Topics on the (Re)organization of Knowledge

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Contents

Chapter 0

Introduction

The theoretical and empirical work of the present dissertation addresses organizational questions on collaborative relations, in the context of knowledge production. Research collaboration refers to the joint work of different parties on a common issue. Collaboration between knowledge producers, researchers, yields potential increase in the efficiency of production or allows the realization of complementarity gains. Nevertheless, the characteristics of the parties, the institutional setting where they belong, and their expertise background influence their goals and perspectives. The aim of this dissertation is to contribute for a better understanding on how these features of a collaborative relation influence its outcome. I also discuss the role of incentives, in the possibility of existing asymmetric information between the parties involved.

Due to the relevance of knowledge for society, an important question is how to create and make the best possible use of knowledge (e.g., Vannevar Bush, 1945; European Commission, 2002; National Science Foundation, 2004).[1] This question, already identified by Hayek (1945), nowadays still does not have a complete and satisfactory answer (European Commission & High Level Expert Research Group, 2003). One crucial difficulty in providing an answer to the problem lays on the dynamism of the process of creating and using knowledge. As societies develop, individual and collective needs change, and with them, it also changes the way the different parties involved interact. The present work addresses two main topics that up to now have not been receiving enough discussion among the economic literature, interdisciplinarity and collaboration between business and science.

In the first topic of this dissertation, I analyze the dichotomy between interdisciplinary research and the organizational way in which modern science is grounded, where disciplines are different and separately defined. The first chapter of the present work, "Incentives for Interdisciplinary Research", is the first in the economic literature, up to my knowledge, developing a positive analysis of the driving forces in interdisciplinary research. In this chapter, I characterize interdisciplinary research by two main aspects. First, production complementarities; second, by the a innate cost disadvantage due to the

[1] Audretsch *et al.* (2002) and Hagedoorn *et al.* (2000) include a historical perspective of the policy on science and technology.

presence of obstacles in the development of a new and unexplored scientific field, and in the need of collaboration between researchers with different scholarly backgrounds. My results show that interdisciplinarity is the option with the highest net benefit, once the cost of *opening* the new scientific path is overcome. On behalf of society, the importance of the intervention of policymakers is felt at two levels. First, to ensure that the research institution has the sufficient monetary resources to support the cost of the process of research. Second, and above all, to guarantee that the goal of production is demanding enough to be worth going through the difficulties of interdisciplinarity. Productive gains due to complementarities of efforts is the main advantage of interdisciplinary organization.

The second topic of this dissertation regards the collaboration between business and science institutions, corporate and academia, with a focus on the dichotomy between basic research and applied research. Several evidences document that when academics and entrepreneurs work together, it is more likely that both achieve valuable outcomes from research (e.g., Lambert, 2003; Zucker & Darby, 1995; Cockburn & Henderson, 1998). Nevertheless, these two types of organizations do not emerge as natural partners. Belonging to different institutional settings (Dasgupta & David, 1994), corporate and academic organizations face different socioeconomic rules in terms of goals, norms of behavior and reward systems. These divergences lead to divergences in the approach and in the objectives when conducting research. As a result, the interaction between entrepreneurs and academics is potentially hindered (e.g., Hall *et al.,* 2001; Siegel, 1999; Hall, 1999; Brainard, 1999; Schartinger *et al.*, 2001).

In the second chapter of the present work, "Business-Science Research Collaboration under Moral-Hazard ", I analyze how the characteristics of partnership agreements are the result of an optimal contract between the parties. The final outcome depends on the structure governing the partnership, and on the informational problems on 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. The results in this chapter show 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. Finally, I derive conditions under which public intervention may be optimal. My analysis contrasts with the existent literature on research partnerships in three main directions. First, it emphasizes the peculiarities of the interaction of business and science; second, it shows the tensions raised in this particular context; and third, it studies the role of the structure of governance and informational problems for solving those tensions.

The third chapter of the present dissertation, "Patents and Business-Science Research Partnerships" is jointly written with Walter Garcia-Fontes. There, we develop an empirical analysis on how the characteristics of the research process, specially its institutional dimension, relate with the patented inventions arising from that research. We focus on one main feature of the patents, its *basicness*, how close they are from the Academic research goal of advancing the existent stock of knowledge. With data from the European survey, PatVal-EU, we construct a composite index of basicness of the patents, weighted by a quality indicator. Our results are aligned with the theoretical work of the second chapter of this dissertation. The institutional identity of the inventing organizations do become visible in the basicness of the patents.

Despite that the current dissertation focuses on the knowledge production, research, the questions here addressed do have broader applications. The results have managerial implications in the organization of inter-firms relations as well as in the relation between a manager and its workers.

Chapter 1

Incentives for Interdisciplinary Research

This chapter benefited from the useful comments of Inés Macho-Stadler, Pau Olivella, Pedro Rey-Biel, Nicola Lacetera, and Joana Pais, to whom I acknowledge. I also received interesting suggestions during the Microeconomics Workshop and the Industrial Organization Informal Seminar at IDEA-UAB, the ENTER Jamboree Meeting 2006 at Stockholm, and the EARIE 2006 Conference at Amsterdam.

1.1 Introduction

Why interdisciplinary research, considered very interesting and important to achieve breakthroughs, is at the same time so neglected among scientific community? There is few understanding of what are the driving forces of the disciplinary pattern in research organizations. In particular, why it is still so scarce the observation of interdisciplinary research, despite all emphasis that it receives from policymakers. The present chapter brings some potential useful results in explaining such puzzling situation, by making a positive (rather than normative) comparison between interdisciplinarity and specialization.

In the current context, *specialization* refers to the case where scientists work separate and independently on their own fields of expertise. This specialized fields are characterized by well-established and long existent scientific foundations. Foundations of the modern organization of science are based in secular structures of these different and separate disciplines.

Over the years, and especially in the two previous decades, however, it has been increased the importance attached to an alternative organizational form, *interdisciplinarity*: the integration of (already existing) disciplines on the development of a new scientific area. Interdisciplinarity has been seen as the most suitable way to solve complex questions arising to societies, as illustrated by The National Academies: "*Advances in science and engineering increasingly require the collaboration of scholars from various fields. This shift is driven by the urgent need to address complex problems that cut across traditional* *disciplines, and the capability of new technologies to both transform existing disciplines and generate new ones.*" (National Academies, 2004). Two world-wide recognized examples of interdisciplinarity illustrate how powerful it can be: the development of genomics, a branch of biotechnology whose roots relate with genetics, molecular biology, analytical chemistry, and informatics; and the development of neurosciences, a new life science evolving from anatomy, physiology, biochemistry, and molecular biology of nerves.

Besides the novelty of the field, interdisciplinarity is also characterized by the requirement of collaboration between different experts. Both defining features of interdisciplinarity are a natural source of difficulties. First, when moving from their scholar background into a new and unexplored discipline, researchers need to adjust to different languages, tools, methodologies, and goals. In the present chapter, these differences between disciplines are embody in the concept of *scientific distance* between fields. A second potential challenge that interdisciplinarity poses to scientists is the need to cooperate with other scientists, with whom they do not share the disciplinary background.

The empirical study of Porac *et al.* (2004) may serve to illustrate my theoretical framework. That paper devotes attention to the scientific performance of two teams of researchers, Astro and Eco. These teams differ in the composition and in the disciplinary expertise of their members, as well as on their research goal.[1] Scientists in Astro have similar scholarly background and work in the well established field of Astrophysics. Researchers in Eco come from different disciplinary backgrounds and are required to work in modelling ecosystems. Modelling ecosystems is a relatively new science, emerging from previously separated fields related with air, water, and land resources. As in my framework, the paper emphasizes the challenge that Eco team members face to overcome the inherent tensions of the new project. On the one hand, these tensions relate to the need of balancing "between their individual discipline-based paradigms and the joint demands of the alliance work" (pp. 673). In the language of my framework, this relates with the scientific distance between the background field of scientists and the new interdisciplinary field.[2] On the other hand, the members of the Eco team also identify the need to develop a routine of communication as well a common language among all members.[3]

With such distinction between interdisciplinarity and specialization, interdisciplinary research presents a starting cost disadvantage embodied in its own definition. Nevertheless, when scientists make an extra-investment of adaptation, interdisciplinary difficulties can be reduced (at least partially). Dan Sperber, an anthropologist involved in the interdisciplinary project "Culture and Cognition" at the University of Michigan recognizes the importance of such adaptation concern: "Serious involvement in interdisciplinary research needs a high investment endeavor. To be able to understand each other and conceive of

[1]One main difference between my framework and Porac et al. (2004) is that, in their case, the comparison is between an *interdisciplinary* and a *specialized* team. By contrast, I consider that under specialization, researchers work separate and independently. With such separation, I avoid discussing team effects, in order to emphasize the issues of coordination and novelty in interdisciplinarity.

[2]The importance of developing and learning specialized codes in an organization is emphasized in a recent paper of Crémer *et al.* (2007).

[3]By contrast, among Astro team none of these questions were relevant.

common goals." (Sperber, 2003). In a static framework as mine, I denominate this extra-investment of the researchers as the *acquisition of adaptative-skills*. It corresponds to an endeavor of learning techniques and tools, allowing the researchers to work on the new discipline, in a less costly way.

Under this framework, I discuss the arguments that lead a research institution to decide between the two types of organization: specialization and interdisciplinarity. For such, I assume researchers to be perfectly coordinated with their employer organization, an university. Then, I consider a simple compensation mechanism for the university, a prize, whose rules are settled by a policymaker.

To emphasize the positive (rather than normative) analysis between interdisciplinarity and specialization, I analyze two alternative informational settings. The first, from the perspective of a policymaker who may allocate funds for one of the two types of organizational structures. For such, it is possible to consider that either it exists perfect and complete information between the policymaker and the research organization, or that a policymaker has enough flexibility in defining the rules for the prizes so that it can still induce the organization to do the first-best. The second setting takes the point of view of the university that owns the resources. The decision of the university regarding which type of research to implement, is influenced by incentives from the policymaker. In this incentives setting, the policymaker defines an unique prize rule for both types of research, and is the university who decides whether it strives for the prize through specialization or through interdisciplinarity.

I do consider that the university aims to maximize the net benefit of its projects, financed by the policymaker. The net benefit maximization goal for the university seems a reasonable assumption, given that it is a research institution with limited resources (as it is explicit by the fact that specialization and interdisciplinarity are two disjoint scenarios). Furthermore, by assuming a research institution that receives public funds, its choice of the type of knowledge is linked with the social value that such decision can provide to society.

My results show that when the purpose is to produce a high level of output, interdisciplinarity is more attractive than specialization. The reason is that interdisciplinarity yields complementary gains, which are not possible in specialization. This means that even if interdisciplinarity involves both researchers for a common output, it may be more efficient than to have them working separately for independent and separate areas. Although interdisciplinarity has a cost disadvantage, comparing with specialization, it is expectable that defining a production goal sufficiently high, favours the choice of interdisciplinarity. These theoretical predictions are aligned with the evidence in Porac *et al.* (2004). There, when comparing the performance pattern of the two teams, they find that the joint production (sum of publications) of their members increases proportionally more in Eco team, the heterogenous group working in a new area.

The results of this chapter may also be seen from a broader perspective. Rather than thinking only on scientific research, it is possible to extend some of the findings to firms, both on their internal organization, and on their relation with other firms.

Within the firm, the current chapter may be useful to study the relation between a principal (manager) and a group of agents (workers) who can either work separate and independently in their domains of expertise, or can join expertises and work as a team for a project new for all of them. In particular, my results show that when the principal cannot enforce the team creation, it is expectable that the agents actually create it, once the goal that the principal requires is sufficiently difficult to be individually obtained.

Considering inter-firms relations, it is also expectable that firms decide to coordinate efforts in a new project, when the gains from cooperation compensate the costs of coordination and of entrance in a new project.

The theme of interdisciplinarity has some common features with the area of human capital and production organized by teams. In particular, this literature provides empirical evidence on an effect that my framework captures: a higher productivity is often associated with the heterogeneous composition of the teams (e.g., Van der Vegt & Janssen, 2003; Hamilton *et al.*, 2003).

My results also have common features with the literature on incentives and coordination costs, namely with Dessein *et al.* (2007). Their work considers the trade-off between the need to standardize and reduce a duplicated activity inside a firm, and the impact that such change in the organizational structure brings in another related task. As in my question, their decision is whether to keep or not activities working separate and independently without realizing a synergy. Nevertheless, we differ on the focus of the argument. They endogenously condition the optimality of the decision on the distortions that it causes in another related task, namely in terms of the incentives to truth revelation of private information. I assume a more general framework (that could be used to encompass their argument), where costs of interdisciplinarity relate not only with the alternative (rather than sequentially related) scenario of specialization, but also and above all with the coordination problems among different parties and with the cost of starting a new, unknown, project.

Despite the above mentioned relation between my chapter and the existent literature, up to my knowledge, there are no theoretical developments on interdisciplinarity, and on its relations with the organizational structure of institutions through incentives. The current work is a first step in filling this gap.

In the next section, I formally present the model and the structure of the game between the policymaker and the research institution. In Section 1.3, I discuss the equilibrium results under alternative settings: when the information between the policymaker and research institution is perfect and complete; when the choice of the productive inputs and the acquisition of the adaptative-skills can not be established by contract; and, finally, when the funding rules for the prizes are restricted to be equal among all scientific fields. In this last setting, I explicit analyze what are the main arguments in favour of interdisciplinarity, from the point of view of the research institution. Section 1.4 concludes. All proofs are in Appendix One.

1.2 The Model

1.2.1 Specialization and Interdisciplinarity

Let us consider a research institution, call it University, that employs two researchers, each one with a different expertise field. For simplicity, the researchers are perfectly identified by their own field, that is, researcher A is an expert in scientific field A, and researcher B is an expert in scientific field B. The two scientific fields are differentiated with respect to their defining characteristics: object of study, language, tools. For the purpose of the current analysis model, I aggregate and reduce those characteristics to a single dimension. Considering such dimension, assume the difference between A and B is measurable and equal to one, as Figure 1.1 shows.

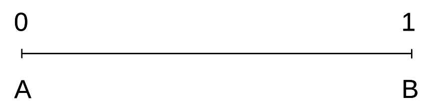

Figure 1.1: Scientific distance between the specialized fields.

At the University, the research activity may follow one of the two possible disjoint patterns: specialization or interdisciplinarity.

In the specialized scenario, each researcher i $(i = A, B)$ works separate and independently on his field of background, producing an amount Y_i of specialized knowledge output, with C_i. Explicitly:

$$Y_i = e_i, \tag{1.2.1}$$

$$C_i = \alpha_i \cdot Y_i, \quad i = A, B, \tag{1.2.2}$$

where $e_i \in \mathbb{R}^+$ is the amount of labor input (effort) spent by researcher i, whereas the cost coefficient $\alpha_i \in (0, 1)$. Although only the labor input is explicitly included in the knowledge technology, other factors affecting the production process of Y_i can be reflected in the value of α_i.

The current analysis focus on the perspective of the University, considering it an unified structure in terms of goals and objectives. In that sense, instead of referring to two types of researchers, it would be possible to talk about two different departments or two areas of research, perfectly coordinated with the organization. For the purpose of a simpler exposition, let us keep the reference to two researchers, but not including any informational problem between them and the University. The following two assumptions serve this purpose.

Assumption 1.1: The labor inputs e_i are perfectly observable and verifiable between the University and its researchers.

Assumption 1.2: The cost coefficients α_i are publicly known.

As an alternative to have each researcher developing specialized knowledge, the University may combine the work of both experts, A and B, for the development of a *new* scientific discipline, field I. In terms of the conjectural dimension for the scientific fields, the new interdisciplinary I lies between the two areas from which it emerges. As Figure 1.2 represents, I assume that the new I is located at a distance ρ from field A and at a distance $(1-\rho)$ from field B, with $\rho \in (0,1)$.

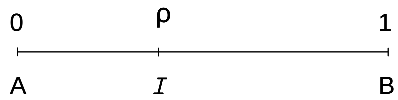

Figure 1.2: Relative position of the interdiciplinary field I.

Being a location characteristic, ρ is a basic feature to identify the new field I. In the present setting, it is assumed to be an exogenous parameter. The interdisciplinary production relies on the collaboration of the two different experts. The contribution of each participant is proportional to the distance between his background field and the new I : the closer he is from I, the more important is his expertise for the production of I. Considering this complementarity property, the production of the interdisciplinary output, Y_I, is described by the following technology:

$$Y_I = \lambda \cdot e_{AI}^{1-\rho} \cdot e_{BI}^{\rho}, \tag{1.2.3}$$

where $\lambda \in \mathbb{R}^+$ is a scaling technological parameter and e_{iI} identifies the amount of labour input of researcher i to output I, $i = A, B$.

Given the relative distribution of the three scientific fields and the way it is related with the parameter ρ, it is possible to center the analysis on the case of $\rho \in \left(0, \frac{1}{2}\right)$, that is, on the case where researcher A is the closest to I. The generalization for the remaining domain of ρ is straightforward. Only when opportune, I emphasize the symmetric case of $\rho \in \left(\frac{1}{2}, 1\right)$, or the even situation of $\rho = \frac{1}{2}$.

For the University, the cost of producing interdisciplinary output reflects, on the one hand, the opportunity cost of the resources employed in production, e_{AI} and e_{BI}, and, on the other hand, the difficulties underlying the development of a new and unexplored field. These difficulties may, however, decrease if there is an extra-involvement of the researchers, that is, if the University invests in the *adaptative-skills* of its workers. Inspired in the concept of *individual's innovative behavior* of Van der Vegt & Janssen (2003), I define the adaptative-skills of a researcher as the intentional exercise of intellectual flexibility, in order to decrease the individual marginal cost of working in the interdisciplinary field. The acquisition of these skills describes, on a static framework as the current one, the process of learning the basic characteristics (language, tools) of the new field. Once such investment is made, the researcher is able to work on the new field in a less costly way. A binary variable θ_i identifies whether researcher i $(i = A, B)$ acquires such adaptative-skills $(\theta_i = 1)$ or not $(\theta_i = 0)$.

Considering these characteristics, the cost of the University to produce interdisciplinary research can, then, be formulated as:

$$C_I = \left(\frac{\rho + \alpha_A}{1-\rho}\right)(1-\rho\theta_A)\, e_{AI} + \left(\frac{1-\rho+\alpha_B}{\rho}\right)(1-(1-\rho)\,\theta_B)\, e_{BI} + \frac{\rho}{1-\rho}\theta_A + \frac{1-\rho}{\rho}\theta_B. \tag{1.2.4}$$

This formalization makes explicit that the acquisition of adaptative-skills for researcher i reduces his marginal cost of effort: for researcher A from $\left(\frac{\rho+\alpha_A}{1-\rho}\right)$ to $(\rho + \alpha_A)$, and for researcher B from $\left(\frac{1-\rho+\alpha_B}{\rho}\right)$ to $(1-\rho+\alpha_B)$. Let m_i be the marginal cost of e_i before the investment in his adaptative-skills, i.e., $m_A = \frac{\rho+\alpha_A}{1-\rho}$ and $m_B = \frac{1-\rho+\alpha_B}{\rho}$. The function (1.2.4) can be re-written as:

$$C_I = m_A (1-\rho\theta_A)\, e_{AI} + m_B (1-(1-\rho)\,\theta_B)\, e_{BI} + \frac{\rho}{1-\rho}\theta_A + \frac{1-\rho}{\rho}\theta_B. \tag{1.2.5}$$

The first two terms in the cost function refer to the cost of the inputs e_{iI}. I refer to them as the *productive cost*. The higher the scientific distance between the original field of researcher i and the new field I, the higher the productive cost. By m_A and m_B, the marginal cost of effort for researcher A is then increasing with ρ, whereas the marginal cost of effort B is decreasing with ρ. The investment in the adaptative-skills, $\theta_i = 1$, decreases the marginal cost of e_{iI}.

To benefit from adaptative-skills it is necessary to invest on them. The last two terms in function (1.2.5) reflect the cost of these investments. I assume the cost of acquiring adaptative-skills is proportional to the distance ρ.

Comparing both benefits and costs of the adaptative-skills, it is possible to establish the following lemma.

Lemma 1.2.1 *A University interested in minimizing the cost of producing interdisciplinary research, invests in the adaptative-skills of a researcher only when it employs a sufficiently large amount of his labor input: it invests on adaptative-skills of researcher A when* $e_{AI} \geq \frac{1}{\rho+\alpha_A}$*, and of researcher B when* $e_{BI} \geq \frac{1}{1-\rho+\alpha_B}$.

1.2.2 The Value of Knowledge and the Reward System

Let us consider the existence of a government (the *G*overnment), with an endowment of G monetary resources (exogenous in the current setting). The University may receive these resources through a mechanism of prizes. Acting as an advocate for society, the role of the Government is to define the monetary amount of the prize in each field i, g_i $(i = A, B, I)$, as well as the criterion and respective threshold that the University must fulfill in order to receive that prize. The criterion to receive the prize is unique and defined in terms of a requirement of minimum output $\tilde{y}_i$. This means that the University receives g_i monetary units, if its production in field i is at least $\tilde{y}_i$. Following what is common in the literature, this required minimum performance may also be denominated as the *standard* (e.g., Costrell, 1994; or Betts, 1998).

Being aware, not only of a budget constraint of G monetary units, but also that specialization and interdisciplinarity are two disjoint scenarios, the problem of the Government in choosing the funding rules can be defined as follows.

G1) In the specialized scenario,

$$\max_{(g_i, \tilde{y}_i)_{i=A,B}} V_{AB}\left[Y_A\left(g_A, \tilde{y}_A\right), Y_B\left(g_B, \tilde{y}_B\right)\right]$$

$$s.t. \begin{cases} g_A + g_B \leq G, \\ \Pi_{univ} \geq 0, \end{cases}$$

where $Y_i\left(g_i, \tilde{y}_i\right)$ is the knowledge produced by the University in field i ($i = A, B$), function of the funding rules for field i, and V_{AB} measures the social value of the specialized outputs. Since the welfare function V_{AB} captures the benefits that knowledge brings to the society, I assume it is increasing in its arguments, that is, $\frac{\partial V_{AB}}{\partial Y_i} > 0$. For simplicity, I assume additive separability in the social value of the specialized fields:

$$V_{AB}\left[Y_A\left(g_A, \tilde{y}_A\right), Y_B\left(g_B, \tilde{y}_B\right)\right] = V_A\left[Y_A\left(g_A, \tilde{y}_A\right)\right] + V_B\left[Y_B\left(g_B, \tilde{y}_B\right)\right],$$

where the social value of each specialization is given by an increasing and concave function: $V_i' > 0$, $V_i'' \leq 0$. The generic specification of V_i is compatible with the possibility of A and B being differently important for society.

G2) In the interdisciplinary scenario,

$$\max_{(g_I, \tilde{y}_I)} V_I\left[Y_I\left(g_I, \tilde{y}_I\right)\right]$$

$$s.t. \begin{cases} g_I \leq G, \\ \Pi_{univ} \geq 0, \end{cases}$$

where $Y_I\left(g_I, \tilde{y}_I\right)$ is the knowledge produced by the University in field I, function of the funding rules for field I, and V_I the social value of interdisciplinary research. For the sake of simplicity, I assume $\frac{\partial V_I}{\partial Y_I} > 0$.

After knowing the funding rules defined by the Government, the problem of the University can be seen in two stages:

- *first*, to decide the type of research to be developed, that is, whether the researchers should produce specialized knowledges A and B, collaborate in the interdisciplinary field I, or should not produce any research at all (this outside option is assumed to yield zero profit);

- *second*, to choose the amount of resources to employ in each type of research.

