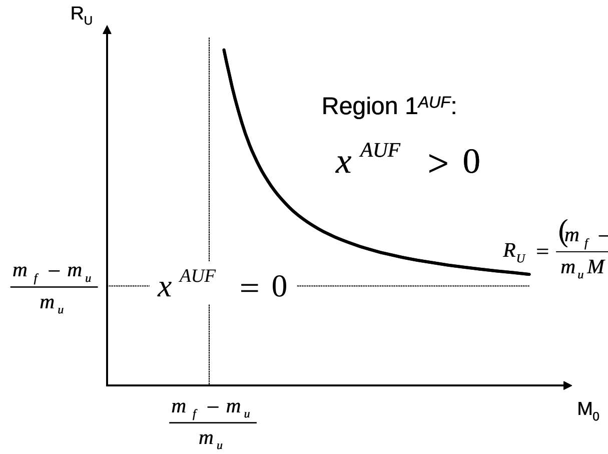


Figure 8: Consortium's optimal project under double moral-hazard.

At $x^{AUF}$, the expected profits of the partners are:

$$E\Pi_F^{AUF} = \frac{[m_u B_f + m_f (B_u - m_u)]^2 \left[k^2 c_u m_f + (1-k)^2 c_f (m_f - m_u)\right]}{2c_f c_u \left[-k^2 c_u m_f (2m_u - m_f) + (1-k)^2 c_f m_u (m_u - 2m_f)\right]^2} \cdot \left[2(1-k)^4 c_f^2 m_u^2 + k^4 c_u^2 m_f - (1-k)^2 k^2 c_f c_u (m_f - m_u)\right],$$

$$E\Pi_U^{AUF} = \frac{[m_u B_f + m_f (B_u - m_u)]^2 \left[-k^2 c_u (m_f - m_u) + (1-k)^2 c_f m_u\right]}{2c_f c_u \left[-k^2 c_u m_f (2m_u - m_f) + (1-k)^2 c_f m_u (m_u - 2m_f)\right]^2} \cdot \left[2k^4 c_u^2 m_f + (1-k)^4 c_f^2 m_u + (1-k)^2 k^2 c_f c_u (m_f - m_u)\right].$$

To have both participations constraints satisfied, we must have $\underline{R}_u < R_U < \bar{R}_U$, where $\underline{R}_u$ solves $E\Pi_U^{AUF} > \frac{(1-k)^2 B_u}{2c_u}$, and $\bar{R}_U$ solves $E\Pi_F^{AUF} > \frac{k^2 B_f}{2c_f}$.

1. The best joint project under double moral-hazard is less basic than the one chosen

with only moral-hazard from the University, since

$$x^{AU} - x^{AUF} = \frac{k^2 c_u m_u \left[(1-k)^2 c_f m_u - k^2 c_u (m_f - m_u)\right]}{\left[-k^2 c_u m_f (2m_u - m_f) - (1-k)^2 c_f m_u (2m_f - m_u)\right]} \cdot \frac{\left[m_u B_f + m_f (B_u - m_u)\right]}{\left[k^2 c_u (m_f - m_u)^2 - (1-k)^2 c_f m_u (2m_f - m_u)\right]}.$$

and, therefore, $x^{AU} - x^{AUF} > 0$ in Region $1^{AUF}$.

■

**Proof of Corollary 3.2.** From the Consortium best choice when only University's effort is non-verifiable, the optimal project for Region $1^{AU}$ is:

$$x^{AU} = \frac{c_u k^2 (m_f - m_u)(B_f + B_u - m_u) + c_f (1-k)^2 \left[(m_f - m_u)(B_u - m_u) - m_u B_f\right]}{c_u k^2 (m_f - m_u)^2 - c_f (1-k)^2 m_u (2m_f - m_u)}.$$

From this expression, we can derive how the interior solution $x^{AU}$ changes with respect to the different parameters:

- $x^{AU}$ is increasing in $B_f$, $\frac{\partial x^{AU}}{\partial B_f} = \frac{c_u k^2 (m_f - m_u) - c_f (1-k)^2 m_u}{c_u k^2 (m_f - m_u)^2 - c_f (1-k)^2 m_u (2m_f - m_u)} > 0$;
- $x^{AU}$ is decreasing in $B_u$, $\frac{\partial x^{AU}}{\partial B_u} = \frac{\left[c_u k^2 + c_f (1-k)^2\right](m_f - m_u)}{c_u k^2 (m_f - m_u)^2 - c_f (1-k)^2 m_u (2m_f - m_u)} < 0$;
- $x^{AU}$ is decreasing in $k$, $\frac{\partial x^{AU}}{\partial \kappa} = -\frac{2(1-k) k c_f c_u m_f (m_f - m_u)\left[m_u B_f + m_f (B_u - m_u)\right]}{\left[c_u k^2 (m_f - m_u)^2 - c_f (1-k)^2 m_u (2m_f - m_u)\right]^2} < 0$;
- $x^{AU}$ is increasing in $c_f$, $\frac{\partial x^{AU}}{\partial c_f} = \frac{(1-k)^2 k^2 c_u m_f (m_f - m_u)\left[m_u B_f - m_f (B_u - m_u)\right]}{\left[c_u k^2 (m_f - m_u)^2 - c_f (1-k)^2 m_u (2m_f - m_u)\right]^2} > 0$;
- $x^{AU}$ is decreasing in $c_u$, $\frac{\partial x^{AU}}{\partial c_u} = -\frac{(1-k)^2 k^2 c_f m_f (m_f - m_u)\left[m_u B_f + m_f (B_u - m_u)\right]}{\left[c_u k^2 (m_f - m_u)^2 - c_f (1-k)^2 m_u (2m_f - m_u)\right]^2} < 0$;
- $x^{AU}$ is decreasing in $m_f$,

$$\frac{\partial x^{AU}}{\partial m_f} = \frac{1}{\left[c_u k^2 (m_f - m_u)^2 - c_f (1-k)^2 m_u (2m_f - m_u)\right]^2} \{-(1-k)^4 c_f^2 m_u (2B_f + B_u - m_u) -$$

$$-k^4 c_u^2 (m_f - m_u)^2 (B_f + B_u - m_u) -$$

$$-(1-k)^2 k^2 c_f c_u \left[m_u (3B_f + 2B_u - 2m_u) + m_f (B_u - m_u) -\right.$$

$$\left. 2m_f m_u (B_f + B_u - m_u)\right]\} < 0;$$

- $x^{AU}$ is increasing in $m_u$,

$$\frac{\partial x^{AU}}{\partial m_u} = \frac{\left[c_u k^2 + c_f (1-k)^2\right]}{\left[c_u k^2 \left(m_f - m_u\right)^2 - c_f (1-k)^2 m_u \left(2m_f - m_u\right)\right]^2} \cdot$$

$$\cdot \left\{c_u k^2 \left(m_f - m_u\right)^2 \left(B_f + B_u - m_u\right) + \right.$$

$$\left. + c_f (1-k)^2 \left[2 m_f B_u + m_u \left(B_f + B_u\right) - m_f m_u \left(m_u + 2 B_u\right)\right]\right\} > 0.$$

■

**Proof of Proposition 3.3.** When the University receives a share $t_f \in (0,1)$ of the market value, in case of a successful invention, the University's choice for its effort is given by:

$$\max_{\{e_u\}} E\Pi_U = \left[k e_f + (1-k) e_u\right] \left(t_f V_F + V_U\right) - C_U.$$

From this, we obtain the optimal solution $e_u^{AUT} \in \left(e_u^{AU}, e_u^*\right)$, with

$$e_u^{AUT} = \frac{1-k}{c_u} \left(t_f V_F + V_U\right) = \frac{1-k}{c_u} \left(t_f B_f + B_u - m_u - \left(t_f m_f - m_u\right) x\right).$$

Taking into account the University's behavior, the solution to the Consortium's maximization problem comes:

$$e_f^* = \frac{k}{c_f} \left(V_F + V_U\right) = \frac{k}{c_f} \left[B_f + B_u - m_u - \left(m_f - m_u\right) x\right],$$

$$x^{AUT} = \frac{1}{c_u k^2 \left(m_f - m_u\right)^2 - c_f (1-k)^2 \left(m_u - t_f m_f\right) \left[\left(2 - t_f\right) m_f - m_u\right]} \cdot$$

$$\cdot \left\{c_u k^2 \left(m_f - m_u\right) \left(B_f + B_u - m_u\right) + \right.$$

$$\left. + c_f (1-k)^2 \left[\left(m_f - m_u\right)\left(B_u - m_u\right) - \left(m_u - m_f t_f \left(2 - t_f\right)\right) B_f\right]\right\}.$$

The expected gain to the Firm is then

$$E\Pi_F^{AUT} = \frac{\left[m_u B_f + m_f \left(B_u - m_u\right)\right]^2 (1-k)^2}{2 c_u \left[k^2 c_u \left(m_f - m_u\right)^2 - (1-k)^2 c_f m_u \left(2 m_f - m_u\right)\right]^2} \left\{2 k^4 c_u^2 \left(m_f - m_u\right)\left(m_u - t_f m_f\right) + \right.$$

$$\left. + 2 (1-k)^4 c_f^2 \left(m_f - m_u\right)\left(m_u - t_f m_f\right) - (1-k)^2 k^2 c_f c_u \left[\left(1 + t_f\right) m_f - 2 m_u\right]^2\right\}.$$

The Firm is willing to collaborate when $E\Pi_F^{AUT}$ is at least equal to $\frac{k^2 B_f}{2 c_f}$.
At $t_f = 1 - \sqrt{1 - \frac{m_u}{m_f}}$, this restriction is still not satisfied and, therefore, $t_f \in \left(0, 1 - \sqrt{1 - \frac{m_u}{m_f}}\right)$. Considering this interval for $t_f$, the best joint project is still less applied than in the first best, $x^{AUT} > 0$, when
$R_U > \frac{\left(m_f - m_u\right)\left(B_f + B_u - m_u\right)}{\left[m_u - m_f \left(2 - t_f\right) t_f\right] B_f - \left(m_f - m_u\right)\left(B_u - m_u\right)} \iff R_U > \frac{\left(m_f - m_u\right)\left(M_0 + 1\right)}{\left[m_u - m_f \left(2 - t_f\right) t_f\right] M_0 - \left(m_f - m_u\right)}$ and

$B_f > \frac{(m_f - m_u)(B_u - m_u)}{m_u - m_f(2-t_f)t_f} \Longleftrightarrow M_0 > \frac{m_f - m_u}{m_u - m_f(2-t_f)t_f}$. The first condition emphasizes the importance of $e_u$ for the success of the project, whereas the second condition relates with the value that a success has for the Firm (hence, to the Consortium). For these range of parameters, the joint expected gain $EW^{AUT}$ is concave on $x$, guaranteeing that $x^{AUT}$ is actually a maximizer for $EW$. In fact, the condition for a concave $EW^{AUT}$ is

$$R_U > \frac{(m_f - m_u)^2}{(m_u - t_f m_f)\left[(2 - t_f) m_f - m_u\right]},$$

satisfied whenever $x^{AUT} > 0$, because

$$\frac{(m_f - m_u)(B_f + B_u - m_u)}{[m_u - m_f (2 - t_f) t_f] B_f - (m_f - m_u)(B_u - m_u)} - \frac{(m_f - m_u)^2}{(m_u - t_f m_f)\left[(2 - t_f) m_f - m_u\right]} > 0.$$

For $t_f \in \left(0, 1 - \sqrt{1 - \frac{m_u}{m_f}}\right)$, the selected collaborative project can still be equal to the first-best. This happens when:

**i)** $EW^{AUT}$ is concave, but we are in Region $2^{AUT}$. In this case, we automatically have $x^{AUT} < 0$, and therefore the best possible project is $x = 0$;

**ii)** $EW^{AUT}$ is convex, but $EW^{AUT}(0) > EW^{AUT}(1)$, which happens when the Firm's contribution for the success of the project is relatively more relevant than the University's:

$$R_F > \frac{m_u (2B_u - m_u) + 2(B_f m_u - B_u m_f) - m_f t_f (2B_f - m_f)(2 - t_f)}{m_f - m_u}.$$

The proof that $x^{AUT} < x^{AU}$ for Region $1^{AUT}$ comes from $\frac{\partial x^{AUT}}{\partial t_f} < 0$, since

$$\frac{\partial x^{AUT}}{\partial t_f} = \frac{(1-k)^2}{c_u (D_T)^2} 2 (1 - t_f) v_f (B_f D_T + v_f N_T)$$

where $D_T$(=denominator of $x^{AUT}$) $< 0$, and $N_T$(=numerator of $x^{AUT}$) $< 0$.