U1) In case of specialization, the amount of labor used in each project (e_A, e_B) solves

$$\max_{(e_A,e_B)} \sum_{i=A,B} g_i - C_i(e_i)$$
$$s.t.\ g_i > 0 \text{ only if } Y_i(e_i) \geq \tilde{y}_i\ ,\ i = A, B;$$

U2) In case of interdisciplinarity, the amount of inputs employed in the new field $I\ \ (e_{AI}, e_{BI})$, and the investment in the adaptative-skills of the researchers (θ_A, θ_B) are chosen in agreement with

$$\max_{(e_{AI},e_{BI},\theta_A,\theta_B)} g_I - C_I(e_{AI}, e_{BI}, \theta_A, \theta_B)$$
$$s.t.\ g_I > 0 \text{ only if } Y_I(e_{AI}, e_{BI}) \geq \tilde{y}_I.$$

Without introducing any uncertainty for the outputs and for the rewards, as well as assuming full commitment from both participants, Government and University, the timing of the game is completely described by a two stages sequence: first, the Government announces the funding rules $(g_i, \tilde{y}_i)$, $i = A, B, I$; second, the University decides on the type of research, on the amount of productive resources, and on the acquisition of the adaptative-skills.

The predictions of the model are presented in the following section, where alternative informational contexts are analyzed. The first, the benchmark situation, deals with complete and perfect information among the Government and the University, as well as no restriction in the funding rules. This means that, when defining the rules for the prizes, the Government is able to delineate all the decisions of the University. In the second scenario,there is the introduction of non-contractibility on the choice of the inputs and on the acquisition of adaptative-skills, but allowing for distinct funding rules per field. In the last setting, imposing the restriction of a unique funding policy for all the three scientific fields, I analyze the moral-hazard problem on the choice of the type of research. I then discuss the reasons underlying the preferences of the University between specialization and interdisciplinarity. In all these three contexts, I apply the solution concept of Sub-game Perfect Nash equilibrium.

1.3 The Equilibrium

1.3.1 The Benchmark

Consider first that there is complete and perfect information between the Government and the University. With all the research choice variables being contractible, the Government decides: whether it asks the University to undertake the specialized research or interdisciplinarity, what is the amount of the labor inputs that should be employed in each type of research, and in the case of interdisciplinarity whether there is an investment in the adaptative-skills of the researchers. Given the budget restriction of G monetary units, the Government establishes the value of the prize for each field, ensuring that the University is willing to participate in such contract.

Backward induction leads to the optimal solution. Thus, let us proceed analyzing the result for each type of research. At the end, the comparison of both specialization and interdisciplinary scenarios, allows to conclude which is socially preferred.

Proposition 1.3.1 *Assuming complete and perfect information between the Government and the University, the social optimal solution for the specialized research satisfies the following conditions:*

i) relative marginal benefit equals to relative marginal cost

$$\frac{\frac{\partial v_A}{\partial Y_A}(e_A)}{\frac{\partial v_B}{\partial Y_B}(e_B)} = \frac{\alpha_A}{\alpha_B}; \tag{1.3.1}$$

ii) zero-profit for the University

$$\Pi_i (g_i, e_i) = 0, \quad i = A, B; \tag{1.3.2}$$

iii) exhausting of Governmental budget

$$g_A + g_B = G. \tag{1.3.3}$$

When the decision is for specialization, efficiency drives to the exhausting budget condition (1.3.3), since no alternative use is considered for the monetary resources G. With a higher prize, the University is willing to employ more (costly) resources e_i. Nevertheless, due to the symmetry of information, the Government is able to exactly compensate the University for its production costs. Thus, the optimal level of production for the specialized projects yields zero profit for the University, the same as its outside option, according to (1.3.2). This result links the monetary value of the prizes with the amount of resources spent in production.

Due to the budget constraint, an increase in the production of one specialized output translates in a reduction of the other specialization. From condition (1.3.1), and as expected, the optimal solution for society equates the relative marginal benefit of each knowledge with its relative marginal cost.

Denote by e_i^* the optimal inputs level of input that is obtained from the previous proposition, and by y_i^* the associated knowledge production, $i = A, B$. The maximum social welfare under this choice for the specialized research comes as $V_{AB}^* = \sum_{i=A,B} V_i \left(y_i^*\right)$.

For the alternative interdisciplinary scenario, it is possible to anticipate that some of the previous results remain valid. In the social optimum solution, both arguments of efficiency and symmetry of information still apply and, hence, both results of budget constraint exhaustion and zero profit are binding.

Differing from the specialized scenario, however, the social welfare function V_I is increasing in only one argument, Y_I, which enable us to derive explicit functions for the optimal level of the inputs. The best decision concerning the investment on the adaptative-skills of the researchers follows in a straightforward way.

Proposition 1.3.2 *Assuming complete and perfect information between the Government and the University, the social optimal interdisciplinary solution is defined by:*

$$e_{AI}^* = \frac{g_I - \frac{\rho}{1-\rho}\theta_A - \frac{1-\rho}{\rho}\theta_B}{m_A \cdot (1-\rho\theta_A) \cdot \frac{1}{(1-\rho)}}; \tag{1.3.4}$$

$$e_{BI}^* = \frac{g_I - \frac{\rho}{1-\rho}\theta_A - \frac{1-\rho}{\rho}\theta_B}{m_B \cdot \left[1-(1-\rho)\,\theta_B\right] \cdot \frac{1}{\rho}}; \tag{1.3.5}$$

$$\Pi_I \left(g_I, e_{AI}^*, e_{BI}^*, \theta_A, \theta_B\right) = 0; \tag{1.3.6}$$

$$g_I = G; \tag{1.3.7}$$

and, therefore, the associated social optimal interdisciplinary output is

$$y_I^* \left(\theta_A, \theta_B\right) = \lambda \frac{G - \frac{\rho}{1-\rho}\theta_A - \frac{1-\rho}{\rho}\theta_B}{m_A^{1-\rho} m_B^{\rho} \left(\frac{1-\rho\theta_A}{1-\rho}\right)^{1-\rho} \left(\frac{1-(1-\rho)\theta_B}{\rho}\right)^{\rho}}. \tag{1.3.8}$$

The social optimal investment on the adaptative-skills of the researchers depends positively on the monetary resources G. For $\rho \in \left(0, \frac{1}{2}\right)$, the explicit conditions for optimal (θ_A, θ_B) are:

$$\left(\theta_A^*, \theta_B^*\right) = \begin{cases} (0,0) \text{ when } 0 \leq G \leq \frac{\rho}{(1-\rho)\left[1-(1-\rho)^{1-\rho}\right]}, \\ (1,0) \text{ when } \frac{\rho}{(1-\rho)\left[1-(1-\rho)^{1-\rho}\right]} \leq G \leq \frac{1-\rho}{\rho(1-\rho^{\rho})} + \frac{\rho}{1-\rho}, \\ (1,1) \text{ when } G \geq \frac{1-\rho}{\rho(1-\rho^{\rho})} + \frac{\rho}{1-\rho}. \end{cases}$$

Because the social optimal interdisciplinary solution maximizes the output Y_I, the investment on the adaptative-skills should only be made when it induces an increase on Y_I. For a small budget G, the best option is to spent it only on the productive inputs and not on the adaptative-skills. At an intermediate level of G, it pays to invest in one of the researchers, the closest to I, who is collaborating more in production and has the smallest cost to acquire the adaptative-skills.[4] For a sufficiently high budget, the welfare maximizing decision is to invest in both adaptative-skills. Formally, the conditions for optimal (θ_A, θ_B) come from the upper-envelope curve of $y_I^*(\theta_A, \theta_B)$, considering the different possible combinations of (θ_A, θ_B). It is then possible to depict the optimal interdisciplinary production as a function of G (please refer to Figure 1.3).

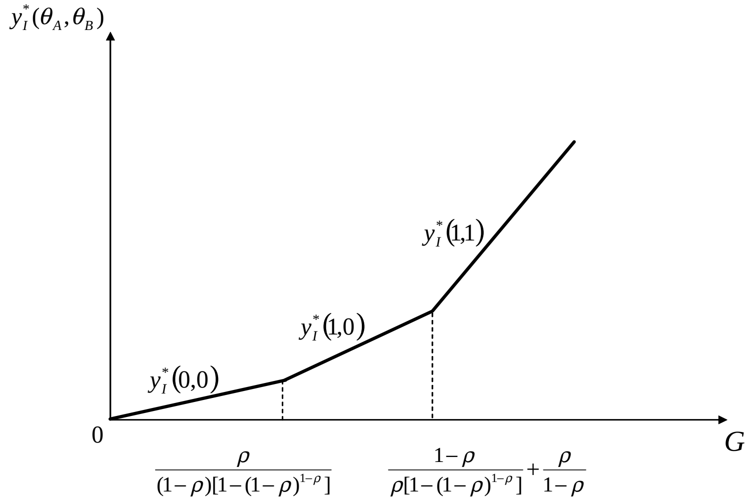

Figure 1.3: Social optimal interdisciplinary output, for $\rho \in \left(0, \frac{1}{2}\right)$.

Some comparative statics results follow from the previous proposition.

Corollary 1.3.1 *The optimal involvement of a researcher i in the common project,* e_{iI}^* $(i = A, B)$ *increases when: i) his cost coefficient* α_i *decreases, or ii) he acquires adaptative-skills* $(\theta_i = 1)$. *When the other researcher j acquires adaptative-skills* $(\theta_j = 1)$, e_{iI}^* *decreases,* $j \neq i$. *For* $\rho \in \left(0, \frac{1}{2}\right)$, *a marginal increase in* ρ *: i) has a negative impact on* e_{AI}^* *when the optimal decision on adaptative-skills is* $(\theta_A^*, \theta_B^*) = (0, 0)$ *or* $(\theta_A^*, \theta_B^*) = (1, 0)$, *and when* $(\theta_A^*, \theta_B^*) = (1, 1)$ *for* $G > \frac{1-2\rho^2}{\rho^2}$; *ii) has a positive impact on* e_{BI}^*, *when the combination* (θ_A, θ_B) *is the optimal one.*

When the productive marginal cost of a researcher increases through α_i, the optimal solution requires that i's marginal benefit also increases. Since i's marginal benefit is decreasing in e_{iI}, I obtain that his optimal level of involvement in interdisciplinarity decreases, $\frac{\partial e_{iI}^*}{\partial \alpha_i} < 0$.

The acquisition of adaptative-skills has a double effect. On the one hand, the investment on such skills lowers the budget available to compensate the employment of inputs, decreasing e_{iI}^*. On the other hand, the researcher acquiring the adaptative-skills lowers his productive marginal cost, and therefore he should work more on the common project. At the optimal combination (θ_A^*, θ_B^*) : for the researcher acquiring the adaptative-skills, it dominates the decreasing marginal cost effect and, therefore, $\frac{\partial e_{iI}^*}{\partial \theta_i} > 0$; for the other

[4]This means that for $\rho \in \left(0, \frac{1}{2}\right)$ researcher A should have adaptative-skills, for $\rho \in \left(\frac{1}{2}, 1\right)$ researcher B is the chosen one, and for $\rho = \frac{1}{2}$ it is indifferent whether the acquisition is for A or B (but not both).

researcher, however, it only exists the negative effect of a smaller budget, resulting in $\frac{\partial e^*_{jI}}{\partial \theta_i} < 0$ (or, equivalently, $\frac{\partial e^*_{iI}}{\partial \theta_j} < 0$).

When $\rho \in \left(0, \frac{1}{2}\right)$ and it increases marginally (meaning that after the change, ρ is still in the same interval) two effects happen. First, A's effort becomes more costly. Second, it increases the cost of investing in A's adaptative-skills, reducing the budget available to remunerate the productive efforts. Both effects have a negative impact on e^*_{AI} and, therefore, $\frac{\partial e^*_{AI}}{\partial \rho}\left(\theta^*_A, \theta^*_B\right) < 0$. By opposite argument, as ρ increases, I becomes closer to B and, hence, it is optimal to increase e^*_{BI}, i.e., $\frac{\partial e^*_{BI}}{\partial \rho}\left(\theta^*_A, \theta^*_B\right) > 0$. When $\left(\theta^*_A, \theta^*_B\right) = (1, 1)$ the condition of $G > \frac{1-2\rho^2}{\rho^2}$ ensures that the increase in the available budget due to a smaller cost of investing in B's adaptative-skills is not sufficiently powerful to invert the sign of $\frac{\partial e^*_{AI}}{\partial \rho}$.

From the previous proposition, it is also possible to derive some results of comparative statics for the optimal interdisciplinary production.

Corollary 1.3.2 *The optimal interdisciplinary production level, y^*_I, decreases with an increase of i's cost coefficient, α_i, $i = A, B$. For $\rho \in \left(0, \frac{1}{2}\right)$ and $\alpha_A = \alpha_B = \alpha$, a marginal increase in ρ decreases y^*_I: i) when $\left(\theta^*_A, \theta^*_B\right) = (0, 0)$, or $(1, 1)$; ii) or when $\left(\theta^*_A, \theta^*_B\right) = (1, 0)$ and the researcher B has a high relative marginal cost, that is,* $\log\left(\frac{m_B}{m_A} \cdot \frac{1}{\rho}\right) > 1 - \frac{1}{m_A} + \frac{1}{m_B} + \frac{1}{\rho(1-\rho)}$.

As it follows from the negative relation between e^*_{iI} and α_i, whenever the productive marginal cost of at least one of the researchers increases, the maximum possible output decreases, $\frac{\partial y^*_I}{\partial \alpha_i} < 0$.

The response of y^*_I to a change in ρ is ambiguous, since ρ has opposite effects on both e^*_{AI} and e^*_{BI}, and also because ρ defines the importance of each researcher in the interdisciplinary production technology (1.2.3). Nevertheless, when researchers have equal cost coefficients, $\alpha_A = \alpha_B = \alpha$, and researcher B's relative marginal cost is sufficiently high, I may anticipate that a marginal increase in ρ has a negative impact on y^*_I, as Figure 1.4 shows. Intuitively, when ρ gets closer to $\frac{1}{2}$, and because A's collaboration is still more relevant for the interdisciplinary production, the increase in his cost is not totally compensated by the decrease in B's cost. As a result, the optimal output level decreases.

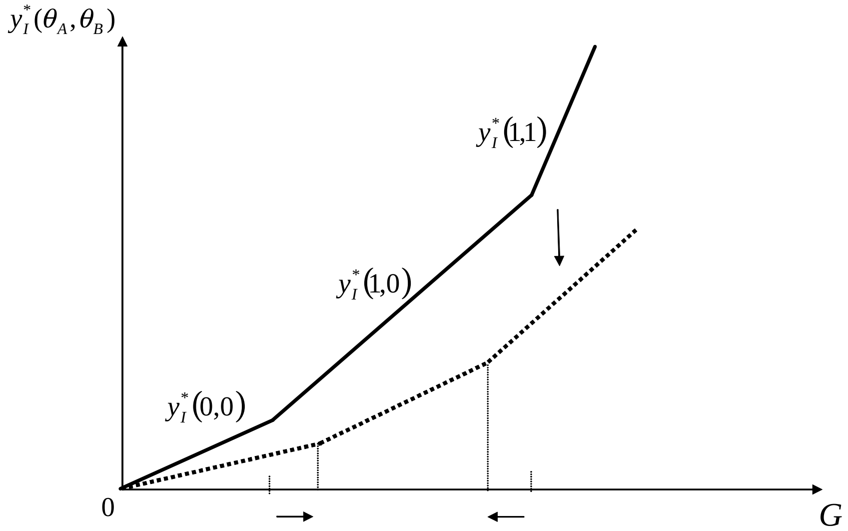

Figure 1.4: How y_I^* changes when ρ increases, for $\rho \in \left(0, \frac{1}{2}\right)$.

When $y_I^*(1,0)$, the lack of ambiguity is only solved for a researcher B with sufficiently high marginal cost, that is, for $\log\left(\frac{m_B}{m_A}\frac{1}{\rho}\right) > 1 - \frac{1}{m_A} + \frac{1}{m_B} + \frac{1}{\rho(1-\rho)}$. This condition guarantees that the negative impact that ρ has on e_{AI}^* dominates over the positive effect that it has on e_{BI}^*. To better understand the need for this condition, notice that at the starting situation, A has a relatively higher participation in the production process than B. This is due to field I being closer to A, $\rho \in \left(0, \frac{1}{2}\right)$, and because A is less costly in production than B, by $(\theta_A, \theta_B) = (1, 0)$ and $\alpha_A = \alpha_B = \alpha$. When A collaborates more, the interdisciplinary technology (Cobb-Douglas) claims that I are less willing to give up of B's participation. Therefore the ambiguity of ρ's impact over y_I^* only vanishes when B's collaboration is very small, so that the negative impact of $\frac{\partial e_{AI}^*}{\partial \rho}$ dominates over the positive impact of $\frac{\partial e_{BI}^*}{\partial \rho}$. A sufficiently high productive marginal cost for researcher B ensures that small collaboration.

With the social optimal interdisciplinary production defined by the previous proposition, it is possible to represent the interdisciplinary social value by $V_I^*(y_I^*)$. It follows that, for a given G, the social optimal decision is to have interdisciplinarity whenever $V_I^*(y_I^*) \geq V_{AB}^*(y_A^*, y_B^*)$. As modeled, the functions V reflect the benefits for society from each type of research. Without entering in a normative comparison of such benefits, it is possible to advance that different types of interdisciplinarity (here reflected in the value of ρ) may lead to different social optimal decisions. In fact, as latter is made explicit, a more *central* interdisciplinarity may be *too* costly to undertake.

1.3.2 When resources and adaptative-skills are non-contractible

When defining the rules of the prizes, the Government may establish the monetary values g_i, $i = A, B, I$, conditional on the production level, $\tilde{y}_i$. Given that there is no uncertainty in the production, these funding rules determine the level of the productive efforts. Furthermore, since $(g_i, \tilde{y}_i)$ can differ between fields, there is still sufficiently flexibility to choose the first-best option of the Government, namely in terms of the type of research. However, it may be interesting to study how the decision variables of the University, efforts and acquisition of the adaptative-skills, depend on the funding rules. This section analyses it in detail.

The choice variables of the Government are now: first, the type of research, specialization or interdisciplinarity; second, the funding rules for specialization, $(g_A, \tilde{y}_A)$ and $(g_B, \tilde{y}_B)$, and for interdisciplinarity, $(g_I, \tilde{y}_I)$.

Once accepting the proposal of the Government, and facing a discrete-type of reward (getting or not the prize), the University decides on the resources spent, and on the investment in the adaptative-skills. Because there is no extra-benefit of producing above the required standard, a profit maximizer institution seeks the most efficient way of producing, at most, that level.[5]

Proposition 1.3.3 *Given the funding policy for field i, $(\tilde{y}_i, g_i)$, $i = A, B, I$, the best choice for the University is:*

a) under specialization

$$e_i^U = \tilde{y}_i \ , \ \ i = A, B; \tag{1.3.9}$$

b) under interdisciplinarity

$$\begin{cases} e_{AI}^U = \tilde{y}_I \cdot \left[\frac{m_B}{m_A} \cdot \left(\frac{1-\rho}{1-\rho\theta_A}\right)\left(\frac{1-(1-\rho)\theta_B}{\rho}\right)\right]^{\rho} \cdot \frac{1}{\lambda}, \\ e_{BI}^U = \tilde{y}_I \cdot \left[\frac{m_A}{m_B} \cdot \left(\frac{\rho}{1-(1-\rho)\theta_B}\right)\left(\frac{1-\rho\theta_A}{1-\rho}\right)\right]^{1-\rho} \cdot \frac{1}{\lambda}. \end{cases} \tag{1.3.10}$$

The investment in the adaptative-skills is increasing in both policy variables, $\tilde{y}_I$ and g_I : for smaller values g_I and $\tilde{y}_I$, the University prefers not to acquire any adaptative-skills; for intermediate g_I and $\tilde{y}_I$, it invests in the researcher that is closer to field I; and for high values of g_I and $\tilde{y}_I$, it acquires both adaptative-skills. When $\rho \in \left(0, \frac{1}{2}\right)$, the relevant thresholds for acquiring adaptative-skills of A are $(\tilde{y}_I, g_I) = (\tilde{y}_I^{00}, g_I^{00}) =$
$= (\lambda m_A^{\rho-1} m_B^{-\rho}\left(\frac{\rho}{1-\rho}\right)\rho^{\rho}\left[\left(\frac{1}{1-\rho}\right)^{1-\rho} - 1\right]^{-1} , \frac{\rho}{(1-\rho)\left[1-(1-\rho)^{1-\rho}\right]})$
and for the adaptative - skills of B are $(\tilde{y}_I, g_I) = (\tilde{y}_I^{10}, g_I^{10}) =$
$= (\lambda m_A^{\rho-1} m_B^{-\rho}\left(\frac{1-\rho}{\rho}\right)\left[\left(\frac{1}{\rho}\right)^{\rho} - 1\right]^{-1} , \frac{(1-\rho)^2+\rho^2(1-\rho^{\rho})}{\rho(1-\rho)(1-\rho^{\rho})})$.

The outside option of no research is preferred: i) to specialization when the standard

[5] This conclusion is in line with Result 1 of Betts (1998).

$\tilde{y}_i$ *is at least* $\frac{g_i}{\alpha_i}$*,* $i = A, B$*; ii) and to interdisciplinarity when* $\tilde{y}_I$ *is at least*
$\tilde{y}_I^{11} = \lambda m_A^{\rho-1} m_B^{-\rho} \left(g_I - \frac{\rho}{1-\rho} - \frac{1-\rho}{\rho} \right)$.

As in the benchmark situation, the acquisition of the adaptative-skills depends positively on the amount of funds available for the interdisciplinary project. Having to choose how to spend the funds, the priority is to remunerate the inputs necessary to produce and, only after, to invest in more efficient ways of producing.

More interesting is to notice that, even if the prize g_I allows to acquire adaptative-skills, the optimal decision is contingent on $\tilde{y}_I$. As the required production increases, it also increases the effort the researchers must exert to accomplish it. But the higher the effort, the higher the benefits of acquiring adaptative-skills. Thus, only when the policy is sufficiently demanding, the investment is made. This result follows from Lemma 1.2.1 . Formally, I can derive the conditions for University's best choice (θ_A, θ_B) through the upper envelope-curve of the profit curves $\Pi_I^U(\theta_A, \theta_B)$, when considering the different possible combinations of (θ_A, θ_B) . Figure 1.5 illustrates the reasoning, plotting the maximum interdisciplinary profit of the University as a function of the standard $\tilde{y}_I$. The figure stands for the case of a prize sufficiently high to allow the acquisition of skills for both researchers, i.e., $g_I \geq g_I^{10}$.

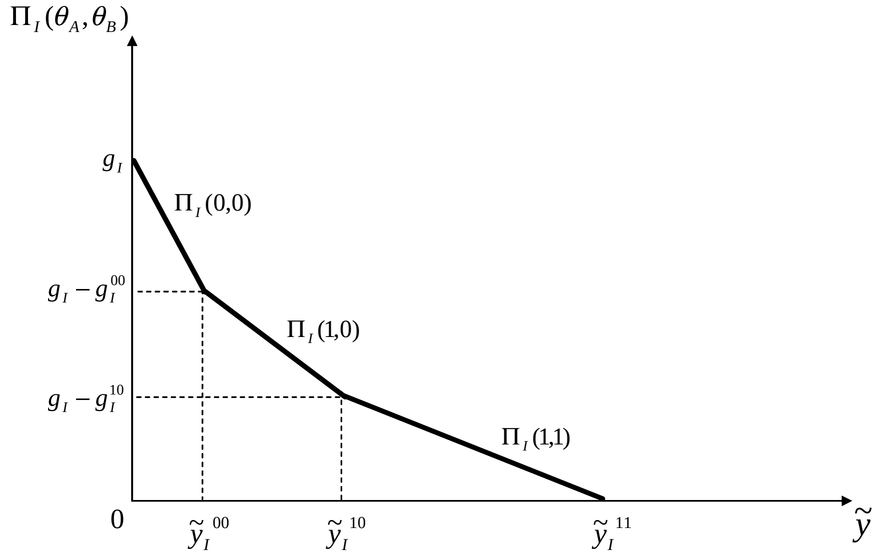

Figure 1.5: Maximum interdisciplinary profit, for $\rho \in \left(0, \frac{1}{2}\right)$.