Figure 9 bellow shows Consortium's optimal project when $e_u$ is non-verifiable, both with transfer $t_f$ (situation $AUT$) and without transfer (situation $AU$). As told in the main text, *Region* $1^{AUT} \subset$*Region* $1^{AU}$.

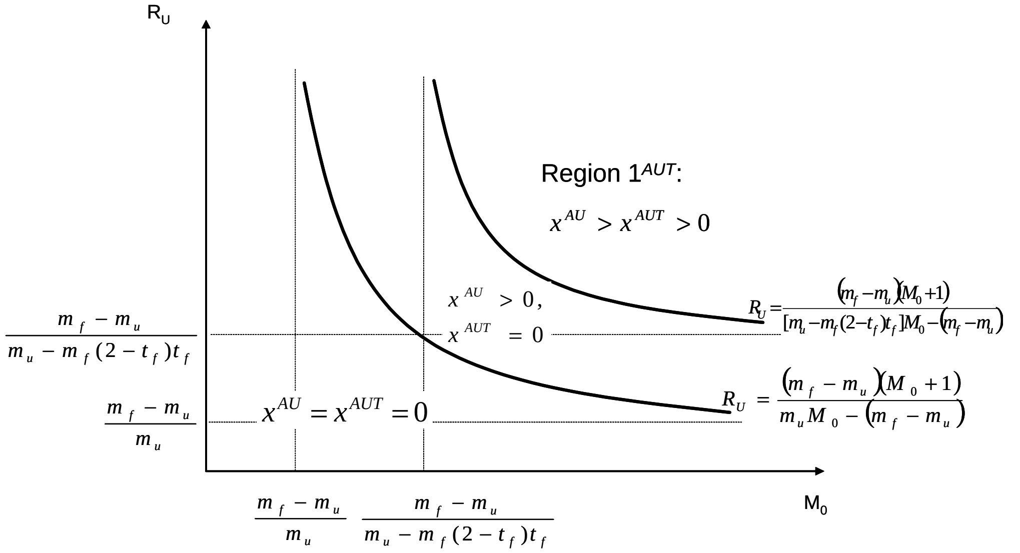


Figure 9: Consortium's optimal project when $e_U$ is non-verifiable. With transfer $t_f$: $x^{AUT}$, without transfer: $x^{AU}$.

■

**Proof of Proposition 3.4.** When the Firm governs the collaboration and the University's effort is verifiable, the design of the contract comes from the following optimization problem:

$$\max_{\{x, e_f, e_u\}} E\Pi_F = [ke_f + (1-k)\,e_u]\,V_F - C_F,$$

$$\text{s.t.} \begin{cases} E\Pi_U = [ke_f + (1-k)\,e_u]\,V_U - C_U \geq \frac{(1-k)^2 B_u^2}{2c_u}, \\ 0 \leq x \leq 1. \end{cases}$$

The first-order conditions for this constrained maximization are:

$$e_f = \frac{k}{c_f}\left(V_F + \gamma_1 V_U\right), \tag{16}$$

$$e_u = \frac{1-k}{c_u}\left(V_F + \gamma_1 V_U\right), \tag{17}$$

$$[ke_f + (1-k)\,e_u]\,(\gamma_1 m_u - m_f) = \gamma_3 - \gamma_2, \tag{18}$$

$$\gamma_1 = 0 \text{ or } E\Pi_U = \frac{(1-k)^2 B_u^2}{2c_u}, \tag{19}$$

$$\gamma_2 = 0 \text{ or } x = 0, \tag{20}$$

$$\gamma_3 = 0 \text{ or } x = 1, \tag{21}$$

$$\gamma_i > 0,\; i = 1, 2, 3. \tag{22}$$

where $\gamma_i$ are the Lagrangian multipliers of the constraints.

Searching for the solutions of this problem that are relevant for the proof of the proposition, several cases are possible:

**case 1.** $0 < x < 1$ :

From conditions (20) and (21), $\gamma_2 = \gamma_3 = 0$. Replacing in (18), it comes $\gamma_1 = \frac{m_f}{m_u} > 0$. Conditions (16) and (17) then state the optimal value for the efforts levels:

$$\begin{aligned} e_f &= \frac{k}{c_f}\left(B_f - m_f + \frac{m_f}{m_u}B_u\right), \\ e_u &= \frac{1-k}{c_u}\left(B_f\frac{m_u}{m_f} + B_u - m_u\right). \end{aligned}$$

By condition (19): $\gamma_1 > 0$, which means that the participation constraint of the University is biding: $E\Pi_U = \frac{(1-k)^2 B_u^2}{2c_u}$. The substitution of the solutions for $e_f$ and $e_u$ in this situation gives the optimal type of project:

$$\begin{aligned} x = & \frac{1}{2m_f m_u \left[k^2 c_u m_f + (1-k)^2 c_f m_u\right]\left[m_u\left(B_f - m_f\right) + m_f B_u\right]} \cdot \\ & \cdot \left\{(1-k)^2 c_f m_u^2 \left[m_f^2\left(2B_u - m_u\right) + m_u B_f^2\right] - \right. \\ & \left. -2k^2 c_u m_f^2 \left(B_u - m_u\right)\left[m_f\left(B_u - m_u\right) + m_u B_f\right]\right\}. \end{aligned}$$

when $\frac{k^2 c_u}{(1-k)^2 c_f} > \frac{m_u^2\left[m_f^2(2B_u - m_u) + m_u B_f^2\right]}{2m_f^2(B_u - m_u)\left[m_f(B_u - m_u) + m_u B_f\right]}$ that is, parameters are in Region $1P_U$, this solution is negative $x < 0$ which is out of the domain of $x$. In Region $2P_U$, $x > 0$ and the only concern is to compare this value of $x$ with 1 (the upper bound in the domain of $x$). In any case, in Region $2P_U$, $0 < x \leq 1$.

**case 2.** $x = 0$ :

From condition (21): $\gamma_3 = 0$. Replacing in condition (18), it comes

$$\left[ke_f + (1-k)e_u\right]\left(\gamma_1 m_u - m_f\right) = -\gamma_2. \tag{23}$$

Two alternatives then appear:

**alternative 1.** $E\Pi_U > \frac{(1-k)^2 B_u^2}{2c_u}$.

In this alternative, by condition (19), $\gamma_1 = 0$. But then, (17) gives $e_u = \infty$, which is impossible.

**alternative 2.** $E\Pi_U = \frac{(1-k)^2 B_u^2}{2c_u}$.

From this participation constraint, it is possible to obtain an expression of $e_u$ as a function of $e_f$ :

$$e_u = \frac{(1-k)(B_u - m_u) + \sqrt{2kc_u (B_u - m_u) e_f - (1-k)^2 m_u (2B_u - m_u)}}{c_u}.$$

Replacing this expression in $E\Pi_F (e_f, x = 0)$ and maximizing in order to $e_f$, we obtain the optimal level of Firm's effort.

■

**Proof of Proposition 3.5.** Under University's moral-hazard and Firm's governance, at the second stage, the University chooses its level of involvement in the collaboration, by solving:

$$\max_{\{e_u\}} E\Pi_U = pV_U - C_U.$$

The optimal rule is $e_u = \frac{1-k}{c_u} V_U = \frac{1-k}{c_u} (B_u - m_u + m_u x)$.

Anticipating this behavior, when the Firm purposes the collaboration, it chooses the project and its level of effort according to

$$\max_{\{x, e_f\}} E\Pi_F = [ke_f + (1-k) e_u] V_F - C_F.$$

From what we obtain: $e_f = \frac{k}{c_f} V_F = \frac{k}{c_f} (B_f - m_f x)$. When $R_U > \frac{m_f}{2m_u}$, $E\Pi_F$ is a concave function of $x$, and its maximum given by:

$$x^F = \frac{c_u k^2 B_f m_f + c_f (1-k)^2 [m_f (B_u - m_u) - m_u B_f]}{m_f \left[k^2 c_u m_f - 2(1-k)^2 c_f m_u\right]}.$$

$x^F > 0$ for $M_0 > \frac{m_f}{m_u}$ and $R_U > \frac{m_f B_f}{m_u B_f - m_f (B_u - m_u)} \iff \frac{m_f M_0}{m_u M_0 - m_f}$, that is, for parameters in Region $1^{FG}$.

Since $\frac{m_f M_0}{m_u M_0 - m_f} > \frac{m_f}{2m_u}$, the condition $R_U > \frac{m_f M_0}{m_u M_0 - m_f}$ is sufficient to ensure concavity.

■

**Proof of Proposition 3.6.** Under Firm's moral-hazard and University's governance, at the second stage, the Firm chooses its level of involvement in the collaboration, by solving:

$$\max_{\{e_f\}} E\Pi_F = pV_F - C_F.$$

The optimal rule is $e_f = \frac{k}{c_f} V_F = \frac{k}{c_f} (B_f - m_f x)$.

Anticipating this behavior, when the University purposes the collaboration, it chooses the project and its level of effort according to

$$\max_{\{x,e_u\}} E\Pi_U = [ke_f + (1-k)\, e_u]\, V_U - C_U.$$

From what we obtain: $e_u = \frac{1-k}{c_u} V_U = \frac{1-k}{c_u}(B_u - m_u + m_u x)$. For $R_F > \frac{m_u}{2m_f}$, $E\Pi_U$ is a concave function of $x$, and its maximum given by:

$$x^U = \frac{c_u k^2 [m_f (B_u - m_u) - m_u B_f] - c_f (1-k)^2 m_u (B_u - m_u)}{m_u \left[c_f (1-k)^2 m_u - 2c_u k^2 m_f\right]}.$$

$x^U < 1$ for $\frac{B_u}{B_f - m_f} > \frac{m_u}{m_f} \iff S_1 > \frac{m_u}{m_f}$ and $\frac{k^2 c_u}{(1-k)^2 c_f} > \frac{m_u S_1}{m_f S_1 - m_u} \iff R_F > \frac{m_u S_1}{m_f S_1 - m_u}$, that is, for parameters in Region $1^{UG}$.

Since $\frac{m_u B_u}{m_f B_u - m_u \left(B_f - m_f\right)} > \frac{m_u}{2m_f}$, the condition $R_F > \frac{m_u B_u}{m_f B_u - m_u \left(B_f - m_f\right)}$ is sufficient to ensure concavity.

■

**Proof of Corollary 3.3.** From Proposition 3.2, $0 < x^{AUF} < x^{AU}$ in Region $1^{AUF}$. Since Region $1^{FG}$ ⊂Region $1^{AUF}$, then it trivially comes that $0 < x^{AUF} < x^{AU}$ in Region $1^{FG}$. Furthermore, in Region $1^{FG}$ it also holds that $x^F - x^{AUF} < 0$, since

$$x^F - x^{AUF} = -[m_u B_f + m_f (B_u - m_u)] \left[ \left( \frac{k^2}{c_f} m_f - \frac{(1-k)^2}{c_u} m_u \right)^2 + \frac{(1-k)^2}{c_u} \frac{k^2}{c_f} \right].$$

■

**Proof of Proposition 4.1.** After observing the Social Planner's choice of the prize and the Consortium's choice of the type of project, the partner with non-verifiable effort decides on its level of effort. By backward induction, we obtain the equilibrium solution. Regarding the non-verifiability of efforts, we may have three different scenarios. The analysis, below, regards each of these scenarios.