From the solution of the interdisciplinary problem stated in Proposition 1.3.3, it is possible to derive some comparative statics results.

Corollary 1.3.3 *At the optimal solution for the University, the effort of researcher i in the interdisciplinary project,* e_{iI}^U*, increases when: i) his cost coefficient* α_i *decreases, or the cost coefficient of the other researcher* α_j *increases, ii) he acquires adaptative-skills* $(\theta_i = 1)$*, or the other expert does not* $(\theta_j = 0)$*,* $j \neq i$*. A negative relation between* e_{AI}^U *and* ρ *is guaranteed when* $\frac{(1-\rho\theta_A)m_A}{[1-(1-\rho)\theta_B]m_B} > \frac{1-\rho}{\rho}$.

To produce the required $\tilde{y}_I$ at the most efficient way, whenever the productive marginal cost of one expert decreases, the University should increase his contribution for the common project, so that $\frac{\partial e_{iI}^U}{\partial \alpha_i} < 0$. By a similar argument, and using the complementary characteristic of interdisciplinarity, i should work more when j's marginal cost increases, $\frac{\partial e_{iI}^U}{\partial \alpha_j} > 0$. Since the productive marginal cost of the researchers depends negatively on the acquisition of the adaptative-skills, in the optimal solution $\frac{\partial e_{iI}^U}{\partial \theta_i} > 0$ and $\frac{\partial e_{iI}^U}{\partial \theta_j} < 0$. Regarding the impact of the distance parameter ρ on the level of efforts chosen by the University, opposite effects emerge. Because ρ determines not only the cost of producing the interdisciplinary output, but also the process of production itself, ambiguity is solved when the relative marginal cost of e_{AI} is higher than the relative importance of e_{AI} for the interdisciplinary production. Under such restriction, a negative relation between e_{AI}^U and ρ stands out.

Corollary 1.3.4 *Given the funding policy of the Government for interdisciplinarity* $(\tilde{y}_I, g_I)$, *the maximum profit that the University may obtain with this type of research, conditional on the acquisition or not of the adaptative-skills, is given by*

$$\begin{aligned}\Pi_I^U(\theta_A,\theta_B) &= g_I - \frac{\rho}{1-\rho}\theta_A - \frac{1-\rho}{\rho}\theta_B - \frac{\tilde{y}_I}{\lambda}\cdot\left[m_A\left(1-\rho\theta_A\right)\right]^{1-\rho}\cdot \\ &\quad \cdot\left[m_B\left(1-\left(1-\rho\right)\theta_B\right)\right]^{\rho}\cdot\left[\left(\frac{1-\rho}{\rho}\right)^{\rho}+\left(\frac{\rho}{1-\rho}\right)^{1-\rho}\right],\end{aligned}$$

which increases with: i) a higher value of the prize, g_I; and ii) a smaller productive marginal cost for the researchers, α_i.

When $\rho \in \left(0, \frac{1}{2}\right)$ and $\alpha_A = \alpha_B = \alpha$, a marginal increase in ρ decreases $\Pi_I^U(\theta_A,\theta_B)$, when i) $(\theta_A,\theta_B) = (0,0)$; ii) $(\theta_A,\theta_B) = (1,0)$ and $\log\left(\frac{m_B}{\rho m_A}\right) > \frac{\rho}{1-\rho+\alpha}$; or iii) $(\theta_A,\theta_B) = (1,1)$ and $\log\left(\frac{m_B}{m_A}\right) > -2 + \frac{1+\alpha}{1-\rho+\alpha} - \frac{1+\alpha}{\rho+\alpha} + \frac{\tilde{y}_I}{\lambda}\cdot\frac{\frac{1}{\rho^2}-\frac{1}{(1-\rho)^2}}{m_B^{\rho}m_A^{1-\rho}}$.

The achievement of a given standard, with higher productive marginal costs, necessarily leads to a smaller interdisciplinary profit, meaning that $\frac{\partial \Pi_I^U}{\partial \alpha_i}(\theta_A,\theta_B) < 0$. Considering the effect of ρ in the interdisciplinary profit, the conclusion is ambiguous for general values of the parameters. Nevertheless, when $\alpha_A = \alpha_B = \alpha$ and the researcher B (the researcher furthest from I) is sufficiently costly, I may conclude that $\frac{\partial \Pi_I^{MU}}{\partial \rho}(\theta_A,\theta_B) < 0$.

In the particular setting of our analysis, two characteristics have a significative role for the results. First, the lack of incentive of the University to exceed the standard, offsets the potential asymmetric information problem. Second, since the funding rules may differ between fields, the Government has enough flexibility to implement the first-best solution.

Corollary 1.3.5 *Let (e_A, e_B) and (θ_A,θ_B) be non-verifiable. Assuming that the Government can choose different funding policies $(\tilde{y}_i, g_i)$ for each field i $(i = A, B, I)$, it is still possible to achieve the first-best solution. Then, the funding rules for the specialized* *projects must be* $\tilde{y}_A = y_A^*$, $\tilde{y}_B = y_B^*$, $g_A = \alpha_A \cdot y_A^*$, *and* $g_B = \alpha_B \cdot y_B^*$, *whereas for the interdisciplinary research* $\tilde{y}_I(\theta_A, \theta_B) = y_I^*(\theta_A, \theta_B)$, *and* $g_I = G$.[6]

The final decision on which type of research must be contracted, follows from the comparison of the maximum social welfare on both situations. Interdisciplinarity is the best choice for the society when $V_I(\tilde{y}_I) \geq V_{AB}(\tilde{y}_A, \tilde{y}_B)$.

1.3.3 When the funding policy is restricted

Suppose now that the type of research to implement is a decision of the University. For that, let us assume that the Government is restricted to an unique funding rule, common to the three scientific disciplines: $(\tilde{y}_i, g_i) = (\tilde{y}, g)$, $i = A, B, I$. As a consequence, the timing of decisions is:

1. the Government chooses the funding rule $(\tilde{y}, g)$;
2. once knowing the rule, the University decides,
   - i) whether the researchers work separately on their specialized fields, collaborate with each other on the interdisciplinary field I, or undertake the alternative outside option of no research;
   - ii) the amount of resources to employ in the research, and the acquisition of the adaptative-skills.

At a first glance, it may seem that specialization is being favoured by the funding rule, since it enables the University to receive $2g$, whereas interdisciplinarity, at most, yields g. Specialization can, therefore, appear as the obvious choice for the University. As I show, it is not always so. Interdisciplinary research can still be the best option for a profit maximizer organization.

In order to centralize the discussion on the comparison between specialization and interdisciplinarity, rather than in potential asymmetries of costs between the two original fields A and B, I use the following assumption:

Assumption 2: The researchers have equal cost coefficients, i.e., $\alpha_A = \alpha_B = \alpha$.

The main results remain valid under more general conditions. In the end of this section, I briefly comment the case of $\alpha_A \neq \alpha_B$.

The comparison between the profitability of the two types of research depends on the value of the parameters, and the two following propositions stand out the main results.

[6] The symbol $(^*)$ means that the value of the variables is the same as in first-best (please refer to the benchmark model, Propositions 1.3.1 and 1.3.2).

Proposition 1.3.4 *Let the governmental funding policy be defined per scientific project, and equal on all fields, i.e.,* $(\tilde{y}_i, g_i) = (\tilde{y}, g)$, $i = A, B, I$. *Then, the University prefers to develop the interdisciplinary research when the required standard is sufficiently high.*

I start by illustrating the reasoning using a graph. The relative position of the two profit curves, under specialization and under interdisciplinarity, depends on the value of parameters. As such, Figure 1.6 considers the case of $\frac{2\alpha\lambda}{m_A^{1-\rho}m_B^{\rho}} \in \left(\frac{1-\rho[2-\rho(2-\rho^{\rho})-g(1-\rho)(1-\rho^{\rho})]}{\rho^{\rho}(1-\rho)^2}, \frac{(1-\rho)^{\rho}[g(1-\rho)+\rho]-g(1-\rho)^2}{(1-\rho)\rho^{1+\rho}}\right)$:

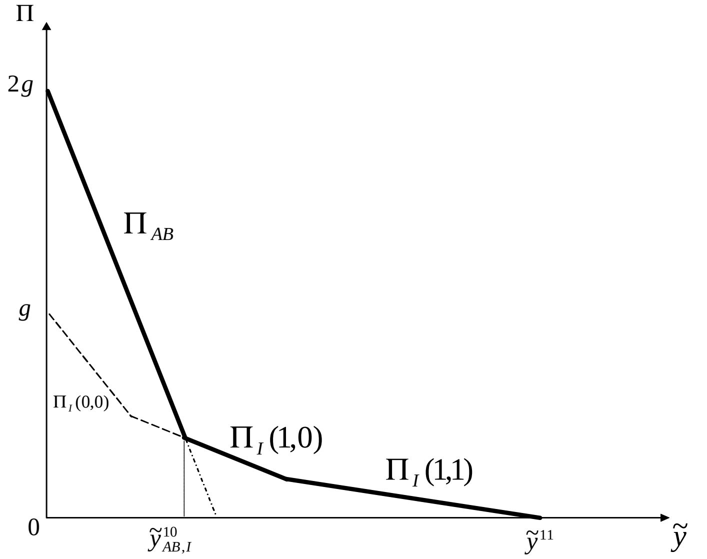

Figure 1.6: Specialized profit (Π_{AB}) and interdisciplinary profit (Π_I), for $\rho \in \left(0, \frac{1}{2}\right)$.

When the requirement of production is small (below $\tilde{y}^{10}_{AB,I}$), the cost of joining both researchers in the unique project on a new area, where both have to *go native*, does not compensate the reward of two specialized projects. Therefore, the most rewarding option is to keep both researchers working in their expertise areas, and applying for two separate prizes.

When the funding policy is sufficiently demanding (above $\tilde{y}^{10}_{AB,I}$), the conclusion reverses. A larger output level is less costly to produce when the University combines the work of the two different experts. Complementarity generates productivity gains that are not possible to achieve under specialization. This cooperative advantage is reinforced by a potential smaller cost, due to the acquisition of adaptative-skills. Together, for a sufficiently high production level, these two characteristics result in such a smaller cost for interdisciplinary research that more than compensates its initial disfavored position on the reward scheme.

Although interdisciplinarity may be a better option than specialization for a standard above $\tilde{y}^{10}_{AB,I}$, when the requirement is too much demanding (higher than $\tilde{y}^{11}$), the University prefers not to apply to any prize at all.

From this analysis, it is possible to infer that the comparison between the profitability of each type of research depends on the value of the parameters. The comparative statistic result then follows.

Proposition 1.3.5 *Let* (e_A, e_B) *and* (θ_A, θ_B) *be non-contractible and the funding policy* $(\tilde{y}, g)$ *be unique for all possible fields. Then, under Assumption 2 and* $\rho \in \left(0, \frac{1}{2}\right)$:

a) an increase in the cost coefficient of the researchers, α*, favors the choice for interdisciplinarity;*

b) an increase in ρ *favors the choice for specialization, when the relative marginal cost of researcher B is sufficiently high, i.e., when: i)* $\log\left(\frac{m_B}{\rho m_A}\right) > \frac{\rho}{1-\rho+\alpha}$ *if the optimal* $(\theta_A, \theta_B) = (1, 0)$; *and ii)* $\log\left(\frac{m_B}{m_A}\right) > -2 + \frac{1+\alpha}{1-\rho+\alpha} - \frac{1+\alpha}{\rho+\alpha} + \frac{\tilde{y}_I}{\lambda} \cdot \frac{\frac{1}{\rho^2} - \frac{1}{(1-\rho)^2}}{m_B^{\rho} m_A^{1-\rho}}$ *if the optimal* $(\theta_A, \theta_B) = (1, 1)$.

Because the coefficient α stands for the productive marginal cost of the researchers, it affects both interdisciplinarity and specialization. When outputs are separately produced, as in the specialized scenario, an increase in the individual marginal cost affects the cost structures of both fields A and B, in a direct proportion to the effort of the researchers. When both researchers interact, though, the change leads to a reallocation on the individual contributions for the common project I. As a result, interdisciplinary research is less penalized by an increase in α.

The distance parameter ρ is only relevant for the interdisciplinary option, but it influences in several opposite ways. On the one hand, when $\rho \in \left(0, \frac{1}{2}\right)$ and it increases marginally, it becomes more costly for A to collaborate in the production and to acquire adaptative-skills. For researcher B the impact is reversed, thus creating an ambiguity on the interdisciplinary profit. When the relative marginal cost of B is sufficiently high, his collaboration in the common project is small enough to guarantee that the negative result of A dominates. Intuitively, whenever ρ gets closer to $\frac{1}{2}$, but still B's higher familiarity with the new discipline does not compensates A's higher difficulty, interdisciplinarity becomes less interesting for the University.

Restricted funding policy and $\alpha_A \neq \alpha_B$

Consider now the case where the two specialized fields A and B have different cost coefficients. In particular, let $\alpha_A > \alpha_B : \ \alpha_A = \beta\alpha_B$, $\beta > 1$.

As far as the specialized projects are concerned, the maximum value of $\tilde{y}$ that makes the University indifferent between participating or not, is now different for each field. In fact, until $\tilde{y} = \frac{g}{\alpha_B}$ the University is willing to develop specialized output B, but it produces output A only if $\tilde{y} \leq \frac{g}{\alpha_A}$. For such case of interest, $\alpha_A > \alpha_B$, this means that when the required standard is sufficiently high, only the specialized field B is relevant for the University. Figure 1.7 illustrates the argument.

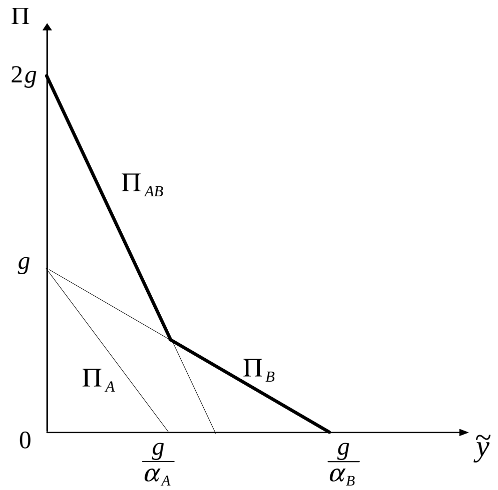

Figure 1.7: Specialized profit when $\alpha_A > \alpha_B$.

To compare the maximum profit of the University under specialization and under interdisciplinarity, I have to consider that B alone may be a relevant choice. Despite this new fact, Proposition 1.3.4 still holds, since the University still prefers to develop the interdisciplinary research when the required standard $\tilde{y}$ is sufficiently high.

Regarding Proposition 1.3.5, the impact that an increase in the marginal cost of one of the specialized fields, α_i $(i = A, B)$, has on the choice between specialization and interdisciplinarity is now dependent on the distance parameter, ρ.

Proposition 1.3.6 *Let* (e_A, e_B) *and* (θ_A, θ_B) *be non-contractible and the funding policy* $(\tilde{y}, g)$ *be unique for all possible fields. Assume different cost coefficients, such that* $\alpha_A > \alpha_B$. *Then,*

a) in the case where the specialization in field B*, alone, is never an optimal choice for the University, the impact that an increase in* α_i *has on the choice between specialization and interdisciplinarity depends on* ρ *: i) an increase on* α_A *favors interdisciplinarity if* $\frac{1+\alpha_A}{\alpha_B} > \frac{1-\rho}{\rho}$*; ii) and increase on* α_B *favors interdisciplinarity if* $\frac{1+\alpha_B}{\alpha_A} > \frac{\rho}{1-\rho}$*;*

b) in the case where the specialization in field B*, alone, may be an optimal choice for the University: i) an increase in* α_A *enlarges the range of the standard* $\tilde{y}$ *where only* B *is chosen, making interdisciplinarity less interesting for the University; ii) an increase in* α_B *has the opposite effect, that is, it favours the choice of interdisciplinarity, when* $\lambda > \frac{1}{\rho^\rho}\left(\frac{m_A}{m_B}\right)^{1-\rho}$.

Changing ρ, and therefore the location of field I, has similar results to the ones described in Proposition 1.3.5.

1.4 Conclusion

Interdisciplinarity, the development of a new scientific discipline with foundations in well-established disciplines, has recently gain visibility as a promising way of solving complex questions of societies. Despite this renowned importance, scholars and scientific institutions do not always share this enthusiasm when deciding the allocation of research resources. This chapter shows that under a horizontal differentiation of scientific expertises it is efficient to combine them in a new field, only when the resulting complementary gains compensate the entrance and coordination costs. When the goal to achieve is minor, it is expectable researchers work separate and independently in their expertise fields. Nevertheless, when the goal is sufficiently audacious, the productive gains from cooperation make interdisciplinarity a more benefic pattern than specialization.

In this chapter I take the perspective of a research organization, an university, whose activities receive a reward from a policymaker, a government, in the form of prizes. In this case, the university seeks to match at most the required standard, since it has no extra-reward from producing above it. The first-best solution is achievable whenever the type of research is contractible and the funding rules differ between fields. The acquisition of adaptative-skills is optimal, not only when the value of the prize is sufficient to pay for such investment, but also when the saving in cost that they allow, compensates the investment. The acquisition of the adaptative-skills is, then, conditional on a high interdisciplinary production.

When the government is restricted to establish a unique funding rule, common to all fields, the type of research is decided by the university. It may seem that specialization is favored, due to its potential higher revenue and less disadvantaged cost structure. Nevertheless, when the required production is sufficiently high, interdisciplinarity becomes the best option, due to complementarity gains in production. An excessively high production requirement, however, discourages the development of any type of research.

Besides gains from complementary inputs, the preference of the university for interdisciplinarity is also affected by two other factors.

First, the cost of the traditional fields. Higher cost makes both specialized and interdisciplinary research more expensive. Due to the presence of complementarity in interdisciplinary production, it is possible to reallocate the contribution of each research. This is, however, not possible for specialization. As a consequence, interdisciplinarity is relatively favored by an increase in these innate costs. In other words, we expect that institutions with higher costs, thus less efficient in producing the traditional fields of research, do consider interdisciplinarity as a more interesting option.

Second, when the interdisciplinary field is more *central* so that no researcher is particularly familiar with it, specialization is a better alternative for the research institution. In this case, the increase in the cost of the effort of the closest researcher, and therefore also the one whose involvement is more important, may be too high.

The results in this chapter can be applied to a broader range of problems. In particular, it is possible to link them to the organizational structure of firms. From an internal perspective, they can be applied to a firm that faces the possibility of having two units operating separate and independently in two known domains, or to allocate them in a new and cooperative one.

The present work may also be linked with problems in mergers of firms, when it involves the exploration of a new area of business, with which no partner is familiar.

The aim of this chapter is not to discuss organizational or informational issues between the employer organization, the university, and its workers. By definition, interdisciplinarity relies on the collaboration between different researchers, with different scientific backgrounds. Conflict of interests may then arise within the interdisciplinary group, making relevant the design not only of the internal organization among researchers, but also of the relation between the group and the host-research institution. In future work, I plan to develop these issues.

It is worthy emphasizing the pertinent conclusion that interdisciplinarity may be an interesting option for research institutions, once the cost of *opening* the new scientific path is overcome. Besides the support that policymakers can give to institutions, ensuring the monetary means to face this cost, their role is crucial to guarantee that the performance required is sufficiently high to be worth going through difficulties.

1.5 Appendix One

Proof of Lemma 1.2.1. By the definition of the interdisciplinary cost C_I in (1.2.5), if there is no acquisition of adaptative-skills of researcher A, the cost of the interdisciplinary project is:

$$C_I = m_A e_A + m_B \left[1 - (1-\rho)\,\theta_B\right] e_B + \frac{1-\rho}{\rho}\theta_B.$$

When there is an investment in A's adaptative-skills:

$$C_I = (\rho + \alpha_A) e_A + m_B \left[1 - (1-\rho)\,\theta_B\right] e_B + \frac{\rho}{1-\rho} + \frac{1-\rho}{\rho}\theta_B.$$

Comparing both situations, it is cost minimizing to invest in A's adaptative-skills iff:

$$e_A \geq \frac{1}{\rho + \alpha_A}.$$

Similar reasoning can be developed for the adaptative-skills of B. ■

Proof of Proposition 1.3.1. In the benchmark situation, when the Government asks for specialized research, the problem may be formalized as:

$$\max_{(e_A, e_B, g_A, g_B)} V_{AB} = \sum_{i=A,B} V_i \left[Y_i\left(e_i\right)\right]$$
$$s.t. \begin{cases} \Pi_i = g_i - C_i\left(e_i\right) \geq 0, & i = A, B, \\ g_A + g_B \leq G, \end{cases}$$

where the production functions $Y_i(e_i)$ and the cost functions $C_i(e_i)$ are given by (1.2.1) and (1.2.2), respectively. The first-order conditions are:

$$\begin{cases} \frac{\partial V_i}{\partial Y_i}\frac{\partial Y_i}{\partial e_i}(e_i) = \mu_i \alpha_i, \\ \mu_i = \mu_3, \\ \mu_i (g_i - \alpha_i e_i) = 0, \qquad i = A, B, \\ \mu_3 (g_A + g_B - G) = 0, \\ \mu_i \geq 0, \mu_3 \geq 0, \end{cases}$$

where μ_i is the Lagrangian-multiplier associated with the participation constraint on specialized field i, and μ_3 is the Lagrangian-multiplier for the budget constraint.

From the assumptions on V_i and on α_i, it follows that all μ-multipliers are strictly positive and, hence, all constraints are binding, in the optimum.

Furthermore, from the assumptions on V_i and on the linearity of costs, first-order conditions are also sufficient to obtain a maximum. ■

Proof of Proposition 1.3.2. In the benchmark situation, when the Government asks for the interdisciplinary research, the optimal contract solves

$$\max_{(e_{AI}, e_{BI}, \theta_A, \theta_B, g_I)} V_I [Y_I (e_{AI}, e_{BI})]$$

$$s.t. \begin{cases} \Pi_I = g_I - C_I(e_{AI}, e_{BI}, \theta_A, \theta_B) \geq 0, \\ g_I \leq G, \end{cases}$$

where the production function Y_I is presented in (1.2.3) and the cost function C_I in (1.2.5).

For simplicity, I divide the resolution of this problem in two steps:

- *1st step*: optimal (e_{AI}, e_{BI}, g_I).

  The first-order conditions to obtain the optimal level of inputs and the monetary reward are:

$$\begin{cases} \frac{\partial V_I}{\partial Y_I} \cdot \frac{\partial Y_I}{\partial e_{iI}}(e_{AI}, e_{BI}) = \mu_1 \cdot \frac{\partial C_I}{\partial e_{iI}}(e_{AI}, e_{BI}, \theta_A, \theta_B), \\ \mu_1 = \mu_2, \\ \mu_1 [g_I - C_I(e_{AI}, e_{BI}, \theta_A, \theta_B)] = 0, \qquad i = A, B, \\ \mu_2 (g_I - G) = 0, \\ \mu_1 \geq 0, \ \mu_2 \geq 0, \end{cases}$$

  where μ_1 is the Lagrangian-multiplier associated with the participation constraint of the University, and μ_2 is the multiplier associated with the budget condition. Solving the system, I obtain results (1.3.4), (1.3.5), (1.3.6), and (1.3.7). Assumptions on the function V_I, the linearity of the cost function in the decision variables, and the convexity of the production technology, ensure that the conditions above are necessary and sufficient for a maximum.