**Scenario 1.** Only the effort of the University is non-verifiable.

At the last stage, the University's problem

$$\max_{\{e_u\}} E\Pi_U = [ke_f + (1-k)\, e_u]\, [V_U + (1-\alpha)\, z] - C_U,$$

has the solution $e_u = \frac{(1-k)}{c_u} [V_U + (1-\alpha)\, z]$.

At the previous stage, maximizing the joint expected gain, $EW$, the Consortium best options are $e_f = \frac{k}{c_f}\left[V_F + V_U + z\right]$ and $x^{AU} = \frac{1}{c_u k^2 \left(m_f - m_u\right)^2 - c_f (1-k)^2 m_u \left(2m_f - m_u\right)} \cdot$
$\cdot \{c_u k^2 (m_f - m_u)(B_f + B_u - m_u + z) +$
$+ c_f (1-k)^2 \left[(m_f - m_u)(B_u - m_u) - m_u B_f - z\left(m_u - m_f (1-\alpha)\right)\right]\}$.

When $M_0 > \frac{m_f}{m_u} - 1$ and $R_U > \frac{\left(m_f - m_u\right)(M_0+1)}{m_u M_0 - \left(m_f - m_u\right)}$, we have $x^{AU}(z=0) > 0$. This means that, without the prize, the Consortium chooses a less applied project than in the first-best, as an incentive mechanism for the University's involvement in the collaboration.

Anticipating Consortium's reaction, the Social Planner's objective function becomes

$$ES = \frac{(1-k)^2 \left[(1-k)^2 c_f + k^2 c_u\right] DF}{2c_u \left[c_u k^2 (m_f - m_u)^2 - c_f (1-k)^2 m_u (2m_f - m_u)\right]},$$

where $D = m_u(\alpha z + B_f) + m_f\left[(1-\alpha) z + B_u - m_u\right] > 0$, and $F = -D + 2z(1+\lambda) m_u$. On a second-order condition for $z$ at the max $ES$, we need $\frac{\partial^2 ES}{\partial^2 z} < 0$, where

$$\frac{\partial^2 ES}{\partial^2 z} = \frac{(1-k)^2 \left[(1-k)^2 c_f + k^2 c_u\right]}{c_u \left[c_u k^2 (m_f - m_u)^2 - c_f (1-k)^2 m_u (2m_f - m_u)\right]} \left[(1-\alpha) m_f + \alpha m_u\right]\left[m_u (2 - \alpha + 2\lambda) - m_f (1-\alpha)\right].$$

Since $c_u k^2 (m_f - m_u)^2 - c_f (1-k)^2 m_u (2m_f - m_u) < 0$ when $x^{AU}(z=0) > 0$, the previous maximizing condition is satisfied for $m_u (2 - \alpha + 2\lambda) - m_f (1-\alpha) > 0$.

From the first-order condition for $z$, we obtain

$$\frac{\partial ES}{\partial z} = 0 \Longleftrightarrow z^{AU} = \frac{\left[(1-\alpha) m_f - (1-\alpha+\lambda) m_u\right]\left[m_u B_f + m_f (B_u - m_u)\right]}{\left[(1-\alpha) m_f + \alpha m_u\right]\left[m_u (2-\alpha+2\lambda) - m_f (1-\alpha)\right]},$$

which is strictly positive for $(1-\alpha) m_f - (1-\alpha+\lambda) m_u > 0 \Longleftrightarrow$
$\Longleftrightarrow \lambda < (1-\alpha)\left(\frac{m_f}{m_u} - 1\right)$.

Considering the optimal $\alpha$ for having the max $ES$,

$$\frac{\partial ES}{\partial \alpha} = \frac{(1-k)^2 z \left[(1-k)^2 c_f + k^2 c_u\right](m_f - m_u) G}{c_u \left[c_u k^2 (m_f - m_u)^2 - c_f (1-k)^2 m_u (2m_f - m_u)\right]},$$

where $G = D - z(1+\lambda) m_u$, with $G > 0$ for $\lambda < (1-\alpha)\left(\frac{m_f}{m_u} - 1\right)$.
Since $c_u k^2 (m_f - m_u)^2 - c_f (1-k)^2 m_u (2m_f - m_u) < 0$ when $x^{AU}(z=0) > 0$, this first derivative is always negative, that is, $ES$ is decreasing on $\alpha$. The solution for $\alpha$ is, then, at the corner $\alpha = 0$. This means that all the prize

$z^{AU} = \frac{\left[m_f-(1+\lambda)m_u\right]\left[m_u B_f+m_f(B_u-m_u)\right]}{m_f\left[2m_u(1+\lambda)-m_f\right]}$, positive for $\frac{m_f}{2m_u} - 1 < \lambda < \frac{m_f}{m_u} - 1$, should be given to the University. As a consequence, the social benefit is:

$$ES^{AU} = \frac{(1-k)^2\left[(1-k)^2 c_f + k^2 c_u\right]\left[m_u B_f + m_f\left(B_u - m_u\right)\right]^2 H}{8\left(1+\lambda\right)^2 c_u m_f m_u\left[c_u k^2\left(m_f - m_u\right)^2 - c_f\left(1-k\right)^2 m_u\left(2m_f - m_u\right)\right]},$$

where $H = m_f + m_f m_u\left(1+\lambda\right)\left(2m_f - 3\right) + 2m_u\left(1+\lambda\right)^2$. Furthermore, the best project is more applied with a prize than without it, since
$x^{AU}\left(\alpha = 0, z^{AU}\right) < x^{AU}\left(z = 0\right)$.