- *2nd step*: optimal (θ_A, θ_B).

From the previous system of conditions, the optimal level of inputs can be written as a function of the adaptative-skills. Therefore, it is also possible to write the interdisciplinary output in terms of (θ_A, θ_B), as explicit in (1.3.8). Since V_I is strictly increasing in y_I, the optimal investment in the adaptative-skills must guarantee maximum production.

Take $\rho \in \left(0, \frac{1}{2}\right)$. Calculating the upper-envelope curve of $y_I^*(\theta_A, \theta_B)$ when considering the possible combinations (θ_A, θ_B), I verify that the maximum interdisciplinary output is achieved when:

$$(\theta_A, \theta_B) = \begin{cases} (0,0) \text{ if } 0 \leq G \leq \frac{\rho}{(1-\rho)\cdot\left[1-(1-\rho)^{1-\rho}\right]}, \\ (1,0) \text{ if } \frac{\rho}{(1-\rho)\cdot\left[1-(1-\rho)^{1-\rho}\right]} \leq G \leq \frac{1-\rho}{\rho\cdot(1-\rho^\rho)} + \frac{\rho}{1-\rho}, \\ (1,1) \text{ if } G \geq \frac{1-\rho}{\rho\cdot(1-\rho^\rho)} + \frac{\rho}{1-\rho}. \end{cases}$$

Similar and symmetric results can be developed for the remaining values of ρ. ■

Proof of Corollary 1.3.1. From expressions (1.3.4) and (1.3.5), it is easily verifiable that a decrease in α_i has a positive effect on e_{iI}^*, $i = A, B$.

To verify how θ_i affects e_{iI}^* and e_{jI}^*, $j \neq i$, let us consider the case of $\rho \in \left(0, \frac{1}{2}\right)$. In the optimal solution, researcher A is the first to acquire adaptative-skills and he does it for $G \geq \frac{\rho}{(1-\rho)\left[1-(1-\rho)^{1-\rho}\right]}$. Comparing the value for e_{AI}^* when $(\theta_A, \theta_B) = (0,0)$ with the one when $(\theta_A, \theta_B) = (1,0)$, I obtain the following condition :

$$e_{AI}^*(1,0) \geq e_{AI}^*(0,0) \Leftrightarrow \frac{G(1-\rho)^2}{\rho+\alpha_A} \geq \frac{\left(G - \frac{\rho}{1-\rho}\right)(1-\rho)}{\rho+\alpha_A} \Leftrightarrow G \geq \frac{1}{1-\rho},$$

which is satisfied for $G \geq \frac{\rho}{(1-\rho)\cdot\left[1-(1-\rho)^{1-\rho}\right]}$. The investment in θ_B is interesting when $G \geq \frac{1-\rho}{\rho(1-\rho^\rho)} + \frac{\rho}{1-\rho}$. To have a positive relation between B's adaptative-skills and his level of input, I need to guarantee that:

$$e_{BI}^*(1,0) \geq e_{BI}^*(1,1) \Leftrightarrow \frac{\left(G - \frac{\rho}{1-\rho} - \frac{1-\rho}{\rho}\right)\rho}{1-\rho+\alpha_B} \geq \frac{\left(G - \frac{\rho}{1-\rho}\right)\rho^2}{1-\rho+\alpha_B} \Leftrightarrow G \geq \frac{1}{\rho} + \frac{\rho}{1-\rho}.$$

Given the domain where it is optimal to have $\theta_B = 1$, this condition holds.

For the remaining possible values of ρ, by similar reasoning, I can verify that the participation of each researcher increases when he acquires adaptative-skills. Efficiency arguments support such adjustment.

As far as the effect of ρ in e_j is concerned, let us consider again the case of $\rho \in \left(0, \frac{1}{2}\right)$ and the optimal decision on the acquisition of the adaptative-skills. Then, the impact that ρ has on e^*_{AI} is:

$$\begin{aligned}
\frac{\partial e^*_{AI}(0,0)}{\partial\rho} &= -\frac{G(1-\rho)(1+\rho+2\alpha_A)}{(\rho+\alpha_A)^2}<0;\\
\frac{\partial e^*_{AI}(1,0)}{\partial\rho} &= -\frac{G(1+\alpha_A)+\alpha_A}{(\rho+\alpha_A)^2}<0;\\
\frac{\partial e^*_{AI}(1,1)}{\partial\rho} &= -\frac{\rho[-2+(2+G)\rho]+\alpha_A[-1+(2+G)\rho^2]}{\rho^2(\rho+\alpha_A)^2},\\
&\quad \text{but since } [-2+(2+G)\rho]>0 \text{ for } G\geq\frac{1-\rho}{\rho\cdot(1-\rho^\rho)}+\frac{\rho}{1-\rho},\\
&\quad \text{it is sufficient that } G>\frac{1-2\rho^2}{\rho^2} \text{ to ensure that } \frac{\partial e^*_{AI}(1,1)}{\partial\rho}>0.
\end{aligned}$$

The impact that ρ has on e^*_{BI} is:

$$\begin{aligned}
\frac{\partial e^*_{BI}(0,0)}{\partial\rho} &= \frac{G\rho(2-\rho+2\alpha_B)}{(1-\rho+\alpha_B)^2}>0;\\
\frac{\partial e^*_{BI}(1,0)}{\partial\rho} &= \frac{(1-\rho)\rho[G(2-\rho)(1-\rho)-\rho(3-\rho)]+\rho\alpha_B\left[2G(1-\rho)^2-\rho(3-2\rho)\right]}{(1-\rho)^2(1-\rho+\alpha_B)^2},\\
&\quad \text{but for } G\geq\frac{\rho}{(1-\rho)\cdot\left[1-(1-\rho)^{1-\rho}\right]},\\
&\quad \text{always hold } G(2-\rho)(1-\rho)-\rho(3-\rho)>0\\
&\quad \text{and } 2G(1-\rho)^2-\rho(3-2\rho)>0, \text{ so } \frac{\partial e^*_{BI}(1,0)}{\partial\rho}>0;\\
\frac{\partial e^*_{BI}(1,1)}{\partial\rho} &= \frac{(2+G)(1-\rho)\rho-1}{(1-\rho)(1-\rho+\alpha_B)}>0 \text{ because in the domain } G\geq\frac{1-\rho}{\rho\cdot(1-\rho^\rho)}+\frac{\rho}{1-\rho},\\
&\quad \text{it is true that } (2+G)(1-\rho)\rho-1>0.
\end{aligned}$$

■

Proof of Corollary 1.3.2. As stated in Proposition 1.3.2, in the benchmark model, the optimal solution for the interdisciplinary production is

$$y^*_I(\theta_A,\theta_B)=\lambda\frac{G-\frac{\rho}{1-\rho}\theta_A-\frac{1-\rho}{\rho}\theta_B}{m_A^{1-\rho}m_B^{\rho}\left(\frac{1-\rho\theta_A}{1-\rho}\right)^{1-\rho}\left(\frac{1-(1-\rho)\theta_B}{\rho}\right)^{\rho}},$$

where $m_A=\frac{\rho+\alpha_A}{1-\rho}$, and $m_B=\frac{1-\rho+\alpha_B}{\rho}$. Graphically, it can be represented in terms of G, as the upper envelope curve of the all four lines $y^*_I(0,0)$, $y^*_I(1,0)$, $y^*_I(0,1)$, and $y^*_I(1,1)$. As Figure 1.8 below shows, the relevant tresholds are $G^{10}=\frac{\rho}{(1-\rho)\left[1-(1-\rho)^{1-\rho}\right]}$ and $G^{11}=\frac{1-\rho}{\rho(1-\rho^\rho)}+\frac{\rho}{1-\rho}$.

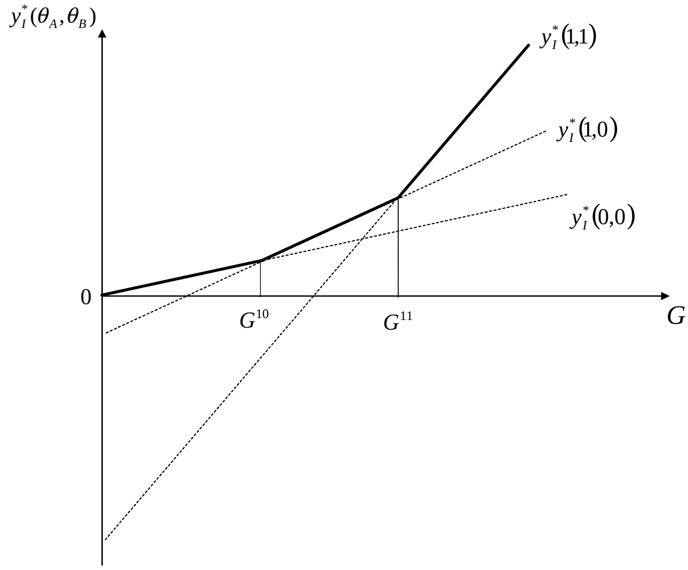

Figure 1.8: The upper envelope-curve of the different possible interdisciplinary outputs.

For $\alpha_A = \alpha_B = \alpha$, the change in the slopes of the three upper lines due to a marginal change in ρ is:

$$\begin{aligned}
\frac{\partial\left(\text{slope of } y_I^*(0,0)\right)}{\partial \rho} &= \frac{\partial\left(\lambda \frac{1}{m_A^{1-\rho}\left(\frac{1}{1-\rho}\right)^{1-\rho} m_B^{\rho}\left(\frac{1}{\rho}\right)^{\rho}}\right)}{\partial \rho} \\
&= \lambda\left(1-\rho\right)^{1-\rho} \cdot \rho^{\rho} \cdot m_A^{1-\rho} \cdot \left(\frac{1}{m_B}\right)^{\rho} \cdot \\
&\quad \cdot \left\{\log\left(\frac{\rho m_A}{m_B}\right) - \frac{1}{m_A} + \frac{1}{m_B}\right\},
\end{aligned}$$

$$\begin{aligned}
\frac{\partial\left(\text{slope of } y_I^*(1,0)\right)}{\partial \rho} &= \frac{\partial\left(\lambda \frac{1}{m_A^{1-\rho m_B \rho}\left(\frac{1}{\rho}\right)^{\rho}}\right)}{\partial \rho} = \\
&= \lambda \rho^{\rho} \cdot \left(\frac{1}{m_A}\right)^{1-\rho} \cdot \left(\frac{1}{m_B}\right)^{\rho} \cdot \\
&\quad \cdot \left\{\log\left(\frac{\rho m_A}{m_B}\right) + 1 - \frac{1}{m_A} + \frac{1}{m_B}\right\},
\end{aligned}$$

$$\begin{aligned}
\frac{\partial\left(\text{slope of } y_I^*(1,1)\right)}{\partial \rho} &= \frac{\partial\left(\lambda \frac{1}{m_A^{1-\rho} m_B^{\rho}}\right)}{\partial \rho} = \\
&= \lambda\left(\frac{1}{m_A}\right)^{1-\rho} \cdot \left(\frac{1}{m_B}\right)^{\rho} \cdot \\
&\quad \cdot \left\{\log\left(\frac{m_A}{m_B}\right) - \frac{1}{m_A} + \frac{1}{m_B}\right\}.
\end{aligned}$$

For $\rho \in \left(0, \frac{1}{2}\right)$,

$$\text{it is true that: } \log\left[\left(\frac{m_A}{m_B}\right)\left(\frac{\rho}{1-\rho}\right)\right] - \frac{1}{m_A} + \frac{1}{m_B} < 0,$$

$$\text{therefore } \frac{\partial \left(\text{slope of } y_I^* (0,0)\right)}{\partial \rho} < 0;$$

$$\text{it is true that: } \log\left(\frac{m_A}{m_B}\right) - \frac{1}{m_A} + \frac{1}{m_B} < 0,$$

$$\text{therefore } \frac{\partial \left(\text{slope of } y_I^* (1,1)\right)}{\partial \rho} < 0;$$

$$\text{if } \log\left(\frac{\rho m_A}{m_B}\right) + 1 - \frac{1}{m_A} + \frac{1}{m_B} < 0,$$

$$\text{then } \frac{\partial \left(\text{slope of } y_I^* (1,0)\right)}{\partial \rho} < 0.$$

As far as the change in the value at the origin is concerned:

$$\begin{aligned}
\frac{\partial \left|\text{value at origin of } y_I^* (1,0)\right|}{\partial \rho} &= \frac{\partial \left(\lambda \frac{\frac{\rho}{1-\rho}}{m_A^{1-\rho} m_B^{\rho} \left(\frac{1}{\rho}\right)^{\rho}}\right)}{\partial \rho} = \\
&= \lambda \frac{1}{\rho+\alpha} \cdot \rho^{1+\rho} \cdot \left(\frac{m_A}{m_B}\right)^{\rho} \cdot \\
&\quad \cdot \left\{\log\left[\left(\frac{m_A}{m_B}\right)\rho\right] - \frac{1}{m_A} + \frac{1}{m_B} + 1 + \frac{1}{\rho(1-\rho)}\right\},
\end{aligned}$$

$$\begin{aligned}
\frac{\partial \left|\text{value at origin of } y_I^* (1,1)\right|}{\partial \rho} &= \frac{\partial \left(\lambda \frac{\frac{\rho}{1-\rho} + \frac{1-\rho}{\rho}}{m_A^{1-\rho} m_B^{\rho}}\right)}{\partial \rho} = \\
&= \lambda \left(\frac{1}{m_A}\right)^{1-\rho} \cdot \left(\frac{1}{m_B}\right)^{\rho} \cdot \\
&\quad \cdot \left\{\frac{1-2\rho(1-\rho)}{\rho(1-\rho)} \cdot \log\left(\frac{m_A}{m_B}\right) - \frac{1-2\rho(1-\rho)}{\rho(\rho+\alpha)} + \right. \\
&\quad \left. \frac{1-2\rho(1-\rho)}{(1-\rho)(1-\rho+\alpha)} + \frac{1}{(1-\rho)^2} - \frac{1}{\rho^2}\right\}.
\end{aligned}$$

For $\rho \in \left(0, \frac{1}{2}\right)$,

$$\text{it is true that: } \left\{ \begin{array}{c} \frac{1-2\rho(1-\rho)}{\rho(1-\rho)} \cdot \log\left(\frac{m_A}{m_B}\right) - \frac{1-2\rho(1-\rho)}{\rho(\rho+\alpha)} + \\ + \frac{1-2\rho(1-\rho)}{(1-\rho)(1-\rho+\alpha)} + \frac{1}{(1-\rho)^2} - \frac{1}{\rho^2} \end{array} \right\} < 0,$$

$$\text{therefore } \frac{\partial \left|\text{value at origin of } y_I^*(1,1)\right|}{\partial \rho} < 0,$$

$$\text{if } \left\{ \log\left(\frac{\rho m_A}{m_B}\right) - \frac{1}{m_A} + \frac{1}{m_B} + 1 + \frac{1}{\rho(1-\rho)} \right\} < 0,$$

$$\text{then } \frac{\partial \left|\text{value at origin of } y_I^*(1,0)\right|}{\partial \rho} < 0.$$

A variation in ρ also affects the intersection points of the three lines, G^{10} and G^{11}:

$$\begin{aligned} \frac{\partial\left(G^{10}\right)}{\partial \rho} &= \frac{\partial\left(\frac{\rho}{(1-\rho)\left[1-(1-\rho)^{1-\rho}\right]}\right)}{\partial \rho} = \\ &= \frac{-1 + (1-\rho)^2 + (2-\rho)\rho^2 - (1-\rho)^2 \rho \log(1-\rho)}{(1-\rho)^{2-\rho}\left[\rho - 1 + (1-\rho)^{\rho}\right]^2}, \end{aligned}$$

$$\begin{aligned} \frac{\partial\left(G^{11}\right)}{\partial \rho} &= \frac{\partial\left(\frac{1-\rho}{\rho(1-\rho^{\rho})} + \frac{\rho}{1-\rho}\right)}{\partial \rho} = \\ &= \frac{-1 + 2\rho + \rho^{2+2\rho} - \rho^{\rho}\left[-1 + \rho\left(1 + \rho\left[4 + \rho(\rho-3)\right]\right) + (\rho-1)^3 \rho \log(\rho)\right]}{(1-\rho)^2 \rho^2 (\rho^{\rho}-1)^2}. \end{aligned}$$

For $\rho \in \left(0, \frac{1}{2}\right)$,

$$\text{it is true that } \left\{-1 + (1-\rho)^2 + (2-\rho)\rho^2 - (1-\rho)^2 \rho \log(1-\rho) > 0\right\},$$

$$\text{therefore } \frac{\partial\left(G^{10}\right)}{\partial \rho} > 0,$$

$$\text{it is true that } \left\{-1 + 2\rho + \rho^{2+2\rho} - \rho^{\rho}\left[-1 + \rho\left(1 + \rho\left[4 + \rho(\rho-3)\right]\right) + (\rho-1)^3 \rho \log(\rho)\right] < 0\right\}, \text{ therefore } \frac{\partial\left(G^{11}\right)}{\partial \rho} < 0.$$

■

Proof of Proposition 1.3.3. When the resources and the adaptative-skills are non-contractible, the problem of the University under specialization is

$$\begin{aligned} \max_{(e_A, e_B)} \Pi_{AB} &= \sum_{i=A,B} g_i - C_i(e_i) \\ & \quad s.t. \quad Y_i(e_i) \geq \tilde{y}_i, \quad i = A, B, \end{aligned}$$

where $(\tilde{y}_i, g_i)$ is defined by the Government.

The first-order conditions of this problem are:

$$\begin{cases} \mu_i = \alpha_i, \\ \mu_i \cdot [\tilde{y}_i - Y_i(e_i)] = 0, \ i = A, B, \\ \mu_i \geq 0, \end{cases}$$

where μ_i is the Lagrangian-multiplier associated with the standard required for field i.

By definition, $\alpha_i > 0$, which implies that in the optimum $Y_i(e_i) = \tilde{y}_i$. From the production functions (1.2.1) it follows that $e_i^U = \tilde{y}_i$, $i = A, B$. Linearity of the production functions and of the costs functions ensure the first-order conditions are necessary and sufficient for having a maximum.

When the University decides for the interdisciplinary project, its problem becomes

$$\begin{aligned} \max_{(e_{AI}, e_{BI}, \theta_A, \theta_B)} \Pi_I &= g_I - C_I \left(e_{AI}, e_{BI}, \theta_A, \theta_B\right) \\ &\quad s.t. \quad Y_I \left(e_{AI}, e_{BI}\right) \geq \tilde{y}_I. \end{aligned}$$

The first-order conditions are:

$$\begin{cases} \mu_I \cdot \frac{\partial Y_I(e_{AI}, e_{BI})}{\partial e_{iI}} = \frac{\partial C_I(e_{AI}, e_{BI}, \theta_A, \theta_B)}{\partial e_{iI}}, \quad i = A, B, \\ \mu_I \cdot [\tilde{y}_I - Y_I(e_{AI}, e_{BI})] = 0, \\ \mu_I \geq 0, \end{cases}$$

where μ_I is the Lagrangian-multiplier associated with the production requirement. By the first condition, I obtain $\mu_I > 0$. This implies that the *funding-policy* constraint is biding: $Y_I(e_A, e_B) = \tilde{y}_I$. Replacing this result into the first condition, I obtain the expressions in (1.3.10). Concavity of the production technology as well as linearity of the cost, make first-order conditions necessary and sufficient for a maximum.

Replacing the equilibrium solution for the inputs (1.3.10) in the cost function (1.2.5), it is possible to derive the following profit function for interdisciplinarity:

$$\begin{aligned} \Pi_I^U \left(\theta_A, \theta_B\right) &= g_I - \frac{\rho}{1-\rho}\theta_A - \frac{1-\rho}{\rho}\theta_B - \tilde{y}_I \cdot \frac{1}{\lambda} \cdot \left[m_A \left(1 - \rho\theta_A\right)\right]^{1-\rho} \cdot \\ &\quad \cdot \left[m_B \left(1 - \left(1-\rho\right)\theta_B\right)\right]^{\rho} \cdot \frac{1}{\rho^{\rho}\left(1-\rho\right)^{1-\rho}}. \end{aligned}$$

Comparing the value of $\Pi_I^U (\theta_A, \theta_B)$ for the different cases of $(\theta_A, \theta_B) = (0,0)$, $(1,0)$, $(0,1)$, and $(1,1)$, I obtain the conditions under which the acquisition of the adaptative-skills is profit maximizer. For $\rho \in \left(0, \frac{1}{2}\right)$, this optimal pattern is

$$
(\theta_A, \theta_B) = \begin{cases}
(0,0)\,, \; if \; g_I \leq \frac{\rho}{(1-\rho)\left[1-(1-\rho)^{1-\rho}\right]}, \\
\qquad \text{or } if \; g_I > \frac{\rho}{(1-\rho)\left[1-(1-\rho)^{1-\rho}\right]} \; and \\
\qquad \tilde{y}_I \leq \frac{\lambda}{m_A^{1-\rho} m_B^{\rho} \left(\frac{1-\rho}{\rho}\right)\left(\frac{1}{\rho}\right)^{\rho}\left[\left(\frac{1}{1-\rho}\right)^{1-\rho}-1\right]}; \\
(1,0)\,, \; if \; g_I \in \left(\frac{\rho}{(1-\rho)\left[1-(1-\rho)^{1-\rho}\right]}, \frac{(1-\rho)^2+\rho^2(1-\rho^{\rho})}{\rho(1-\rho)[1-\rho^{\rho}]}\right) \; and \\
\qquad \tilde{y}_I > \frac{\lambda}{m_A^{1-\rho} m_B^{\rho} \left(\frac{1-\rho}{\rho}\right)\left(\frac{1}{\rho}\right)^{\rho}\left[\left(\frac{1}{1-\rho}\right)^{1-\rho}-1\right]}, \\
\qquad or \; if \; g_I > \frac{\rho}{(1-\rho)\left[1-(1-\rho)^{1-\rho}\right]} \; and \\
\qquad \tilde{y}_I \in \left(\frac{\lambda}{m_A^{1-\rho} m_B^{\rho} \left(\frac{1-\rho}{\rho}\right)\left(\frac{1}{\rho}\right)^{\rho}\left[\left(\frac{1}{1-\rho}\right)^{1-\rho}-1\right]}, \right. \\
\qquad \qquad \left. \frac{\lambda}{m_A^{1-\rho} m_B^{\rho} \left(\frac{\rho}{1-\rho}\right)\left[\left(\frac{1}{\rho}\right)^{\rho}-1\right]}\right); \\
(1,1)\,, \; if \; g_I > \frac{(1-\rho)^2+\rho^2(1-\rho^{\rho})}{\rho(1-\rho)[1-\rho^{\rho}]} \; and \\
\qquad \tilde{y}_I \in \left(\frac{\lambda}{m_A^{1-\rho} m_B^{\rho} \left(\frac{\rho}{1-\rho}\right)\left[\left(\frac{1}{\rho}\right)^{\rho}-1\right]}, \frac{\left(g_I - \frac{\rho}{1-\rho} - \frac{1-\rho}{\rho}\right)\lambda}{m_A^{1-\rho} m_B^{\rho}}\right);
\end{cases}
$$

For $\rho \in \left(\frac{1}{2}, 1\right)$, similar conditions support the choice of $(\theta_A, \theta_B) \in \{(0,0)\,, (0,1)\,, (1,1)\}$. For $\rho = \frac{1}{2}$, the University is indifferent between $(\theta_A, \theta_B) = (1,0)$ and $(0,1)$, which means that the choice concerns only the number of researchers with adaptative-skills. ∎

Proof of Corollary 1.3.3. From the solution of the interdisciplinary problem stated in Proposition 1.3.3, I obtain the following results:

$$
\begin{aligned}
\frac{\partial e_{AI}^U}{\partial \alpha_A} &= -\frac{\tilde{y}_I}{\lambda} \cdot \frac{\rho}{\rho + \alpha_A} \cdot \left[\frac{m_B}{m_A} \cdot \left(\frac{1-(1-\rho)\theta_B}{1-\rho\theta_A}\right) \cdot \left(\frac{1-\rho}{\rho}\right)\right]^{\rho} < 0; \\
\frac{\partial e_{AI}^U}{\partial \alpha_B} &= \frac{\tilde{y}_I}{\lambda} \cdot \frac{\rho}{1-\rho + \alpha_B} \cdot \left[\frac{m_B}{m_A} \cdot \left(\frac{1-(1-\rho)\theta_B}{1-\rho\theta_A}\right) \cdot \left(\frac{1-\rho}{\rho}\right)\right]^{\rho} > 0;
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial e_{AI}^U}{\partial \theta_A} &= \frac{\tilde{y}_I}{\lambda} \cdot \frac{\rho^2}{1-\rho\theta_A} \cdot \left[\frac{m_B}{m_A} \cdot \left(\frac{1-(1-\rho)\theta_B}{1-\rho\theta_A}\right) \cdot \left(\frac{1-\rho}{\rho}\right)\right]^{\rho} > 0; \\
\frac{\partial e_{AI}^U}{\partial \theta_B} &= -\frac{\tilde{y}_I}{\lambda} \cdot \frac{\rho(1-\rho)}{1-(1-\rho)\theta_B} \cdot \left[\frac{m_B}{m_A} \cdot \left(\frac{1-(1-\rho)\theta_B}{1-\rho\theta_A}\right) \cdot \left(\frac{1-\rho}{\rho}\right)\right]^{\rho} < 0.
\end{aligned}
$$

The global effect of ρ on A's input is:

$$
\begin{aligned}
\frac{\partial e_{AI}^U}{\partial \rho} = \; & \frac{\tilde{y}_I}{\lambda} \cdot \left\{\log\left[\frac{m_B}{m_A} \cdot \left(\frac{1-(1-\rho)\theta_B}{1-\rho\theta_A}\right) \cdot \left(\frac{1-\rho}{\rho}\right)\right] - \right. \\
& \left. -\frac{3 - \frac{1-\rho}{1-\rho\theta_A} - \frac{\rho}{1-(1-\rho)\theta_B}}{1-\rho} - \frac{\rho}{\rho+\alpha_A} - \frac{1}{m_B}\right\} \cdot \\
& \cdot \left[\frac{m_B}{m_A} \cdot \left(\frac{1-(1-\rho)\theta_B}{1-\rho\theta_A}\right) \cdot \left(\frac{1-\rho}{\rho}\right)\right]^{\rho}.
\end{aligned}
$$

A sufficient condition for having a negative relation between e_{AI}^{U} and ρ is:

$$\frac{m_B}{m_A} \cdot \left(\frac{1-(1-\rho)\theta_B}{1-\rho\theta_A} \right) \cdot \left(\frac{1-\rho}{\rho} \right) < 1 \Leftrightarrow \frac{(1-\rho\theta_A)m_A}{[1-(1-\rho)\theta_B]\, m_B} > \frac{1-\rho}{\rho}.$$

Similar expressions can be found for comparative statics on e_{BI}^{U}. ■

Proof of Corollary 1.3.4. Given the best choice of the University for the interdisciplinary resources $\left(e_{AI}^{U}, e_{BI}^{U}, \theta_A, \theta_B\right)$ stated in Proposition 1.3.3, it is straightforward to derive the maximum interdisciplinary profit expression. From there, we can calculate the following derivatives:

$$\frac{\partial \Pi_I^U}{\partial \alpha_A}(\theta_A, \theta_B) = -\frac{\tilde{y}_I}{\lambda} \cdot (m_A)^{-\rho} \cdot (1-\rho\theta_A)^{1-\rho} \cdot$$
$$\cdot \left[m_B\left(1-(1-\rho)\,\theta_B\right)\right]^{\rho} \cdot \left[\left(\frac{1-\rho}{\rho}\right)^{\rho} + \left(\frac{\rho}{1-\rho}\right)^{1-\rho} \right] < 0;$$

$$\frac{\partial \Pi_I^U}{\partial \alpha_B}(\theta_A, \theta_B) = -\frac{\tilde{y}_I}{\lambda} \cdot \left[m_A\left(1-\rho\theta_A\right)\right]^{1-\rho} \cdot (m_B)^{\rho-1} \cdot$$
$$\cdot \left[1-(1-\rho)\,\theta_B\right]^{\rho} \cdot \left[\left(\frac{1-\rho}{\rho}\right)^{\rho} + \left(\frac{\rho}{1-\rho}\right)^{1-\rho} \right] < 0.$$

For general values of the parameters, the final effect of ρ in the interdisciplinary profit is ambiguous, since:

$$\frac{\partial \Pi_I^U}{\partial \rho}(0,0) = \frac{\tilde{y}_I}{\lambda} \cdot \left(\frac{m_B}{m_A}\right)^{\rho} \cdot \left(\frac{1}{1-\rho}\right)^{2-\rho} \cdot \left(\frac{1}{\rho}\right)^{\rho} \cdot$$
$$\cdot \left\{-1-\alpha_A + (\rho+\alpha_A)\cdot\left[\log(m_A) - \log(m_B) + \right.\right.$$
$$\left.\left. + \log\left(\frac{1}{1-\rho}\right) - \log\left(\frac{1}{\rho}\right) + \frac{1+\alpha_B}{1-\rho+\alpha_B}\right]\right\}.$$

Nevertheless, when $\alpha_A = \alpha_B = \alpha$ and $\rho \in \left(0, \frac{1}{2}\right)$, it is possible to conclude that:

i) for $(\theta_A, \theta_B) = (0,0)$: $\frac{\partial \Pi_I^U}{\partial \rho}(\theta_A, \theta_B) < 0$;

ii) for $(\theta_A, \theta_B) = (1,0)$:

$$\frac{\partial \Pi_I^{MU}}{\partial \rho}(1,0) = -\frac{1}{(1-\rho)^2} + \frac{\tilde{y}_I}{\lambda} \cdot \left(\frac{m_B}{m_A}\right)^{\rho} \cdot \left(\frac{1}{1-\rho}\right) \cdot \left(\frac{1}{\rho}\right)^{\rho} \cdot$$
$$\cdot \left\{-1-\alpha_A + (\rho+\alpha_A)\cdot\left[\log(m_A) - \log(m_B) - \right.\right.$$
$$\left.\left. - \log\left(\frac{1}{\rho}\right) + \frac{1}{m_B}\right]\right\}.$$

This means that if $\log\left(\frac{m_B}{m_A}\frac{1}{\rho}\right) > \frac{\rho}{1-\rho+\alpha}$, then $\frac{\partial \Pi_I^U}{\partial \rho}(1,0) < 0$;

iii) for $(\theta_A, \theta_B) = (1,1)$:

$$\begin{aligned} \frac{\partial \Pi_I^U}{\partial \rho}(1,1) &= \frac{1}{\rho^2} - \frac{1}{(1-\rho)^2} + \frac{\tilde{y}_I}{\lambda} \cdot \left(\frac{m_B}{m_A}\right)^{\rho} \cdot \left(\frac{1}{1-\rho}\right) \cdot \\ &\cdot \{-1 - \alpha_A + (\rho + \alpha_A) \cdot [\log(m_A) - \log(m_B) - 2 + \\ &+ \frac{1+\alpha_B}{1-\rho+\alpha_B}\Big]\Big\} \end{aligned}$$

from what $\log\left(\frac{m_B}{m_A}\right) > -2 + \frac{1+\alpha}{1-\rho+\alpha} - \frac{1+\alpha}{\rho+\alpha} + \frac{\frac{1}{\rho^2} - \frac{1}{(1-\rho)^2}}{\frac{\tilde{y}_I}{\lambda} m_B^{\rho} m_A^{1-\rho}} \Longrightarrow \frac{\partial \Pi_I^U}{\partial \rho}(1,1) < 0.$

■

Proof of Corollary 1.3.5. From the profit maximizer behavior of the University stated in Proposition 1.3.3, I obtain that, once deciding for one type of research, the University exactly matches the required standard. The result of this corollary follows straightforward. ■

Proof of Proposition 1.3.4. To obtain the Sub-game Perfect Nash equilibrium solution, I first concentrate in the problem of the University when choosing the resources and the investment on the adaptative-skills. Considering the specialized projects, the profit maximizing choice for the resources is given by

$$\begin{aligned} \max_{(e_A, e_B)} \Pi_{AB} &= 2g - \sum_{i=A,B} C_i(e_i) \\ & s.t. \quad Y_i(e_i) \geq \tilde{y},\ i = A, B, \end{aligned}$$

from which I obtain the solution $e_i^U = \tilde{y}$, and the profit value $\Pi_i^U = g - \alpha \cdot \tilde{y},\ \ i = A, B$. Under Assumption 2, the University never considers the scenario of developing only one specialized project, since either develops both A and B, or no one of them.

Considering the interdisciplinary field, the amount chosen for the inputs and the acquisition of the adaptative-skills solves

$$\begin{aligned} \max_{(e_{AI}, e_{BI}, \theta_A, \theta_B)} \Pi_I &= g - C_I(e_{AI}, e_{BI}, \theta_A, \theta_B) \\ & s.t. \quad Y_I(e_{AI}, e_{BI}) \geq \tilde{y}. \end{aligned}$$

The optimal solutions are similar to the ones presented in Proposition 1.3.3. Again, if choosing interdisciplinarity, the University does not produce above the standard.

For the policymaker, the restriction of having an unique funding rule makes the choice of interdisciplinarity or specialization a non-contractible decision. This means that, if the Government wishes to induce the choice of the interdisciplinary field, the best possible funding rule $(\tilde{y}, g)$ solves:

$$\max_{(\tilde{y},g)} V_I [Y_I (e_{AI}, e_{BI})]$$

$$s.t. \quad \begin{cases} \Pi_I (e_{AI}, e_{BI}, \theta_A, \theta_B) \geq 0, \\ \Pi_I (e_{AI}, e_{BI}, \theta_A, \theta_B) \geq \Pi_{AB} (e_A, e_B), \\ 2g \leq G, \\ e_{iI} = e_{iI} (\tilde{y}), \end{cases} \quad i = A, B,$$

where $e_{iI} (\tilde{y})$ is the solution of the profit maximization problem of the University under interdisciplinarity, and $\Pi_{AB} (e_A, e_B)$ is the maximum value of the specialized choice, obtained from the problem of the University for specialization. Given the linearity of the cost function and the strict convexity of the interdisciplinary technology, the necessary and sufficient conditions to obtain a maximum are:

$$\begin{cases} \frac{\partial V_I}{\partial Y_I} \cdot \frac{\partial Y_I}{\partial \tilde{y}_I} (\tilde{y}) + (\mu_1 + \mu_2) \cdot \frac{\partial \Pi_I}{\partial \tilde{y}} (\tilde{y}) - \mu_2 \cdot \frac{\partial \Pi_{AB}}{\partial \tilde{y}} = 0, \\ (\mu_1 + \mu_2) \cdot \frac{\partial \Pi_I}{g} - \mu_2 \cdot \frac{\partial \Pi_{AB}}{\partial g} - 2\mu_3 = 0, \\ \mu_1 \cdot \Pi_I (e_{AI}, e_{BI}, \theta_A, \theta_B) = 0, \\ \mu_2 \cdot [\Pi_{AB} (e_A, e_B) - \Pi_I (e_{AI}, e_{BI}, \theta_A, \theta_B)] = 0, \\ \mu_3 \cdot (2g - G) = 0, \\ \mu_1 \geq 0, \ \mu_2 \geq 0, \ \mu_3 \geq 0. \end{cases}$$

From the first condition, I obtain

$$\mu_1 + \mu_2 > 0,$$

and from the second condition,

$$\mu_3 = \frac{\mu_1 - \mu_2}{2}.$$

Considering the fact that all Lagrangian-multipliers μ_i, $i = 1, 2, 3$, are non-negative, I conclude that:

$$\begin{aligned} \mu_1 &> 0, \\ \mu_2 &\geq 0. \end{aligned}$$

Therefore, in the optimal situation,

$$\begin{cases} \Pi_I (e_{AI}, e_{BI}, \theta_A, \theta_B) = 0 \Leftrightarrow g = C_I (e_{AI}, e_{BI}, \theta_A, \theta_B), \\ \Pi_I (e_{AI}, e_{BI}, \theta_A, \theta_B) \geq \Pi_{AB} (e_A, e_B). \end{cases}$$

As far as the budget constraint is concerned, in the optimal either

$$\begin{aligned} \mu_3 &> 0 \Longrightarrow 2g = G, \\ \text{or } \mu_3 &= 0 \Longrightarrow 2g \leq G. \end{aligned}$$

Nevertheless, when the Governmental budget G is not exhausted, the other two constraints must be active:

$$2g < G \Longrightarrow \mu_3 = 0 \Longrightarrow \mu_1 = \mu_2.$$

Since $\mu_1 > 0$, it must be that $\mu_2 > 0$, and therefore $\Pi_I = 0$ and $\Pi_I = \Pi_{AB}$.

For the case of $\rho \in \left(0, \frac{1}{2}\right)$, depending on the value of the parameters in the model, it is possible to have one of the following four alternative situations.

Situation 1, when $\frac{(1-\rho)^{\rho}[g(1-\rho)+\rho]-g(1-\rho)^2}{(1-\rho)\rho^{1+\rho}} \leq \frac{2\alpha\lambda}{m_A^{1-\rho}m_B^{\rho}}$, the comparison between the profit functions under specialization and interdisciplinarity rely on two tresholds, $\tilde{y}_{AB,I}^{00} = \frac{g\lambda}{2\alpha\lambda - m_A^{1-\rho}m_B^{\rho}\left(\frac{1}{\rho}\right)^{\rho}\left(\frac{1}{1-\rho}\right)^{1-\rho}}$ and $\tilde{y}^{11} = \frac{\left(g - \frac{\rho}{1-\rho} - \frac{1-\rho}{\rho}\right)\lambda}{m_A^{1-\rho}m_B^{\rho}}$, as Figure 1.9 below shows.

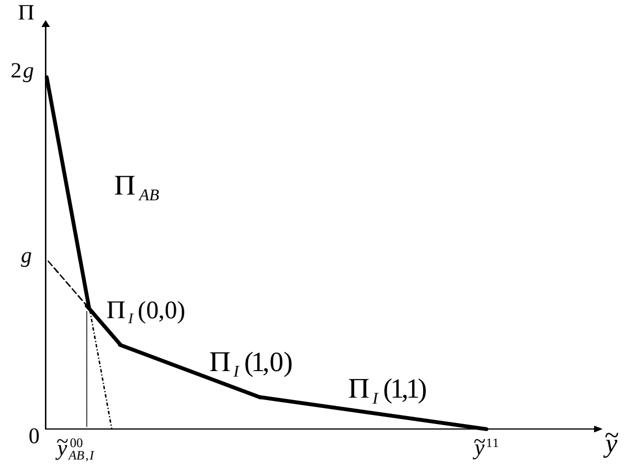

Figure 1.9: Specialized profit (Π_{AB}) and interdisciplinary profit (Π_I), in situation 1.

For $\tilde{y} \in \left(0,\ \tilde{y}_{AB,I}^{00}\right)$, specialization is the best choice of the University. For $\tilde{y} \in \left(\tilde{y}_{AB,I}^{00},\ \tilde{y}^{11}\right)$, it prefers the interdisciplinary project.

Anticipating this behavior, the Government sets $\tilde{y} = \tilde{y}^{11}$ if it wants to induce interdisciplinarity, or $\tilde{y} = \tilde{y}_{AB,I}^{00}$ if it prefers specialization. To know which of the alternative scenarios is actually chosen by the policymaker, the value of $V_I\left(\tilde{y}^{11}\right)$ must be compared with $V_{AB} = \sum_{i=A,B} V_i\left(\tilde{y}_{AB,I}^{00}\right)$.

Situation 2, when $\frac{1-\rho[2-\rho(2-\rho^{\rho})-g(1-\rho)(1-\rho^{\rho})]}{\rho^{\rho}(1-\rho)^2} \leq \frac{2\alpha\lambda}{m_A^{1-\rho}m_B^{\rho}} \leq \frac{(1-\rho)^{\rho}[g(1-\rho)+\rho]-g(1-\rho)^2}{(1-\rho)\rho^{1+\rho}}$, Figure

1.10 represents the comparison between the two types of profit, Π_I and Π_{AB}.

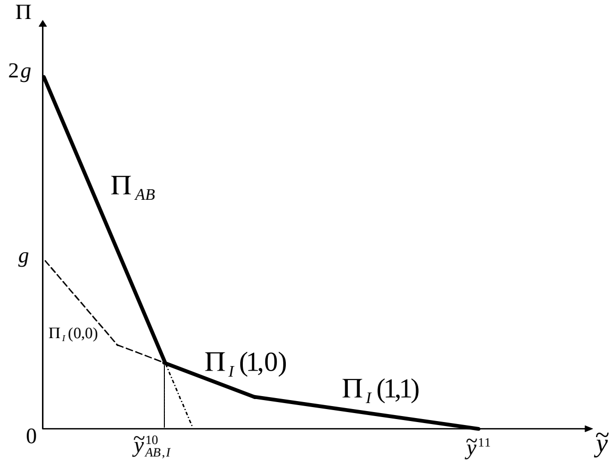

Figure 1.10: Specialized profit (Π_{AB}) and interdisciplinary profit (Π_I), in situation 2.

The University prefers the specialized projects when $\tilde{y} \in \left(0,\ \tilde{y}^{10}_{AB,I}\right)$, where $\tilde{y}^{10}_{AB,I} = \frac{\left(g+\frac{\rho}{1-\rho}\right)\lambda}{2\alpha\lambda - m_A^{1-\rho} m_B^{\rho}\left(\frac{1}{\rho}\right)^{\rho}}$. It prefers the interdisciplinary project when $\tilde{y} \in \left(\tilde{y}^{10}_{AB,I},\ \tilde{y}^{11}\right)$. Predicting this optimal reaction, the Government sets $\tilde{y} = \tilde{y}^{11}$ or $\tilde{y} = \tilde{y}^{10}_{AB,I}$, depending on whether it values more $V_I\left(\tilde{y}^{11}\right)$ or $V_{AB} = \sum_{i=A,B} V_i\left(\tilde{y}^{10}_{AB,I}\right)$, respectively.

Situation 3, when $\frac{2g\rho(1-\rho)}{(2+g)\rho(1-\rho)-1} \leq \frac{2\alpha\lambda}{m_A^{1-\rho} m_B^{\rho}} \leq \frac{1-\rho[2-\rho(2-\rho^{\rho})-g(1-\rho)(1-\rho^{\rho})]}{\rho^{\rho}(1-\rho)^2}$, Figure 1.11 shows how to compare the profitability of both types of projects. Here the relevant treshold for the standard is $\tilde{y}^{11}_{AB,I} = \frac{\left(g+\frac{\rho}{1-\rho}+\frac{1-\rho}{\rho}\right)\lambda}{2\alpha\lambda - m_A^{1-\rho} m_B^{\rho}}$.

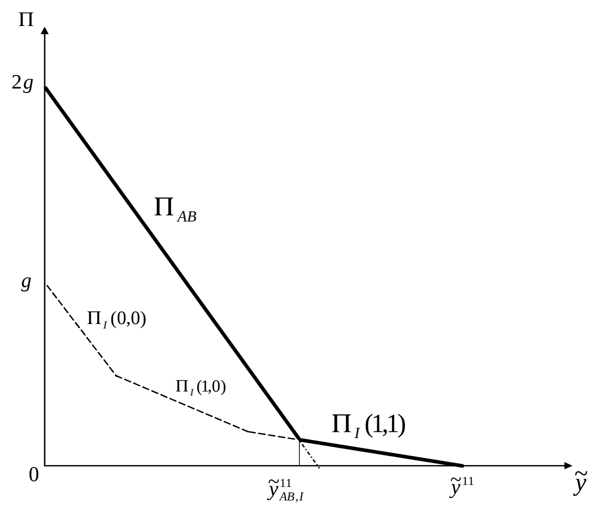

Figure 1.11: Specialized profit (Π_{AB}) and interdisciplinary profit (Π_I), in situation 3.

It then follows that the specialized projects are chosen when $\tilde{y} \in \left(0,\ \tilde{y}^{11}_{AB,I}\right)$, and the interdisciplinary project is preferred when $\tilde{y} \in \left(\tilde{y}^{11}_{AB,I},\ \tilde{y}^{11}\right)$.

The optimal policy is, therefore, to establish $\tilde{y} = \tilde{y}^{11}$ if the Government prefers interdisciplinarity, and $\tilde{y} = \tilde{y}^{11}_{AB,I}$ if it prefers specialization. This preference is determined by comparing $V_I\left(\tilde{y}^{11}\right)$ with $V_{AB} = \sum_{i=A,B} v_i\left(\tilde{y}^{11}_{AB,I}\right)$.

Situation 4, when $\frac{2\alpha\lambda}{m_A^{1-\rho}m_B^{\rho}} \leq \frac{2g\rho(1-\rho)}{(2+g)\rho(1-\rho)-1}$, the University never chooses the interdisciplinary project, as Figure 1.12 helps to conclude.

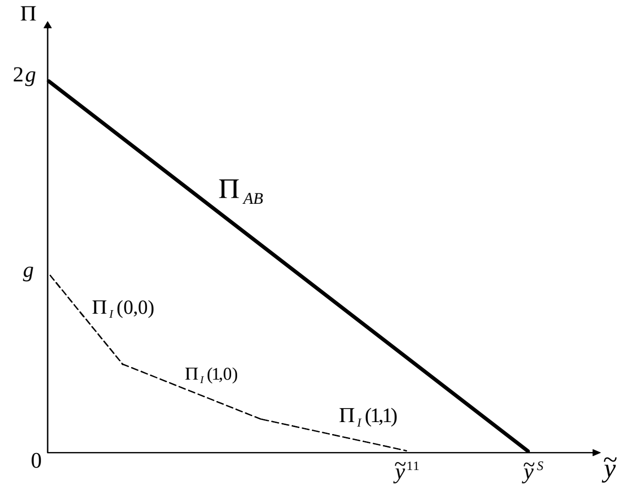

Figure 1.12: Specialized profit (Π_{AB}) and interdisciplinary profit (Π_I), in situation 4.

The University prefers the specialized research whenever $\tilde{y} \in \left(0, \tilde{y}^S\right)$, and decides for its outside option of no research, otherwise. As a consequence, the Government establishes $\tilde{y} = \tilde{y}^S$.

In all the four situations above, whenever interdisciplinarity is a possible best-alternative (Situations 1 to 3), it is actually so, only if the required standard is sufficiently high (above $\tilde{y}^{00}_{AB,I}$, $\tilde{y}^{10}_{AB,I}$, or $\tilde{y}^{11}_{AB,I}$, respectively), but not too much (at most $\tilde{y}^{11}$).

Consider again the previous Situation 3. In particular, let $\tilde{y}^{11}_{AB,I} = \tilde{y}^{11}$. This figure enables us to discuss the case where it is not optimal to exhaust the budget G and why it implies that the incentive-compatibility constraint $\Pi_I\left(e_{AI}, e_{BI}, \theta_A, \theta_B\right) \geq \Pi_{AB}\left(e_A, e_B\right)$

is binding.