**Scenario 2.** Only the effort of the Firm is non-verifiable.

At the last stage, the Firm's problem

$$\max_{\{e_f\}} E\Pi_F = \left[ke_f + \left(1-k\right)e_u\right]\left(V_F + \alpha z\right) - C_F,$$

has the solution $e_f^{AF} = \frac{k}{c_f}\left(V_F + \alpha z\right)$.

At the previous stage, maximizing the joint expected gain, $EW$, the Consortium best options are $e_u = \frac{1-k}{c_u}\left(V_F + V_U + z\right)$ and $x^{AF} = 0$.

Anticipating Consortium's reaction, the Social Planner's objective function becomes

$$\begin{aligned} ES &= \frac{k^2}{c_f}\left(B_f + \alpha z\right)\left[\frac{B_f}{2} + B_u - m_u - \left(\lambda + \frac{\alpha}{2}\right)z\right] + \\ &+ \frac{(1-k)^2}{c_u}\left(B_f + B_u - m_u + z\right)\left[\frac{B_f + B_u - m_u}{2} - \left(\lambda + \frac{1}{2}\right)z\right]. \end{aligned}$$

From the first-order condition for $z$,

$$\frac{\partial ES}{\partial z} = 0 \Longleftrightarrow z^{AF} = \frac{-\lambda\left(1-k\right)^2 c_f\left(B_f + B_u - m_u\right) + k^2 c_u\left[\alpha\left(B_u - m_u\right) - \lambda B_f\right]}{\left(1+2\lambda\right)\left(1-k\right)^2 c_f + \alpha\left(\alpha + 2\lambda\right)k^2 c_u}.$$

The first-order condition to have an interior solution of $\alpha$ that maximizes $ES$ is

$$\frac{\partial ES}{\partial \alpha} = 0 \Longleftrightarrow \frac{k^2 z^2\left[B_u - m_u - z\left(\alpha + \lambda\right)\right]}{c_f} = 0.$$

Substituting $z$ by the previous expression of $z^{AF}$, we obtain that either $z^{AF} = 0$, or

$$\alpha^{AF} = -\frac{\lambda^2 k^2 c_u B_f + \left(1-k\right)^2 c_f\left[\left(1+\lambda\right)^2\left(B_u - m_u\right) + \lambda^2 B_f\right]}{\lambda\left(B_f + B_u - m_u\right)\left[\left(1-k\right)^2 c_f + k^2 c_u\right]} < 0.$$

Since $\alpha^{AF} < 0$ is out of the domain for $\alpha$, we compare the three possible extreme solutions:

i) for $\alpha^{AF} = 0$, the first-order condition for $z$ gives

$$z^{AF} = \frac{-\lambda \left[ (1-k)^2 c_f (B_f + B_u - m_u) + k^2 c_u B_f \right]}{(1+2\lambda)(1-k)^2 c_f} < 0.$$

Since, by domain $z^{AF} \geq 0$, the closest solution to be considered is $z^{AF} = 0$.

ii) for $\alpha^{AF} = 1$, the first-order condition for $z$ gives

$$z_1^{AF} = \frac{-\lambda (1-k)^2 c_f (B_f + B_u - m_u) + k^2 c_u (B_u - m_u - \lambda B_f)}{(1+2\lambda) \left[ (1-k)^2 c_f + k^2 c_u \right]}.$$

When $\lambda < \frac{B_u - m_u}{B_f}$ and $R_U < \frac{B_u - m_u - \lambda B_f}{B_f + B_u - m_u}$, $z^{AF} > 0$. In this case, the expected social gain from collaboration is

$$ES\left(x = 0, \alpha^{AF} = 1, z_1^{AF}\right) = \frac{H}{2(1+2\lambda) c_f c_u \left[ (1-k)^2 c_f + k^2 c_u \right]},$$

where

$$\begin{aligned} H \;=\; & (1-k)^4 c_f^2 (1+\lambda)^2 (B_f + B_u - m_u)^2 + \\ & + k^4 c_u^2 \left[ B_u - m_u + (1+\lambda) B_f \right]^2 + \\ & + (1-k)^2 k^2 c_f c_u \left[ (B_u - m_u)^2 + \right. \\ & \left. + 2(1+\lambda) B_f \left[ (1+\lambda) B_f + 2(2+\lambda)(B_u - m_u) \right] \right]. \end{aligned}$$

iii) for $z^{AF} = 0$, the expected social gain from collaboration is

$$\begin{aligned} ES\left(x = 0, z^{AF} = 0\right) \;=\; & \frac{1}{2 c_f c_u} \cdot \\ & \cdot \left\{ k^2 c_u B_f (B_u - m_u - \lambda B_f) - \right. \\ & \left. - \lambda (1-k)^2 c_f (B_f + B_u - m_u) \right\}. \end{aligned}$$

Comparing $ES\left(x = 0, \alpha^{AF} = 1, z_1^{AF}\right)$ with $ES\left(x = 0, z^{AF} = 0\right)$, we obtain that the former is socially preferred.

In resume, when the Firm's effort in the collaborative project is non-verifiable, the best social solution is to choose the most possible applied research $x^{AF} = 0$. When the cost of public funds is sufficiently small $\left(\lambda < \frac{1}{M_0}\right)$ and the Firm's effort is relatively important for the success of the project $\left(R_U > \frac{M_0 + 1}{1 - \lambda M_0}\right)$, a prize $z_1^{AF} = \frac{-\lambda (1-k)^2 c_f \left(B_f + B_u - m_u\right) + k^2 c_u \left(B_u - m_u - \lambda B_f\right)}{(1+2\lambda)\left[(1-k)^2 c_f + k^2 c_u\right]}$ 0 should be given. In this case, however, only the Firm's participation should receive the extra-reward $\left(\alpha^{AF} = 1\right)$.