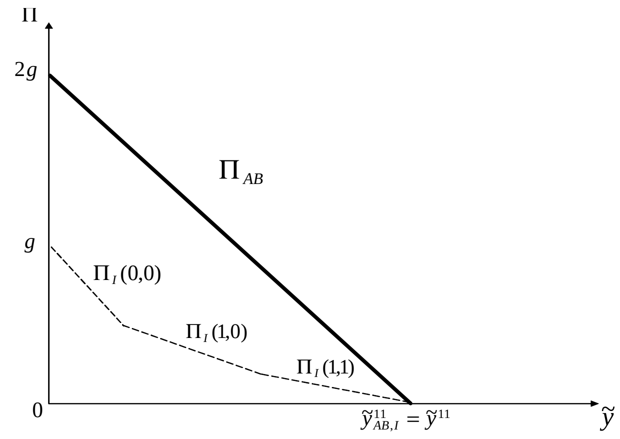

Figure 1.13: Specialized (Π_{AB}) and interdisciplinary (Π_I) profits in a particular sit. 3.

In this case, if to induce $\tilde{y} = \tilde{y}^{11}$ the Government still has $g < \frac{G}{2}$, the budget exhausting is not compatible with the choice for interdisciplinarity. An increase in g has a higher effect on Π_{AB} than on Π_I ($2\partial g$ versus ∂g) and, as a consequence, trying to employ all the monetary resources makes specialization the optimal decision for the University. ■

Proof of Proposition 1.3.5. From the proof of Proposition 1.3.4, it is possible to conclude that, when $\rho \in \left(0, \frac{1}{2}\right)$, the comparison between specialized and interdisciplinary profits depends on how the parameters ratio $\frac{2\alpha\lambda}{m_A^{1-\rho} m_B^{\rho}}$ compares with the three thresholds $\frac{(1-\rho)^{\rho}[g(1-\rho)+\rho]-g(1-\rho)^2}{(1-\rho)\rho^{1+\rho}}$, $\frac{1-\rho[2-\rho(2-\rho^{\rho})-g(1-\rho)(1-\rho^{\rho})]}{\rho^{\rho}(1-\rho)^2}$, and $\frac{2g\rho(1-\rho)}{(2+g)\rho(1-\rho)-1}$.

An increase in α affects positively the ratio $\frac{2\alpha\lambda}{m_A^{1-\rho} m_B^{\rho}}$:

$$\frac{\partial\left(\frac{2\alpha\lambda}{m_A^{1-\rho} m_B^{\rho}}\right)}{\partial\alpha} = \frac{2\lambda\left(1+2\alpha\right) m_A^{\rho-2}}{m_B^{1+\rho}} > 0.$$

Since no threshold depends on α and because the thresholds have a clear order: $\frac{(1-\rho)^{\rho}[g(1-\rho)+\rho]-g(1-\rho)^2}{(1-\rho)\rho^{1+\rho}} \geq \frac{1-\rho[2-\rho(2-\rho^{\rho})-g(1-\rho)(1-\rho^{\rho})]}{\rho^{\rho}(1-\rho)^2} \geq \frac{2g\rho(1-\rho)}{(2+g)\rho(1-\rho)-1}$, an increase in the parameters ratio favors the choice of interdisciplinarity. That is to say, an increase in α expands the range of $\tilde{y}$ where interdisciplinarity is more profitable than specialization.

Since ρ only affects the interdisciplinary profit, I only need the comparative statics results obtained in Corollary 1.3.4. Therefore, when $\rho \in \left(0, \frac{1}{2}\right)$,

$$\text{for } (\theta_A, \theta_B) = (0,0) : \frac{\partial \Pi_I}{\partial \rho}(\theta_A, \theta_B) < 0,$$

$$\text{for } (\theta_A, \theta_B) = (1,0) : \log\left(\frac{m_B}{m_A}\frac{1}{\rho}\right) > \frac{\rho}{1-\rho+\alpha} \Longrightarrow \frac{\partial \Pi_I}{\partial \rho}(\theta_A, \theta_B) < 0,$$

$$\text{for } (\theta_A, \theta_B) = (1,1) : \log\left(\frac{m_B}{m_A}\right) > -2 + \frac{1+\alpha}{1-\rho+\alpha} - \frac{1+\alpha}{\rho+\alpha} + \\ + \frac{\frac{1}{\rho^2} - \frac{1}{(1-\rho)^2}}{\frac{\tilde{y}_I}{\lambda} m_B^{\rho} m_A^{1-\rho}} \Longrightarrow \frac{\partial \Pi_I}{\partial \rho}(\theta_A, \theta_B) < 0.$$

■

Proof of Proposition 1.3.6. When $\alpha_A = \beta\alpha_B$, $\beta > 1$, each situation described in the proof of Proposition 1.3.4 gives place to two alternative scenarios (so, in total, there are eight possible situations), depending on whether the *kink* in the specialized profit curve occurs above or below the interdisciplinary profit curve. In the first case, the relevant alternatives for the University are the specialization in both A and B, only in B, or the interdisciplinarity. In the second case, the option for B alone is never actually considered, and everything remains the same as when $\alpha_A = \alpha_B$. To illustrate, I show two of the eight possible situations.

Situation 2.1, when $\frac{1-\rho[2-\rho(2-\rho^{\rho})-g(1-\rho)(1-\rho^{\rho})]}{\rho^{\rho}(1-\rho)^2} \leq \frac{2\alpha\lambda}{m_A^{1-\rho} m_B^{\rho}} \leq \frac{(1-\rho)^{\rho}[g(1-\rho)+\rho]-g(1-\rho)^2}{(1-\rho)\rho^{1+\rho}}$ and the specialization in field B alone is never optimal. The University prefers specialization in A and B if $\tilde{y} \in \left(0, \tilde{y}_{AB,I}^{10}\right)$, and prefers interdisciplinarity if $\tilde{y} \in \left(\tilde{y}_{AB,I}^{10}, \tilde{y}^{11}\right)$. Figure 1.14 below represents the situation.

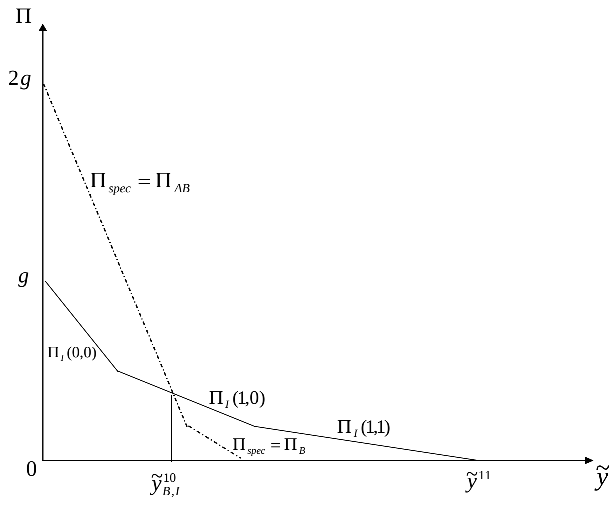

Figure 1.14: Profit comparison, $\alpha_A > \alpha_B$,
B alone is never optimal.

Situation 2.2, when $\frac{1-\rho[2-\rho(2-\rho^{\rho})-g(1-\rho)(1-\rho^{\rho})]}{\rho^{\rho}(1-\rho)^2} \leq \frac{2\alpha\lambda}{m_A^{1-\rho}m_B^{\rho}} \leq \frac{(1-\rho)^{\rho}[g(1-\rho)+\rho]-g(1-\rho)^2}{(1-\rho)\rho^{1+\rho}}$ and the specialization in field B alone is optimal for $\tilde{y} \in \left(\frac{g}{\alpha_A}, \tilde{y}_{B,I}^{10}\right)$, whereas both A and B are chosen for $\tilde{y} \in \left(0, \frac{g}{\alpha_A}\right)$, and interdisciplinarity for $\tilde{y} \in \left(\tilde{y}_{B,I}^{10}, \tilde{y}^{11}\right)$, with $\tilde{y}_{B,I}^{10} = \frac{\frac{\rho}{1-\rho}\lambda}{\alpha_B\lambda - m_A^{1-\rho}m_B^{\rho}\left(\frac{1}{\rho}\right)^{\rho}}$. Figure 1.15 represents the situation.

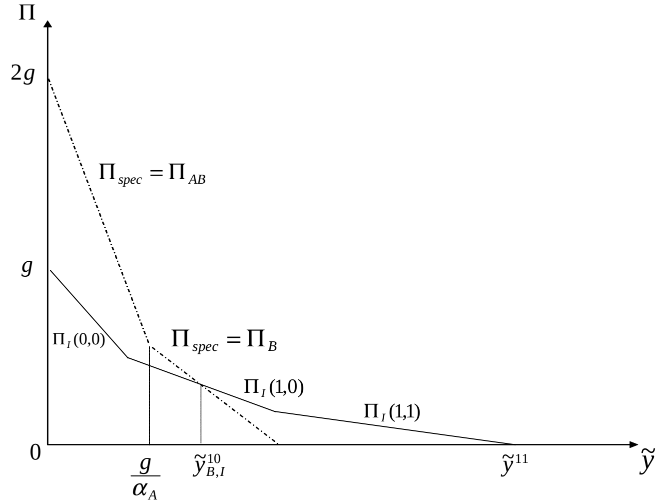

Figure 1.15: Profit comparison, $\alpha_A > \alpha_B$, B alone may be optimal.

The impact of α_i on the choice between specialization and interdisciplinarity can now be analyzed as follows:

a) in the case where B alone is never optimal choice

$$\begin{aligned}
\frac{\partial\left(\frac{(\alpha_A+\alpha_B)\lambda}{m_A^{1-\rho}m_B^{\rho}}\right)}{\partial\alpha_A} &= \frac{\lambda(1-\rho)\left[\rho(1+\alpha_A)-(1-\rho)\alpha_B\right]}{(\rho+\alpha_A)^2}\left(\frac{m_A}{m_B}\right)^{\rho} \\
\text{which is} &> 0 \text{ when } \frac{1+\alpha_A}{\alpha_B} > \frac{1-\rho}{\rho}, \\
\frac{\partial\left(\frac{(\alpha_A+\alpha_B)\lambda}{m_A^{1-\rho}m_B^{\rho}}\right)}{\partial\alpha_B} &= \frac{\lambda(1-\rho)\left[(1-\rho)(1+\alpha_B)-\rho\alpha_A\right]}{(\rho+\alpha_A)(1-\rho+\alpha_B)}\left(\frac{m_A}{m_B}\right)^{\rho} \\
\text{which is} &> 0 \text{ when } \frac{1+\alpha_B}{\alpha_A} > \frac{\rho}{1-\rho}.
\end{aligned}$$

With an increase in α_A, it may happen that B alone may become a relevant alternative, since it is not affected by that change of inefficiency;

b) in the case where B may be a relevant option for intermediate values of the standard:

$$\begin{aligned}
\frac{\partial \tilde{y}_{B,I}^{10}}{\partial \alpha_A} &= \frac{\lambda (1-\rho)\, \rho^{1+\rho} m_A^{\rho} m_B^{\rho}}{\left[\lambda (\rho - 1)\, \rho^{\rho} m_A^{\rho} \alpha_B + (\rho + \alpha_A)\, m_B^{\rho}\right]^2} > 0, \\
\frac{\partial \tilde{y}_{B,I}^{10}}{\partial \alpha_B} &= -\frac{\lambda \rho \left[\lambda - \frac{1}{\rho^{\rho}} m_A^{1-\rho} m_B^{-1+\rho}\right]}{(1-\rho) \left[\lambda \alpha_B - \frac{1}{\rho^{\rho}} m_A^{1-\rho} m_B^{\rho}\right]^2} < 0, \\
& \text{for } \lambda > \frac{1}{\rho^{\rho}} m_A^{1-\rho} m_B^{-1+\rho}.
\end{aligned}$$

■

Chapter 2

Business-Science Research Collaboration under Moral-Hazard

This chapter benefited from helpful comments of Inés Macho-Stadler and David Perez-Castrillo, to whom I acknowledge. The suggestions received from Pedro Rey-Biel, Irina Prokofieva, and Nadia Prokofieva, as well during the Microeconomics Workshop and the Industrial Organization Informal Seminar at IDEA-UAB were very useful.

2.1 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 chapter contributes with a new possible answer

[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).

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 chapter 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 qualified 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 the data, equipment, and market experience of companies also benefits the research of academics. The skills and resources of the firms 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

[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).

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, the primary concern of universities 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 chapter 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 collaboration 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.[4] 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 chapter 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

[4] Porac *et al.* (2004) also argue that the governance structure of alliance have impact not only on the willingness of the partners to collaborate, but also on their ability to coordinate their collaborative efforts.

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 a long-term investment to acquire complementary knowledge. Ultimately, they argue, this investment would bring some insights on how to better conduct and evaluate the own research of firms. The present chapter 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 chapter 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 chapter 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 chapter relates to three main branches of literature. First, my results have some features of research partnership literature that shows the efficiency gains of cooperation 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 chapter 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 chapter, 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 chapter, 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 the effort of scientists. 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 chapter 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 2.3, 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 2.4, I discuss a policy intervention to support the collaboration through subsidies. In Section 2.5, I interpret the results of the model and I address their managerial and policy implications. Conclusion remarks are in Section 2.6. All the proofs are in Appendix Two.

2.2 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 University) and one firm (identified as the Firm). 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 reserach 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 2.1a shows.

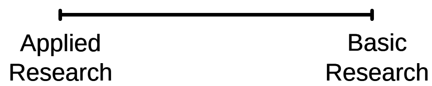

Figure 2.1a: Applied Research and Basic Research.

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 2.1b represents the normalization.

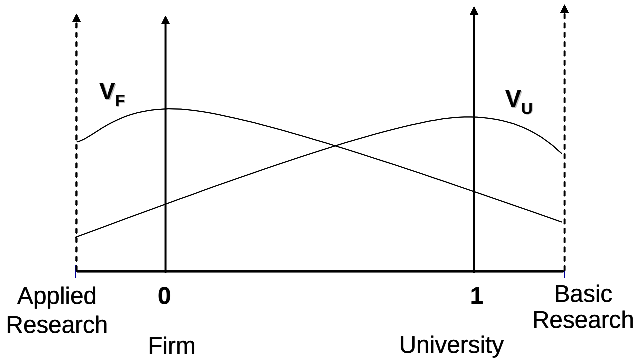

Figure 2.1b: Normalization of the values of a successful project.

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 2.1c represents the new project domain.

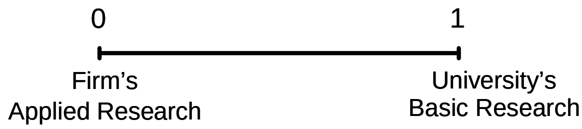

Figure 2.1c: Relevant range of research projects.

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:

$$V_F(x) = B_f - m_f x, \tag{2.2.1}$$
$$V_U(x) = B_u - m_u(1-x), \tag{2.2.2}$$

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 (2.2.1) and (2.2.2) 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:

$$p = ke_f + (1 - k)e_u. \tag{2.2.3}$$

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:

$$C_F = \frac{c_f}{2} e_f^2, \tag{2.2.4}$$

$$C_U = \frac{c_u}{2} e_u^2. \tag{2.2.5}$$

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 $\tilde{m} = \min(m_f, m_u)$.[5]

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 (2.2.1), (2.2.3), and (2.2.4), the Firm's expected gain from developing a research project together with the University, $E\Pi_F$, is described by:

$$E\Pi_F = pV_F(x) - C_F. \tag{2.2.6}$$

Using (2.2.2), (2.2.3), and (2.2.5), the University's expected reward from collaborating is:

$$E\Pi_U = pV_U(x) - C_U. \tag{2.2.7}$$

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 re-

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

sources, 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.

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 2.1 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 2.1: 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 $2UG$.[6]

[6] Ay stands for "Asymmetric information from the party y", while yG stands for "governance of party y".

Outside option Instead of collaborating, each party has the possibility to develop the research by its own, alone.[7] Research alone, however, translates in a small probability of success, or a higher cost, or both.

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

$$\max_{\{x,e_f\}} E\Pi_F = p_F V_F(x) - C_F, \tag{2.2.8}$$

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 (2.2.8) and (2.2.6), 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 chapter, 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 Appendix Two.

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

[7] In a more general setup, I 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*, not only I endogenize results, but also I gain some insights on the comparison of the two research scenarios (alone and with collaboration).

2.3 Collaboration Outcomes

2.3.1 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.

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 2.3.1 presents the optimal joint project.

Proposition 2.3.1 *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

$$EW^* = \frac{1}{2}\left[\frac{k^2}{c_f}+\frac{(1-k)^2}{c_u}\right]\left[B_f+B_u-m_u-(m_f-m_u)\,x\right]^2. \tag{2.3.1}$$

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 2.2 represents the situation.

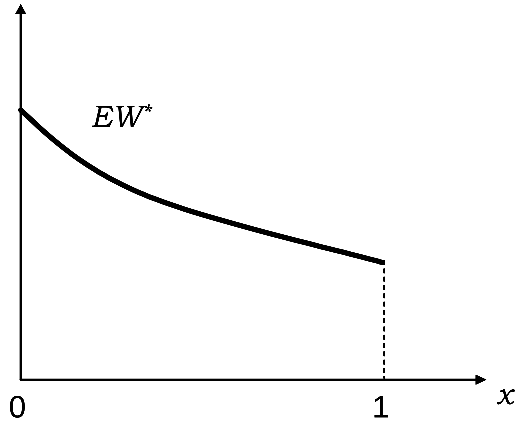

Figure 2.2: Joint expected gain with verifiable efforts, when $m_f > m_u$.

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 2.3.1 *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.

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 2.3.2 *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 2.3 plots the results related with the choice of the project.

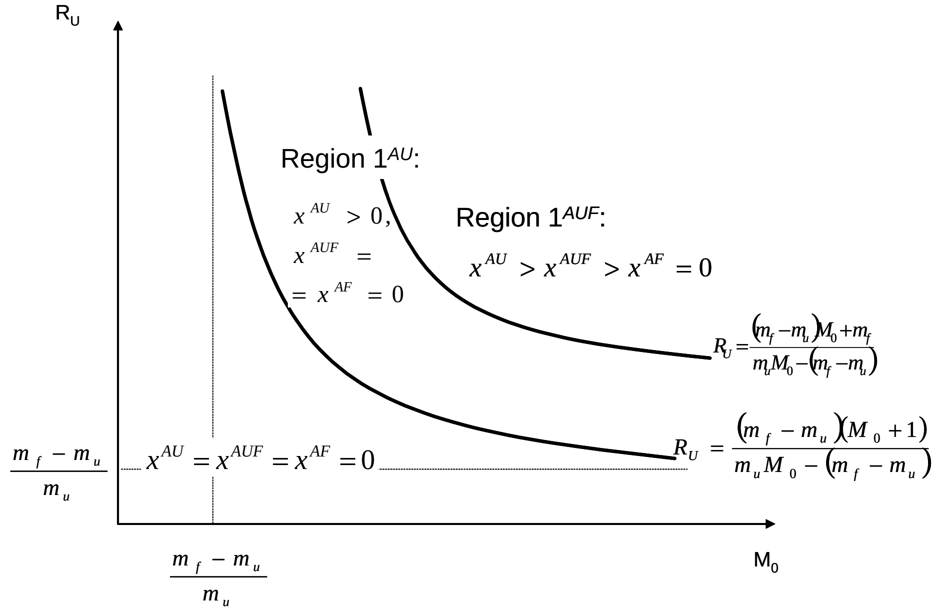

Figure 2.3: Consortium's optimal project with e_u non-verifiable (AU), with e_f non-verifiable (AF), and with both e_u and e_f non-verifiable (AUF).

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 2.4 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}.

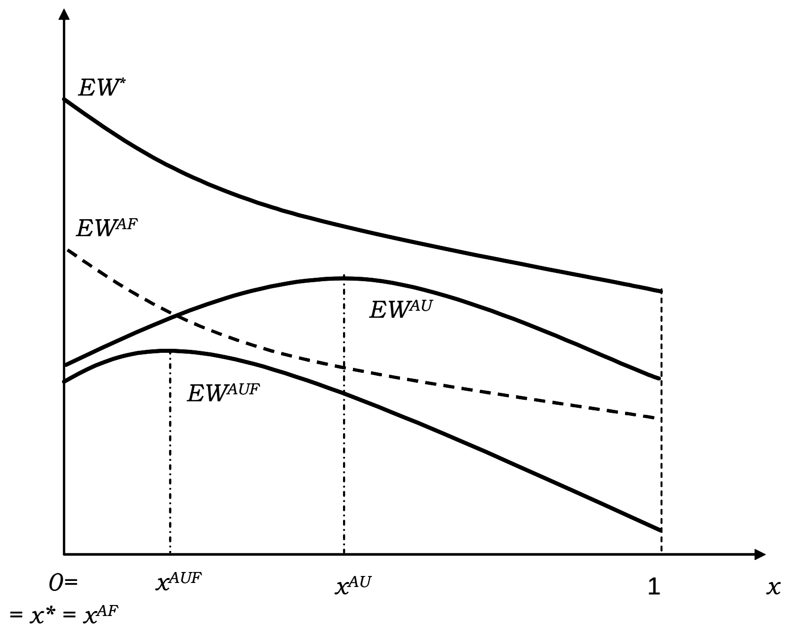

Figure 2.4: Optimal joint expected gain under first-best (EW^*), moral hazard from one of the partners (Firm, EW^{AF}; University, EW^{AU}), and double moral-hazard (EW^{AUF}).

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

Corollary 2.3.2 *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 2.3.3 *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 2.5 presents the proposition, in Region 1^{AUT}.

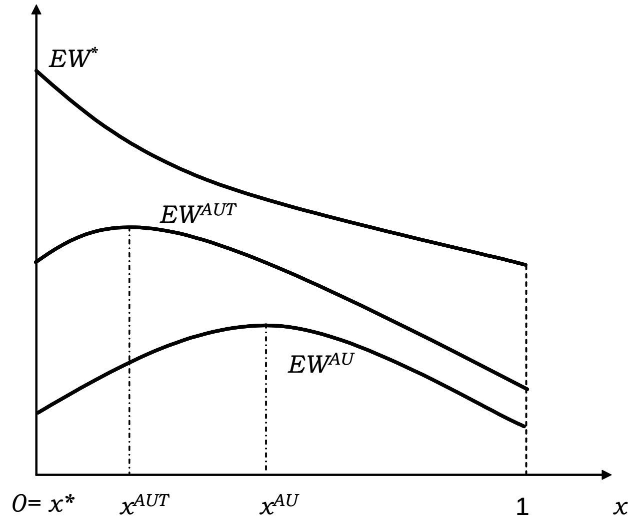

Figure 2.5: Joint expected gain in the first-best (EW^*), and under University's moral-hazard (with transfer, EW^{AUT}; without transfer, EW^{AU}).

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 $x^{AU} > 0$.[8]

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 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.

[8] Figure 2.9, in the Appendix Two, represents these two regions.

2.3.2 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.[9]

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 1P_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 2P_U: otherwise.

Proposition 2.3.4 *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* 1P_U*, the Firm proposes its most preferred project* $x = 0$*. In Region* 2P_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 1P_U. There, the damage that an applied project causes to the University is completely compensated by the increase in the probability of success when collaborating with the Firm.[10]

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:

[9] 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.

[10] As stated in the *Model* section, in this chapter the focus is on the role of incentives for the outcome of collaboration. As Proposition 2.3.4 shows, however, participation constraints can also affect the outcome of collaboration. Future work may enlarge this discussion.

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 2.3.5 *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.

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 $R_F > \frac{m_u S_1}{m_f S_1 - m_u}$;

Region 2^{UG}: otherwise.

Proposition 2.3.6 *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.

2.3.3 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 2.3.3 *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 2.6 below presents this corollary as well as the expected joint gain for the different scenarios, considering parameters in Region 1^{FG}.

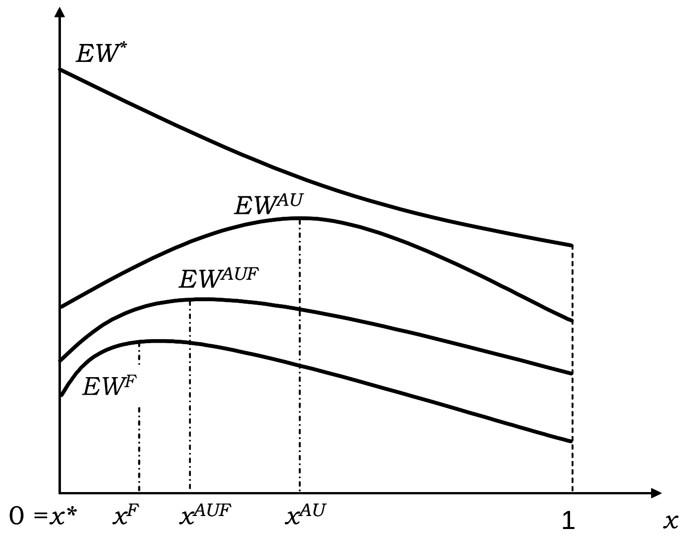

Figure 2.6: Joint expected gain under Consortium (EW^*, EW^{AU}, EW^{AUF}), and under Firm's governance with non-verifiable e_u (EW^F).

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.

2.4 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.[11] In the case of a research project, these benefits can be several. In the framework of the present chapter, 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 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 (2.2.3), (2.2.1), (2.2.2), (2.2.4), and (2.2.5), 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

[11] 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).

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:

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

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

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

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, λ, 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 2.4.1 *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.*[12]

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,

[12] In Appendix Two, the proof of the proposition makes explicit the upper boundary of λ compatible with the prize of each partner.

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.

2.5 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:[13]

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:

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

[13] 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:

$$e_i^* \quad : \quad \frac{\partial p}{\partial e_i}(e_f, e_u)\left[V_F(x) + V_U(x)\right] = \frac{\partial C_i}{\partial e_i}(e_f, e_u) + \frac{\partial C_j}{\partial e_i}(e_f, e_u), \tag{2.5.1}$$

$$x^* \quad : \quad p(e_f, e_u)\left[\frac{\partial V_F}{\partial x} + \frac{\partial V_U}{\partial x}\right] = 0, \tag{2.5.2}$$

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 (2.5.2) 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:

$$\begin{aligned} e_j^{Ai} \quad &: \quad \frac{\partial p}{\partial e_j}(e_f, e_u)\left[V_F(x) + V_U(x)\right] + \frac{\partial p}{\partial e_i}\frac{\partial e_i}{\partial e_j}(e_f, e_u)\, V_j(x) \\ &= \quad \frac{\partial C_j}{\partial e_j}(e_f, e_u) + \frac{\partial C_i}{\partial e_j}(e_f, e_u), \end{aligned} \tag{2.5.3}$$

$$x^{Ai} \quad : \quad p(e_f, e_u)\left[\frac{\partial V_F}{\partial x} + \frac{\partial V_U}{\partial x}\right] + \frac{\partial p}{\partial e_i}\frac{\partial e_i}{\partial x}(e_f, e_u)\, V_j(x) = 0. \tag{2.5.4}$$

Comparing (2.5.3) and (2.5.4) with the previous (2.5.1) and (2.5.2), 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 2.5.1 *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:

$$\begin{aligned} e_j^{jG} &: \frac{\partial p}{\partial e_j}(e_f, e_u) V_j(x) + \frac{\partial p}{\partial e_i}\frac{\partial e_i}{\partial e_j}(e_f, e_u) V_j(x) \\ &= \frac{\partial C_j}{\partial e_j}(e_f, e_u), \quad (2.5.5) \\ x^{jG} &: p(e_f, e_u)\frac{\partial V_j}{\partial x} + \frac{\partial p}{\partial e_i}\frac{\partial e_i}{\partial x}(e_f, e_u) V_j(x) = 0. \quad (2.5.6) \end{aligned}$$

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 2.5.2 *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.*

2.6 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. My results 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 2.3.3: 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).

2.6.1 Managerial Implications

The results of this chapter 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 and, in particular, there was no exact goal that the university should fulfill. In this scenario, 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).

2.6.2 Policy Implications

From the policy point of view, my analysis delivers some implications discussed below.

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.

2.7 Conclusion

This chapter 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 the effort of the partners, 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 chapter 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 chapter 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.

2.8 Appendix Two

Proof of Proposition 2.3.1. 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:

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

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:

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

■

Proof of Corollary 2.3.1.

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
$$\frac{\partial EW^*(0)}{\partial \kappa} = [k(c_f + c_u) - c_f]\frac{(B_f + B_u - m_u)^2}{c_f c_u},$$
$$\text{which is positive when } k > \frac{c_f}{c_f + c_u};$$
$$\frac{\partial EW^*(0)}{\partial c_f} = -\frac{k^2}{2c_f^2}(B_f + B_u - m_u) < 0;$$
$$\frac{\partial EW^*(0)}{\partial c_u} = -\frac{(1-k)^2}{2c_u^2}(B_f + B_u - m_u) < 0;$$
$$\frac{\partial EW^*(0)}{\partial B_f} = \frac{\partial W^*(0)}{\partial B_u} = \frac{1}{2}\left[\frac{k^2}{c_f} + \frac{(1-k)^2}{c_u}\right] > 0;$$
$$\frac{\partial EW^*(0)}{\partial m_u} = -\frac{1}{2}\left[\frac{k^2}{c_f} + \frac{(1-k)^2}{c_u}\right] < 0.$$

■

Proof of Proposition 2.3.2. 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 Consor-

tium maximizes the total collaboration gain by choosing:

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

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

Figure 2.7 represents the situation.

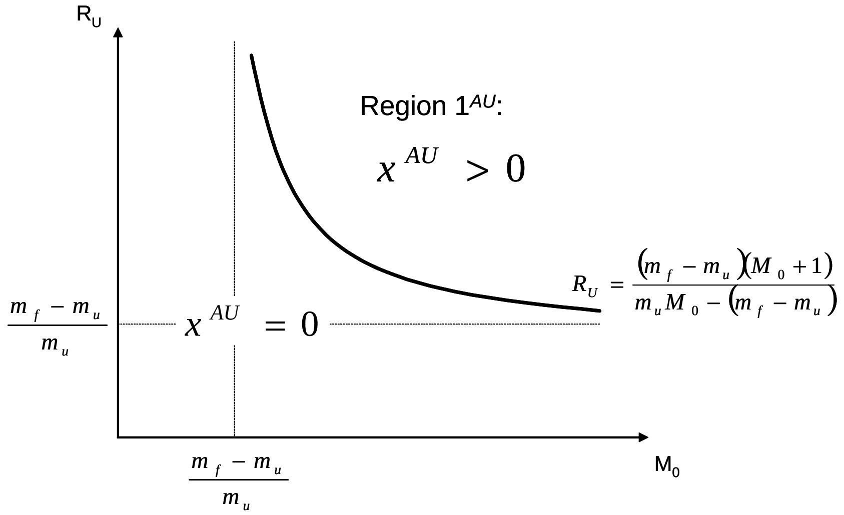

Figure 2.7: Consortium's optimal project when e_U is non-verifiable, x^{AU}.

When $R_U < \frac{\left(m_f-m_u\right)\left(B_f+B_u-m_u\right)}{m_u\left(B_f-m_f\right)-\left(m_f-m_u\right)B_u}$, 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 $R_U > \frac{m_f\left(2m_u - m_f\right)}{\left(m_f - m_u\right)^2}$, 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,

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

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

2. if $m_f < 2m_u$ and $R_U < \frac{m_f\left(2m_u - m_f\right)}{\left(m_f - m_u\right)^2}$, EW^{AF} is concave on x. The type of project that maximizes EW^{AF} is then $x = \frac{c_u k^2\left[\left(m_f - m_u\right)B_f + m_f\left(B_u - m_u\right)\right] + c_f (1-k)^2\left(m_f - m_u\right)\left(B_f + B_u - m_u\right)}{c_f (1-k)^2\left(m_f - m_u\right)^2 - c_u k^2 m_f\left(2m_u - m_f\right)}$, 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

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

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 $E\Pi_U^{AF} > \frac{(1-k)^2 B_u}{2c_u} \Leftrightarrow R_U < \frac{2\left(B_u - m_u\right)}{m_u\left(2B_u - m_u\right)}$.

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 $R_U > \frac{m_f\left(m_f - 2m_u\right)}{m_u\left(2m_f - m_u\right)}$. In this range of parameters, the Consortium selects

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

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 2.8 presents this result.

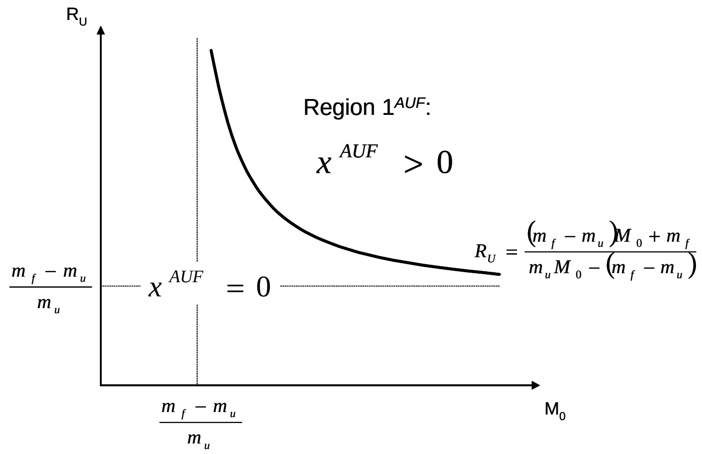

Figure 2.8: Consortium optimal with double moral-hazard.

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

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

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

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

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

■

Proof of Corollary 2.3.2. From the Consortium best choice when only University's effort is non-verifiable, the optimal project for Region 1^{AU} is:

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

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

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

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

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

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

- x^{AU} is increasing in m_u,

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

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

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

■

Proof of Proposition 2.3.3. 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:

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

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

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

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

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

The expected gain to the Firm is then

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

The Firm is willing to collaborate when $E\Pi_F^{AUT}$ is at least equal to $\frac{k^2 B_f}{2c_f}$.
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 $R_U > \frac{(m_f - m_u)(B_f + B_u - m_u)}{[m_u - m_f(2-t_f)t_f]B_f - (m_f - m_u)(B_u - m_u)} \iff R_U > \frac{(m_f - m_u)(M_0 + 1)}{[m_u - m_f(2-t_f)t_f]M_0 - (m_f - m_u)}$ and $B_f > \frac{(m_f - m_u)(B_u - m_u)}{m_u - m_f(2-t_f)t_f} \iff M_0 > \frac{m_f - m_u}{m_u - m_f(2-t_f)t_f}$. 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

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

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

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

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 2.9 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}.

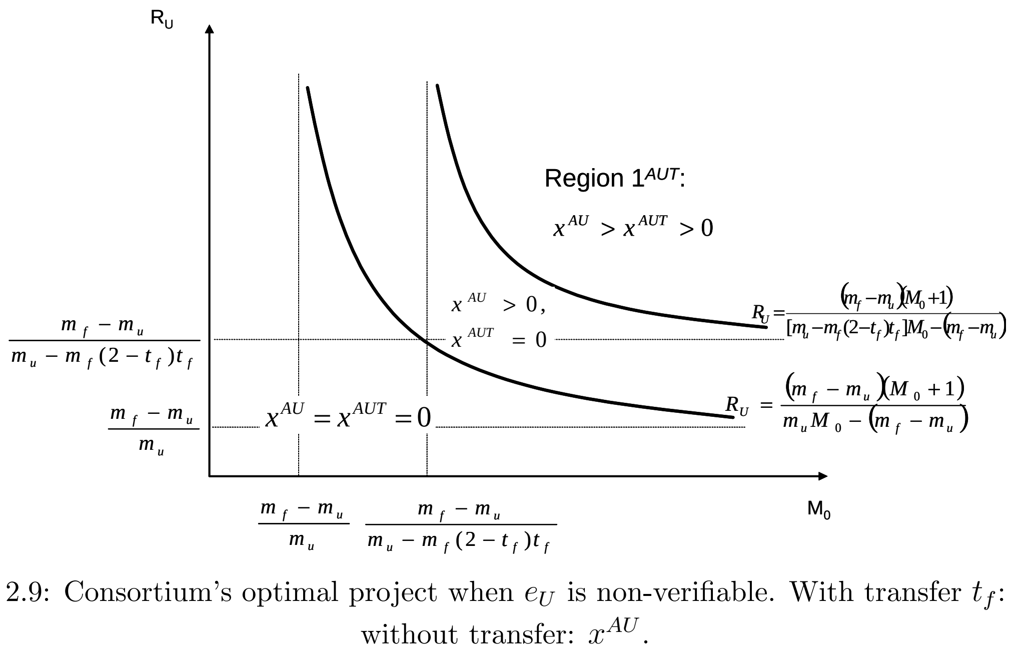

Figure 2.9: Consortium's optimal project when e_U is non-verifiable. With transfer t_f: x^{AUT}, without transfer: x^{AU}.

■

Proof of Proposition 2.3.4. 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:

$$e_f = \frac{k}{c_f}\left(V_F + \gamma_1 V_U\right), \tag{2.8.1}$$

$$e_u = \frac{1-k}{c_u}\left(V_F + \gamma_1 V_U\right), \tag{2.8.2}$$

$$[ke_f + (1-k)\,e_u]\,(\gamma_1 m_u - m_f) = \gamma_3 - \gamma_2, \tag{2.8.3}$$

$$\gamma_1 = 0 \text{ or } E\Pi_U = \frac{(1-k)^2 B_u^2}{2c_u}, \tag{2.8.4}$$

$$\gamma_2 = 0 \text{ or } x = 0, \tag{2.8.5}$$

$$\gamma_3 = 0 \text{ or } x = 1, \tag{2.8.6}$$

$$\gamma_i > 0,\ i = 1, 2, 3. \tag{2.8.7}$$

where γ_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 (2.8.5) and (2.8.6), $\gamma_2 = \gamma_3 = 0$. Replacing in (2.8.3), it comes $\gamma_1 = \frac{m_f}{m_u} > 0$. Conditions (2.8.1) and (2.8.2) then state the optimal value for the efforts levels:

$$e_f = \frac{k}{c_f}\left(B_f - m_f + \frac{m_f}{m_u}B_u\right),$$

$$e_u = \frac{1-k}{c_u}\left(B_f\frac{m_u}{m_f} + B_u - m_u\right).$$

By condition (2.8.4): $\gamma_1 > 0$, 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:

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

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 (2.8.6): $\gamma_3 = 0$. Replacing in condition (2.8.3), it comes

$$[ke_f + (1-k) e_u] (\gamma_1 m_u - m_f) = -\gamma_2. \qquad (2.8.8)$$

Two alternatives then appear:

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

In this alternative, by condition (2.8.4), $\gamma_1 = 0$. But then, (2.8.2) 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 2.3.5. 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 2.3.6. 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 $\frac{m_u B_u}{m_f B_u - m_u (B_f - m_f)} > \frac{m_u}{2m_f}$, the condition $R_F > \frac{m_u B_u}{m_f B_u - m_u (B_f - m_f)}$ is sufficient to ensure concavity.

■

Proof of Corollary 2.3.3. From Proposition 2.3.2, $0 < x^{AUF} < x^{AU}$ in Region 1^{AUF}. Since Region $1^{FG} \subset$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

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

■

Proof of Proposition 2.4.1. 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

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

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

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

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

where $D = m_u\left(\alpha z + B_f\right) + m_f\left[(1-\alpha)\, z + B_u - m_u\right] > 0$, 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

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

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

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

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 α 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 α. The solution for α 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:

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

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

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

At the last stage, the Firm's problem

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

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

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

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

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

From the first-order condition for z,

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

The first-order condition to have an interior solution of α that maximizes ES is

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

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

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

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

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

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

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

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

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

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

where

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

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

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

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:

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

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

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

When $M_0 > \frac{m_f}{m_u} - 1$ and $R_U > \frac{\left(m_f - m_u\right) M_0 + m_f}{m_u M_0 - \left(m_f - m_u\right)}$, 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

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

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

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

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

where $J = -(1-\alpha) m_f - \alpha m_u + \frac{1}{R_U} [(1 + \alpha + 2\lambda) m_f - \alpha m_u] +$
$+ R_U [(2 - \alpha + 2\lambda) m_u - (1-\alpha) m_f]$. 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,

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

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

Since the second derivative of ES with respect to α 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 α. As a consequence, the optimal value for α must be at one of the corners, $\alpha = 0$ or $\alpha = 1$.

The best social choice with respect to z and α 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 α, the expected social gain from collaboration is

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

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 α, the expected social gain from collaboration is

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

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

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

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

$$R_U\left[1 - \frac{m_u}{m_f}(1+2\lambda)\right] + 1 + \frac{m_u}{m_f} > \frac{1}{R_U}\left(1 + 2\lambda - \frac{m_u}{m_f}\right) \tag{2.8.9}$$

and

$$R_U\left[1 - \frac{m_u}{m_f}(1+\lambda)\right] + 1 > \frac{1}{R_U}\lambda, \tag{2.8.10}$$

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

$$R_U\left[1 - 2\frac{m_u}{m_f}(1+\lambda)\right] + 1 < \frac{1}{R_U}(1+2\lambda). \tag{2.8.11}$$

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

$$R_F\left[(1+2\lambda)\frac{m_f}{m_u} - 1\right] + \frac{1}{R_F}\left(1 + 2\lambda - \frac{m_f}{m_u}\right) > 1 + \frac{m_f}{m_u} \tag{2.8.12}$$

and

$$R_F\left[2(1+\lambda)\frac{m_f}{m_u} - 1\right] + \frac{1}{R_F}(1+2\lambda) > 1, \tag{2.8.13}$$

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

$$R_F\left[(1+\lambda)\frac{m_f}{m_u} - 1\right] + \frac{1}{R_F}\lambda < 1. \tag{2.8.14}$$

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 2.5.1. Comparing conditions (2.5.4) and (2.5.2), 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 (2.5.3) and (2.5.1), 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 2.5.2. Comparing conditions (2.5.6) to (2.5.2), 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 (2.5.6) and (2.5.4), 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. ■

Chapter 3

Patents and Business-Science Research Partnerships

This chapter is a joint work with Walter Garcia-Fontes (UPF, CREA).

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3.1 Introduction

The aim of this chapter is to look for empirical evidence on how a successful outcome of a research project, a patentable *invention*, is affected by the characteristics of the research leading to that invention. Using patents as proxies for inventions, and an European dataset of patents and inventors, PatVal-EU, we try to infer whether the institutional differences of the research organizations behind the inventions translate into different levels of *basicness* for the patents.

We consider two main institutional settings with which research organizations identify themselves: Academia and Corporate. As previous literature emphasizes (e.g., Dasgupta & David, 1994), one main difference between these two institutions is the purpose they pursue when a research project is undertaken. Academic organizations aim for discoveries that advance the existent stock of knowledge. Corporate organizations are more interested in profitable solutions for practical problems. Following OECD (2002), we identify the experimental and theoretical work developed with the former goal as *basic research*, while the later purpose defines *applied research*.

The analysis of the current chapter relies on one output of research, patented inventions, from which both Academic and Corporate organizations can benefit. Given the institutional differences indicated above, we expect divergences on the research project that each type of organization prefers. We then search whether empirical evidences at the level of patented inventions emphasize the institutional setting behind, and how they change under a partnership. We then focus on one main feature of patents: their *basicness*, how close they are to the Academic setting, and in the particular case of this chapter, how close they are to the main scientific research goal. To provide a proxy for this feature, we construct a composite index.[1] We then weight this index by an indicator of the *quality* of the patents. As argued in the literature (e.g., Trajtenberg *et al.*, 1990), to give a higher weight to higher *quality* patents is a way of favoring more *meaningful* inventions in the analysis, thus increasing the potential validity of the results.

Our conceptual framework builds on the previous chapter of this dissertation, where the type of research project is seen as the outcome of an optimal contract between the parties involved in the process of research.[2] In practice, this means we anticipate that Academic inventors produce more *basic* patents than Corporate inventors, and a co-invention between both types of inventors is associated with an intermediate basicness. This change in the degree of basicness of the research is interpreted as an optimal decision to guarantee, first, that both parties are interested in participating in the common project, and second that they allocate a higher level of resources (effort) to the common endeavor. If one of the parties is significantly important for the success of the research, and if success is sufficiently important for the other party, we then expect that the type of the project comes closer to the preferences of the first party.

The verifiability (hence contractibility) of resources is the basis for the incentives argument of choosing a type of research that is not the most preferred for the party that is governing the partnership. In our data, however, no information is available on the resources that each party actually allocates during the process of research. For that reason, in this chapter, we do not discuss the question of incentives in terms of *verifiability.* Instead, we relate it to the capacity of the parties to commit on the allocation of a certain level of resources. The higher the capacity of commitment, the smaller the problem of incentives. Furthermore, we conjecture that the level of interaction between the partners in research is one of the main arguments determining their capacity of commitment. The higher the interaction, the higher the possibility to monitor and account for the efforts involved in the project, as well as the better the chance that partners know each other in order to develop enforcement mechanisms for planed investments. Under this conjecture, a higher interaction between partners is associated with a higher capacity of commitment and, hence, in a type of research project that is closer to the interests of the main-inventing organization. In practice, we consider the information available in the survey on the importance of interactions between the main-inventor and people from outside his (her) employer organization, as a proxy for the interaction between partners in research. We then check whether important interactions are associated with differences in the patterns of basicness.

Despite the large heterogeneity that our empirical analysis seems to capture, our re-

[1] In the patent literature, the construction of composite indexes for variables that are not directly measurable is frequently used (e.g., Lanjouw & Schankerman, 1999; Lechevalier *et al.*, 2006).

[2] In the previous chapter, Academia and Corporate are represented by a University and a Firm, respectively.

sults generally confirm our initial expectations. A pretty standard pattern is confirmed empirically: patents invented by Academia do seem to be more basic than those arising from Corporate. More interestingly, in case of a partnership, the identity of the organization employing the main-inventor is important. When a Corporate main-inventor has an Academic co-inventor, patents show a basicness index that is smaller than when the main-inventor is Academic, but higher than when all inventors are Corporate. For the reverse situation where Academic main-inventors have Corporate co-inventors, however, it is not always possible to detect significative differences in the basicness, comparing with the situation where all inventors are Academic. Despite not being exactly our prior expectation, this last fact does not contradict the theoretical results in which we build our analysis.

Our empirical results are also consistent with the initial predictions on the impact of interactions between main-inventors and people outside their employer organizations. This finding is the main contribution of this chapter. The effect of interactions is more visible for Corporate main-inventors with Academic co-inventors, than when the roles are reversed. Nevertheless, in both situations it is possible to detect that a higher interaction is associated with a change in the basicness of the patents, towards the level of basicness that exists when there is no partnership with a different type of organization. This result and its interpretation are new to the literature, as far as we know.

In the next section we present a small literature review of related papers. In Section 3.3 we resume the theoretical framework of our analysis. Section 3.4 describes the methodology that we use, sources of data and variables. Section 3.5 presents the empirical analysis. In Section 3.6 we conclude.

3.2 Literature Review

Following the classification presented by Basberg (1987), our chapter belongs to the literature that uses patents as indicators of technological changes to analyze the process and output of the research activity.[3] In this literature, our work relates with four main branches.