**Scenario 3.** Both efforts of the University and of the Firm are non-verifiable.

At the last stage, from the individual maximization problem of each partner, we obtain the amount of resources that they are willing to allocate for the joint project:

$$e_u^{AUF} = \frac{(1-k)}{c_u}\left[V_U + (1-\alpha)z\right],$$
$$e_f^{AUF} = \frac{k}{c_f}\left(V_F + \alpha z\right).$$

Anticipating these choices, at the previous stage, the Consortium best option to maximize the joint expected gain, $EW$, is

$$x^{AUF} = \frac{1}{c_u k^2 m_f (2m_u - m_f) + c_f (1-k)^2 m_u (2m_f - m_u)} \cdot$$
$$\cdot \left\{-c_u k^2 \left[(m_f - m_u) B_f + m_f (B_u - m_u) + z(m_f - \alpha m_u)\right] + \right.$$
$$\left. + c_f (1-k)^2 \left[m_u B_f - (m_f - m_u)(B_u - m_u) + z(m_u - m_f(1-\alpha))\right]\right\}.$$

When $M_0 > \frac{m_f}{m_u} - 1$ and $R_U > \frac{(m_f - m_u) M_0 + m_f}{m_u M_0 - (m_f - m_u)}$, we have $x^{AUF}(z=0) > 0$. This means that, without prize, given the importance of the University for the joint project, the Consortium prefers to choose a project closer to the academics' interests. Therefore, the chosen project is less applied than in the first-best.

By backward induction, at the first stage, the Social Planner's objective function becomes

$$ES = -\frac{(1-k)^2 k^2 D I}{2\left[c_u k^2 m_f (2m_u - m_f) + c_f (1-k)^2 m_u (2m_f - m_u)\right]},$$

where $D = m_u(\alpha z + B_f) + m_f\left[(1-\alpha) z + B_u - m_u\right]$ and
$I = -D + R_U\left[z(2 - \alpha + 2\lambda) m_u - D\right] + \frac{1}{R_U}\left[2z(\alpha + \lambda) m_f - D\right]$.

From the second-order conditions of $\max ES$, with respect to $z$,

$$\frac{\partial^2 ES}{\partial^2 z} < 0 \Longleftrightarrow$$
$$\Longleftrightarrow \frac{-(1-k)^2 k^2 \left[(1-\alpha) m_f + \alpha m_u\right] J}{\left[c_u k^2 m_f (2m_u - m_f) + c_f (1-k)^2 m_u (2m_f - m_u)\right]} < 0,$$

where $J = -(1-\alpha) m_f - \alpha m_u + \frac{1}{R_U}\left[(1+\alpha+2\lambda) m_f - \alpha m_u\right] +$
$+ R_U\left[(2-\alpha+2\lambda) m_u - (1-\alpha) m_f\right]$. When $x^{AUF}(z=0) > 0$, we have $\left[c_u k^2 m_f (2m_u - m_f) + c_f (1-k)^2 m_u (2m_f - m_u)\right] > 0$, and therefore, the previous condition is satisfied for $J > 0$.

From the first-order condition of $\max ES$, with respect to $z$,

$$\frac{\partial ES}{\partial z} = 0 \Longleftrightarrow z^{AUF} = \frac{-\left[m_u B_f + m_f (B_u - m_u)\right] L}{\left[(1-\alpha) m_f + \alpha m_u\right] J},$$

where $L = -(1-\alpha)m_f - \alpha m_u + \frac{1}{R_U}\left[(\alpha+\lambda)m_f - \alpha m_u\right] +$
$+R_U\left[(1-\alpha+\lambda)m_u - (1-\alpha)m_f\right]$. Given that $J > 0$, a positive solution for $z^{AUF}$ exists whenever $L > 0$.

Since the second derivative of $ES$ with respect to $\alpha$ is given by

$$\frac{\partial^2 ES}{\partial^2 \alpha} = \frac{z^2\left[(1-k)^2 k^2 c_f c_u + k^4 c_u^2 + (1-k)^4 c_f^2\right](m_f - m_u)^2}{c_f c_u\left[c_u k^2 m_f(2m_u - m_f) + c_f(1-k)^2 m_u(2m_f - m_u)\right]} > 0,$$

$ES$ is non-concave with respect to $\alpha$. As a consequence, the optimal value for $\alpha$ must be at one of the corners, $\alpha = 0$ or $\alpha = 1$.

The best social choice with respect to $z$ and $\alpha$ is given by the comparison of $ES$ under the three possible alternatives:

i) at $\alpha^{AUF} = 0$, the first-order condition for $z$ gives $z_0^{AUF} = \frac{-\left[m_u B_f + m_f(B_u - m_u)\right]L_0}{\left[(1-\alpha)m_f + \alpha m_u\right]J_0}$, where $L_0$ corresponds to the value of $L$ when $\alpha = 0$, and $J_0$ to the value of $J$ when $\alpha = 0$. With such values for $z$ and $\alpha$, the expected social gain from collaboration is

$$ES_0^{AUF}\left(\alpha^{AUF} = 0, z_0^{AUF}\right) = \frac{(1+\lambda)^2\left[k^4 c_u^2 m_f + (1-k)^4 c_f^2 m_u\right]^2}{2c_f^2 c_u^2 m_f (1-k)^2 k^2} \cdot \frac{\left[m_u B_f + m_f(B_u - m_u)\right]^2}{\left[c_u k^2 m_f(2m_u - m_f) + c_f(1-k)^2 m_u(2m_f - m_u)\right] J_0};$$

ii) at $\alpha^{AUF} = 1$, the first-order condition for $z$ gives $z_1^{AUF} = \frac{-\left[m_u B_f + m_f(B_u - m_u)\right]L_1}{\left[(1-\alpha)m_f + \alpha m_u\right]J_1}$, where $L_1$ corresponds to the value of $L$ when $\alpha = 1$, and $J_1$ to the value of $J$ when $\alpha = 1$. With such values for $z$ and $\alpha$, the expected social gain from collaboration is

$$ES_1^{AUF}\left(\alpha^{AUF} = 1, z_1^{AUF}\right) = \frac{(1+\lambda)^2\left[k^4 c_u^2 m_f + (1-k)^4 c_f^2 m_u\right]^2}{2c_f^2 c_u^2 m_u (1-k)^2 k_1^2} \cdot \frac{\left[m_u B_f + m_f(B_u - m_u)\right]^2}{\left[c_u k^2 m_f(2m_u - m_f) + c_f(1-k)^2 m_u(2m_f - m_u)\right] J};$$

iii) at $z^{AUF} = 0$, the expected social gain from collaboration is

$$ES^{AUF}\left(z^{AUF} = 0\right) = \frac{(1-k)^2 k^2 c_u c_f\left[m_u B_f + m_f(B_u - m_u)\right]^2\left[1 + \frac{1}{R_U} + R_U\right]}{2\left[c_u k^2 m_f(2m_u - m_f) + c_f(1-k)^2 m_u(2m_f - m_u)\right]}.$$

Then, the social best choice under non-verifiability of effort from both partners is:

- to give a positive prize $z_0^{AUF}$ only to the University $\left(\alpha^{AUF}=0\right)$ when $\lambda<\frac{1}{2}\left(\frac{m_f}{m_u}-1\right)$ and $R_U \in \left(R_U, \tilde{R}_{u0}\right)$, where $R_{u0}$ is the minimum value of $R_U$ that satisfies both conditions

$$R_U\left[1-\frac{m_u}{m_f}(1+2\lambda)\right]+1+\frac{m_u}{m_f}>\frac{1}{R_U}\left(1+2\lambda-\frac{m_u}{m_f}\right) \tag{24}$$

  and

$$R_U\left[1-\frac{m_u}{m_f}(1+\lambda)\right]+1>\frac{1}{R_U}\lambda, \tag{25}$$

  and $\tilde{R}_{u0}$ is the maximum value of $R_U$ that still satisfies

$$R_U\left[1-2\frac{m_u}{m_f}(1+\lambda)\right]+1<\frac{1}{R_U}(1+2\lambda). \tag{26}$$

  $R_{u0}$ guarantees that the relative importance of the University is sufficiently high, so that its effort for the collaboration receives a prize (positive value of $z$). $\tilde{R}_{u0}$ creates an upper boundary for $R_U$, above which the existence of a prize for the University has an impact in the cost of its effort greater than the impact on the expected revenue. As a consequence, below $R_{u0}$ the best is to subsidize the Firm, whereas above $\tilde{R}_{u0}$ the best is to settle $z=0$.

- to give a positive prize $z_1^{AUF}$ only to the Firm $\left(\alpha^{AUF}=1\right)$ when $\lambda>\frac{1}{2}\left(\frac{m_f}{m_u}-1\right)$ and $R_F \in \left(R_{f1}, \tilde{R}_{f1}\right)$, where $R_{f1}$ is the minimum value of $R_F$ that satisfies both conditions

$$R_F\left[(1+2\lambda)\frac{m_f}{m_u}-1\right]+\frac{1}{R_F}\left(1+2\lambda-\frac{m_f}{m_u}\right)>1+\frac{m_f}{m_u} \tag{27}$$

  and

$$R_F\left[2(1+\lambda)\frac{m_f}{m_u}-1\right]+\frac{1}{R_F}(1+2\lambda)>1, \tag{28}$$

  and $\tilde{R}_{f1}$ is the maximum value of $R_F$ that still satisfies

$$R_F\left[(1+\lambda)\frac{m_f}{m_u}-1\right]+\frac{1}{R_F}\lambda<1. \tag{29}$$

  $R_{f1}$ guarantees that the relative importance of the Firm is sufficiently high so that its collaboration receives a prize with a positive value of $z$. $\tilde{R}_{f1}$ creates an upper boundary for $R_F$, above which the existence of a prize for the Firm has an impact in the cost of its effort greater than the impact on the expected revenue.

■

**Proof of Proposition 5.1.** Comparing conditions (13) and (11), and since $\frac{\partial p}{\partial e_i} > 0$, it becomes clear that the Consortium distorts its choice for the project towards the preferences of party $i$, whenever the external effect caused by $e_i$, $\frac{\partial p}{\partial e_i}\frac{\partial e_i}{\partial x}(e_f, e_u)\, V_j(x)$ dominates: over $p(e_f, e_u)\left[\frac{\partial V_F}{\partial x} + \frac{\partial V_U}{\partial x}\right]$, when only $e_i$ is non-verifiable; or over $p(e_f, e_u)\left[\frac{\partial V_F}{\partial x} + \frac{\partial V_U}{\partial x}\right] + \frac{\partial p}{\partial e_j}\frac{\partial e_j}{\partial x}(e_f, e_u)\, V_i(x)$, when both $e_i$ and $e_j$ are non-verifiable.

When only $e_i$ is non-contractible, comparing conditions (12) and (10), we easily conclude that:

- when efforts are complementaries, $i$'s reaction function $e_i(e_j)$ is such that $\frac{\partial e_i}{\partial e_j} > 0$. In this case, the Consortium chooses a higher $e_j$ than in first-best;
- when efforts are substitutes, $i$'s reaction function $e_i(e_j)$ is such that $\frac{\partial e_i}{\partial e_j} < 0$, Consortium chooses a smaller $e_j$ than in first-best;
- when efforts are independents, $i$'s reaction function $e_i(e_j)$ is such that $\frac{\partial e_i}{\partial e_j} = 0$, Consortium chooses the same $e_j$ as in first-best.

■

**Proof of Proposition 5.2.** Comparing conditions (15) to (11), non-contractability of $e_i$ creates an external effect, on $j's$ decision on the type of project. In this situation, the governing party $j$ is willing to distort its most-preferred project towards $i$'s interests, whenever the external effect $\frac{\partial p}{\partial e_i}\frac{\partial e_i}{\partial x}(e_f, e_u)\, V_j(x)$ dominates over $p(e_f, e_u)\frac{\partial V_j}{\partial x}$. Nevertheless, comparing conditions (15) and (13), it is visible that due to $\left|p(e_f, e_u)\frac{\partial V_j}{\partial x}\right| < \left|p(e_f, e_u)\left[\frac{\partial V_F}{\partial x} + \frac{\partial V_U}{\partial x}\right]\right|$, a decentralized governance always distorts less its first-best project than a Consortium does.
■