The first of these branches of the literature relates with measures of quality of the patents, and with their determinants (Meyer & Tang, 2007, offers a review of these works). The list of indicators of quality as well as determinants of quality is quite extensive. In both sets of information (but not simultaneously) it is possible to find characteristics of the patents, such as: number of citations, family size, number of claims, technological scope, whether the patent was ever opposed or litigated. In the current chapter, and after some exploratory analysis, we include some of these features as determinants of the quality of

[3]This literature (e.g., Basberg, 1987; Trajtenberg *et al.*, 1997) also recognizes the existence of some limitations on considering patents as indicators of technological changes. Neither all inventions are patented (they may be non–patentable or, strategically, they may be kept in secret), nor all patents contain truly innovations. We try to reduce the effect of the later fact by using a quality weight of for basicness index. The former fact makes us more careful in the interpretation of the results.

the patents. Up to now, among this literature on quality (or value) of the patents, there are two papers, Mariani & Romanelli (2006) and Gambardella *et al.* (2006), that use the same survey as we do, PatVal, but for the initial sample of 6 countries. The first of these works measures quality through the number of citations received and a constructed composite index. Our indicator of quality is closer to the approach in the second of these papers, which uses information directly asked in the survey, and related with the value of the patent. Our quality indicator includes more information from the survey than this previous work, but the aim of our chapter is different, as we are not directly interested in the factors affecting the quality of the patents.

A smaller, and second, branch of the literature deals with measuring the basicness of the patented inventions. Although there is a common agreement on the conceptual idea that *basicness* relates with the closeness to the scientific institutional setting, in practice different papers focus on different indicators. The first of these works, Trajtenberg *et al.* (1997) associates basicness with features of quality (as *importance, time* and *technological distances*), or novelty (*backward importance, originality*), and importance of scientific sources of knowledge. To find a link between these features and basicness, they assume that universities produce more basic patents than firms, and then look for the characteristics of the patents that better discriminate among these two institutions. The reasoning in our chapter is the opposite, we search for a set of characteristics that is reasonably linked with the concept of basicness, and we use it to evaluate inventions patented by different institutions. A more recent paper also deals with the concept of basicness, Calderini *et al.* (2007). Nevertheless, it refers to the basicness of publications, and uses it as a determinant for patenting.

Our chapter gives special relevance to the institutional dimension of research leading to the invention. Before us, some other authors have already studied institutional differences in patenting, e.g., Jaffe & Trajtenberg (1996), Rosell & Agrawal (2005), Sapsalis *et al.* (2006). Despite this common feature, these previous works focus on the institutional impact on the *quality* of patents, while we are interested in the impact on their *basicness*.

A fourth, and last, branch of the patent literature related to this chapter is the one studying cooperation between industry and science, e.g., Cassiman *et al.* (2007), Lechevalier *et al.* (2006). Again, our focus is different from this previous literature. While they study the impact that cooperation links have on the *quality* of the resulting patents, we are more interested in their *basicness*, and particularly in the effects of different types of partnership on *basicness*.

3.3 Theoretical Framework

In the present chapter, we try to infer how the characteristics of the invention reflect these two dimensions of the research leading to that invention: the institutional dimension, and the process of research (itself).

From the institutional perspective, we can identify two main settings involved in research activities: one directed mainly to augment the current stock of knowledge, and another oriented to research with the goal of obtaining concrete answers to practical questions. Let us call *Academia* the first setting, and *Corporate* the second. Following what is common in the literature (OECD, 2002), we define the activities of research linked with the first goal (advancement of knowledge) as *basic research*, and the ones linked with the second goal (achievement of answers to practical questions) as *applied research*.

For the sake of simplicity, in this theoretical exposition, we refer to one university (the University), and to one firm (the Firm), as representative members of each institutional setting, Academia and Corporate, respectively. Both organizations, University and Firm, may develop research projects. Since research projects can have both basic and applied features, we identify a project by x, where x denotes the importance of the basic research component in that project, that is, its degree of *basicness*.

A research project can end either in a successful outcome or in a failure. In the case of a success, the project ends in a discovery, yielding a revenue V_i for organization i ($i = U, F$), when i is involved in the research leading to that discovery. Given the goals that each party has for research, the type of project affects the revenues, $V_U(x)$ and $V_F(x)$. Following a normalization procedure similar to the one developed in the previous chapter, we consider $x \in [0, 1]$, $V_U(x)$ increasing in x, and $V_F(x)$ decreasing in x.[4]

In the case of ending in a failure, the project brings no value to any of the parties. With probability $p \in (0, 1)$ there is a successful outcome, where p depends positively on the effort e_i that party i exerts during the research process, such that $\frac{\partial p}{\partial e_i} > 0$, $\frac{\partial^2 p}{\partial e_i^2} \leq 0$. From exerting an effort, party i bears a cost $C_i(e_i)$, where we assume $\frac{\partial C_i}{\partial e_i} \leq 0$, $\frac{\partial^2 C_i}{\partial e_i^2} \geq 0$, and C_i does not depend on e_j. Three alternative cases are then possible:

1. complementarity of efforts in the probability of success, $\frac{\partial^2 p}{\partial e_i \partial e_j} > 0$;
2. substitutability of efforts, $\frac{\partial^2 p}{\partial e_i \partial e_j} < 0$;
3. independence of efforts, $\frac{\partial^2 p}{\partial e_i \partial e_j} = 0$.

As far as the research process is concerned, we may consider two alternative situations: the research is conducted under a partnership of the two organizations, or each one conducts it individually and separately.

[4] The theoretical model in this section follows closely the analysis in the previous chapter of this dissertation. We consider that a successful project ends in a discovery, which yields different (and independent) payoffs for the two organizations. Nevertheless, here, we introduce some additional simplifications. We just analyze one successful outcome of research (patented invention), from which both University and Firm benefit.

In case of individual research, and for simplicity, we assume that there is no interaction between the two organizations, neither at the level of the research process (itself), nor at the level of the outcomes. Under this scenario, party i chooses the amount of effort e_i, and the type of project x to develop, solving the following problem:

$$\begin{aligned} \max_{\{x,e_i\}} E\Pi_i(e_i,x) &= p(e_i)V_i(x) - C_i(e_i) \\ s.t.\ E\Pi_i &\geq \bar{u}_i, \end{aligned} \tag{3.3.1}$$

where $\bar{u}_i$ is the (general) payoff of i in its outside option to research. Let $e^*_{i,alone}$ and $x^*_{i,alone}$ be the optimal solutions to this problem.

In the alternative case of a partnership, the effort of both parties contributes to the success of the project, and the expected gain of i comes:

$$E\Pi_i(e_f,e_u,x) = p(e_f,e_u)V_i(x) - C_i(e_i). \tag{3.3.2}$$

Comparing (3.3.2) with the objective function in (3.3.1), it is clear that the decision of having a partner in research allows i to benefit from the effort of its partner j (higher probability of success, for the same e_i), but the type of project x may not be the same. In fact, given that the two organizations have different goals for research, the choice of x becomes a source of problems in the partnership. For the sake of simplicity, suppose that party i promotes the relationship. Denote this situation by *decentralized structure of governance from party i*.[5] In this context, party i chooses e_i as well as the project to be jointly developed, and presents it to the other party. For simplification, we assume that e_i is always verifiable. Regarding the effort of the other party, e_j, two (extreme) scenarios are possible: either it is verifiable (hence contractible), or it is non-verifiable (hence non-contractible).

When e_j is verifiable, i's decision is given by:

$$\begin{aligned} &\max_{\{x,e_f,e_u\}} E\Pi_i(e_f,e_u,x) \\ &s.t. \begin{cases} E\Pi_i(e_f,e_u,x) \geq \bar{u}_i, \\ E\Pi_j(e_f,e_u,x) \geq \bar{u}_j, \end{cases} \\ i &\neq j;\ \ i,j = F,U, \end{aligned} \tag{3.3.3}$$

where $\bar{u}_j$ is the (general) payoff of j in its outside option. Let $e^*_{f,i+j}$, $e^*_{u,i+j}$, and x^*_{i+j} be the optimal solutions to this problem. Under a partnership situation as in (3.3.3), it can be shown that party j earns as much as in its outside option, $\bar{u}_j$. Furthermore, $e^*_{i,i+j}$ and x^*_{i+j} are not necessary equal to $e^*_{i,alone}$ and $x^*_{i,alone}$, respectively. When the contribution of

[5] This situation is one of the possibles structures of governance analyzed in the previous Chapter 2. As shown there, the qualitative results here described can be extended for different structures of governance.

e_j to the success of the project is relatively high, to secure that j is willing to participate in the partnership, party i may choose a project closer to the preferences of j, rather than $x^*_{i,alone}$ ($i's$ most preferred project).[6] Another tool that i has available to guarantee the participation of j (for a certain level of e_j) is the level of effort e_i. It is then possible to check that: $e^*_{i,i+j} > e^*_{i,alone}$, when e_i and e_j are complementary; $e^*_{i,i+j} < e^*_{i,alone}$, when e_i and e_j are substitute; and $e^*_{i,i+j} = e^*_{i,alone}$, when e_i and e_j are independent.

When e_j is non-verifiable ($j's$ moral-hazard), i's decision is given by:

$$\begin{aligned} &\max_{\{x,e_i\}} E\Pi_i(e_f, e_u, x) \\ &s.t. \begin{cases} E\Pi_i(e_f, e_u, x) \geq \bar{u}_i, \\ E\Pi_j(e_f, e_u, x) \geq \bar{u}_j, \\ e_j : \arg\max_{\{e'_j\}} E\Pi_j(e_i, e'_j, x), \end{cases} \\ i &\neq j; \quad i, j = F, U. \end{aligned} \tag{3.3.4}$$

Let $e^{Aj}_{i,i+j}$, $e^{Aj}_{j,i+j}$, and x^{Aj}_{i+j} be the optimal solution to this problem. On top of the participation constraint of j, the governing party i faces now an additional restriction: to give incentives for e_j. In this case, the distortions of e_i and x, in comparison with $e^*_{i,alone}$ and $x^*_{i,alone}$, respectively, are expected to be even higher than in problem (3.3.3). This happens when $j's$ contribution for the success of the project is sufficiently important, and a success brings a sufficiently high revenue to i.[7]

In other words, from the theoretical framework, we expect that when (say) a firm is governing a research partnership in which a university participates, the firm chooses a project less applied than it would individually choose. Moreover, this distortion is reinforced when the effort of the university is non-verifiable. If we consider a reverse situation where a university is governing a research partnership, and a firm participates on it, we expect a distortion of the type of project that the university would individually prefer, towards a less basic research project.

Up to now, we focused in two (extremes) scenarios of verifiability of e_j, yes or no. However, we also would like to analyze more intermediate (and realistic) situations. For such, instead of referring to verifiability of e_j, we shift the discussion to the *capacity* of party j *to commit* on a certain level of effort e_j. Furthermore, we believe that the capacity of commitment is positively related with the *interaction* of the partners during the research process. Denote by $\beta \in [0, 1]$ the degree of interaction between the partners, when developing a common project. Under a decentralized structure of governance, we expect that: as β approaches 1 (maximum interaction), the design of the relationship becomes closer to the formalization in problem (3.3.3), while as β decreases towards 0 (minimum interaction), the problem becomes similar to (3.3.4). Under a decentralized governance of i, suppose that e_j can be decomposed in two parts, one in which j can

[6]This result corresponds to Proposition 2.3.4.

[7]This result is shown in Propositions 2.3.5 and 2.3.6.

commit for the partnership, e_j^C, and another in which j cannot commit, e_j^{NC}. Since the capacity of commitment is assumed to be related with interaction of the partners: $e_j = \beta e_j^C + (1-\beta)\, e_j^{NC}$. With this formalization, the decisions in the partnership follow:

$$
\begin{aligned}
&\max_{\{x,e_i,e_j^C\}} E\Pi_i(e_i, e_j^C, e_j^{NC}, \beta, x) = p\left[e_i, \beta e_j^C, (1-\beta)\, e_j^{NC}\right] V_i(x) - C_i(e_i) \\
&s.t. \begin{cases} E\Pi_i(e_i, e_j^C, e_j^{NC}, \beta, x) \geq \bar{u}_i, \\ E\Pi_j(e_i, e_j^C, e_j^{NC}, \beta, x) \geq \bar{u}_j, \\ e_j^{NC} : \arg\max_{\{e_j'\}} E\Pi_j(e_i, e_j^C, e_j', \beta, x), \end{cases} \\
&i \neq j; \quad i, j = F, U. \qquad (3.3.5)
\end{aligned}
$$

In practical terms, this conjecture means that:

- when a firm undertakes a research project, if it does so in partnership with a university, we expect the outcome to be more basic than when it develops the research alone. The distortion towards a more basic research project is higher, the weaker the interaction between the partners;

- when a university undertakes a research project, a similar (and symmetric) outcome is expected: a more applied research than when university makes research alone, and the weaker the interaction, the more applied is the project.

3.4 Methodology

The aim of the present chapter is to clarify how the characteristics of an invention reflect the features of the research process leading to that invention.

In terms of characteristics of the invention, we are particularly interested in its *basicness*. For us, *basicness* means closeness to the main research goal of science (of Academia): to advance the existing stock of knowledge.

As far as the features of the research process are concerned, we focus in two dimensions: on the one hand, the institutional dimension, and on the other hand, the process of research itself. Regarding the institutional dimension of research, we distinguish between Academic and Corporate inventions. To identify them, we use information on the organization employing the main-inventor. We then link the inventor with the organization to which (s)he belongs, and we consider this pair (inventor, organization) as a unique entity, *invention organization*. Furthermore, if there are several inventors, but all belong to the same organization, it is also considered as a unique invention organization. Concerning the process of research, we focus on two aspects. First, whether the invention is the outcome of only one entity (one *invention organization*), or the outcome of several entities, several inventors belonging not to the same organization (we call this scenario *partnership*). Second, whether interactions between inventors (partners) during the research process were important or not to achieve the invention.

Table 3.1 summarizes the different aspects of our analysis.

Characteristics of Research:
Institutional
Academia
Corporate
Process of Research
Individual *vs* Partnership
Interaction: High *vs* Low
$\Longrightarrow$ Characteristics of Invention: Basicness

Table 3.1: Main aspects of the analysis.

As our theoretical framework predicts, we have three main hypotheses:

Hypothesis 1. Academic inventions are more basic than Corporate inventions;

Hypothesis 2. When Academic inventors have Corporate co-inventors, inventions are less basic than when no Corporate co-inventors exist. Conversely, when Corporate inventors have Academic co-inventors, inventions are more basic (less applied) than when no Academic co-inventors exist;

Hypothesis 3. Interaction between partners is negatively related with the effects described in *Hypothesis 2*, that is, the lower the interaction, the higher has to be the distortion of the invention towards the interests of the co-inventors.

We now describe how we try to validate these hypotheses, with the support of a patent dataset.

3.4.1 Data

Taking patents as indicators of inventions, the data used in this chapter corresponds to a Survey of Inventors collected through the PatVal-EU project (Contract HPV2-CT-2001-00013) funded by the European Commission.[8]

Originally the survey was directed to the inventors of 27,531 patents granted at the EPO with priority date in 1993-1997 located in France, Germany, Italy, the Netherlands, Spain and the United Kingdom. The targeted number of patents for which we expected the inventors to respond was 10,000. In the end the European inventors responded to 9,216 questionnaires covering 9,017 patents. The sample was complemented later by inventors from Denmark and Hungary. As a result, the sample we use here is composed by 10,157 patents granted by the EPO, and located in the 8 European countries we mention. After

[8] Up to now, several studies use the PatVal-EU survey database, namely: Patval-EU (2005), Giuri *et al.* (2005), Crespi *et al.* (2005), Gambardella *et al.* (2006a, 2006b), and Mariani & Romanelli (2006). Unless otherwise refer, these works focus in questions different from ours.

cleaning for patents where more than one inventor was interviewed, as well as dropping some cases where one of our key variables has missing values, we are left with a total sample of 9,224 patents with the following distribution by countries: Denmark (5.3%), France (15.9%), Germany (35.4%), Hungary (0.4%), Italy (13.3%), Netherlands (10.8%), Spain (2.7%), and UK (16.3%).[9]

Not all the information necessary for our analysis is, however, directly available in this dataset.[10] Thus, relying on the answers to this survey, we construct variables that can better measure the effects we aim to capture.

In our empirical setting, we take as exogenous the characteristics of the research leading to the patented inventions. Information related with these characteristics constitute our independent variables. Our aim is to analyze how these characteristics affect a particular feature of the patented inventions: its basicness. Our dependent variable then becomes a measure of *basicness* of *meaningful* patents, that is, an indicator of *basicness*, weighted by an indicator of *quality* of the patent.

Dependent Variable: Weighted Basicness

Basicness In order to measure *basicness*, we rely on information in the survey that can be more directly linked with the scientific goal of advancing the stock of knowledge.

The first of these indicators is the importance of different sources of knowledge for the research process. More basic patents have to use sources which have more basic research. Here we use three variables in Likert scales on the importance of different types of knowledge (from 0 to 5, where 0 means not used at all, and 5 very important source), namely:

- $SOURCE1$, importance of university laboratories and faculty as sources of knowledge for the research that led to the patented invention;

- $SOURCE2$, importance of non-university public laboratories as sources of knowledge for the research that led to the patented invention;

- $SOURCE3$, importance of scientific literature as source of knowledge for the research that led to the patented invention.

As Table 3.2 shows, most inventors do not use *Academic* sources of knowledge for research, except for scientific literature ($SOURCE3$) which is declared as fairly important by a significant number of inventors.

[9] When describing the variables, separately, we mention the total number of answers for each related question. Nevertheless, for the regression analysis, we use a total of 7,864 observations whose answers to all the relevant questions were not missing.

[10] PatVal-EU (2005) and Giuri *et al.* (2005) present more complete information on the PatVal-EU survey, but to the initial sample of 9,017 patents and 6 European countries.

Variables	Mean	Nr Observations	Standard Deviation	Min	Max
$SOURCE1$	1.19	8586	1.63	0	5
$SOURCE2$	0.81	8503	1.34	0	5
$SOURCE3$	2.64	8709	1.87	0	5

Table 3.2: Descriptive Statistics of Sources of Knowledge.

The second indicator for basicness is the highest academic degree of the main-inventor, at the time of the research. The higher the academic degree of the inventor, the more likely it is that (s)he is able to produce basic research. Therefore, we use the variable $DEGREE$ which has values from 1 to 4, where 1 corresponds to secondary school or lower (*lower secondary school*), 2 to high school diploma (*upper secondary school*), 3 to tertiary education (*university BA or university Master*), and 4 to PhD (*upper tertiary education*). Table 3.3 shows the descriptive statistics of this indicator.

Variable	Mean	Nr Observations	Standard Deviation	Min	Max
$DEGREE$	3.01	9071	0.76	1	4

Table 3.3: Descriptive Statistics of the Academic Degree of Main-Inventor.

The third, and last, indicator of basicness is the main financing source of the research. It is likely that basic research receives public funding. We then use the variable $FUNDS$, a dummy variable taking the value of 1 if the research process leading to the patent received public funds, and 0 otherwise.

The descriptive statistics of this indicator is presented below, in Table 3.4.

Variable	Mean	Nr Observations	Standard Deviation	Min	Max
$FUNDS$	0.09	8459	0.22	0	1

Table 3.4: Descriptive Statistics of Financing.

From the correlation matrix of these variables (please see Table 3.5 below), it is visible that these variables show significant but low correlation among themselves.

Variables	SOURCE1	SOURCE2	SOURCE3	DEGREE	FUNDS
SOURCE1	1.00				
SOURCE2	0.45^{**}	1.00			
SOURCE3	0.38^{**}	0.26^{**}	1.00		
DEGREE	0.27^{**}	0.14^{**}	0.33^{**}	1.00	
FUNDS	0.02^{*}	-0.01	0.06^{**}	0.06^{**}	1.00

Note: ** significant at the 5% level, * significant at the 10% level.

Table 3.5: Correlation Matrix of the indicators of basicness.

The three indicators related to the sources of knowledge, plus the academic degree indicator, show some co-movement, while the $FUNDS$ indicator seems to be capturing a fairly different feature. It is likely that each one is capturing different aspects related to the basicness of the patent, but within a large heterogeneity.

Given these indicators, and in order to use them for the construction of the basicness measure, one procedure that has been proposed in the literature (e.g., Lanjouw &

Schankerman, 1999) is a composite index. Here, we use the Cronbach Alpha (Cronbach, 1951), a simple approach that allows to create a composite index for the case of scale-type variables.

Cronbach Alpha is defined as

$$\alpha = \frac{K\bar{r}}{1 + (K-1)\bar{r}}, \tag{3.4.1}$$

where K is the number of indicators (in our case $K = 5$), and $\bar{r}$ is the average correlation defined over the correlations r_{ij} between the different indicators as follows

$$\bar{r} = \frac{\sum_{i=2}^{K}\sum_{j=1}^{i-1} n_{ij} r_{ij}}{\sum_{i=2}^{K}\sum_{j=1}^{i-1} n_{ij}}.$$

n_{ij} is the number of observations that is used in calculating correlation r_{ij}.

Table 3.6 shows the descriptive statistics of the index α, while Table 3.7 presents the correlation between our basicness measure α and the different individual indicators.

Variable	Mean	Nr Observations	Standard Deviation	Min	Max
α	-0.01	9571	0.67	-2.65	3.24

Table 3.6: Descriptive Statistics of Basicness composite index.

Variables	Correlation with α
$SOURCE1$	0.3940
$SOURCE2$	0.4759
$SOURCE3$	0.4220
$DEGREE$	0.4870
$FUNDS$	0.6398

Table 3.7: Correlation of indicators and the index α.

From a quantitative perspective, the index α does not have any interpretation, since it is just a composite scale that tries to maximize the correlation with the different variables that compose the index. α has, however, an ordinal interpretation, that we use to compare the *basicness* of different patents.

Quality To guarantee that patents are better proxies of inventions (*meaningful* patents), we need to weight our measure of basicness by a measure of the *quality* of the patents. To construct this measure, we make the average of two questions directly related with the value of the patents.

The first of these questions is $VALUE$, inventor's estimation of the economic and strategic value of the patent, in comparison with other patents in the same industry or technological field. The variable is equal to:

- 0.95, if the patent is in the top 10%,
- 0.825, if it is top 25% but not top 10%,

- 0.625, if it is top 50% but not top 25%,
- 0.25, if it is bottom 50%.

The final value of the variable is then normalized using the mean of the technological class of the patent. Technological classes are defined according to the ISI-INIPI-OST1 classification (30 classes).

The second question of the survey used to construct the measure of quality is $PATPR$, inventor's estimation for the minimum price (in Euros) that the applicant would ask to a potential competitor interested in buying the patent on the day it was granted, should the applicant have by then all the information on the value of the patent that is available when the survey is run. The variable is coded as:

- 0.015, if less than 30,000 €,
- 0.065, if between 30,000€ and 100,000€,
- 0.2, if between 100,000€ and 300,000€,
- 0.65, if between 300.000€ and 1 €million,
- 2, if between 1 €million and 3 €millions,
- 6.5, if between 3 €millions and 10 €millions,
- 20, if between 10 €millions and 30 €millions,
- 65, if between 30 €millions and 100 €millions,
- 200, if between 100 €millions and 300 €millions,
- 400, if more than 300.000 €millions.

Again the variable is normalized by the mean of the technological class of the patent. The descriptive statistics of these two variables are in Table 3.8 below.

Variables	Mean	Nr Observations	Standard Deviation	Min	Max
VALUE	1.00	8016	0.47	0.36	1.92
PATPR	1.00	8107	0.52	0.21	3.00

Table 3.8: Descriptive Statistics of Indicators of Quality.

We will use the average of these two variables, $AQuality$, whose descriptive statistics are given in Table 3.9.

Variable	Mean	Nr Observations	Standard Deviation	Min	Max
AQuality	0.99	7013	0.39	0.31	2.24

Table 3.9: Descriptive Statistics of Average Quality.

Our dependent variable, a continuous indicator of quality-weighted-basicness, is then defined as:

$$W\_Basicness = \alpha * AQuality, \quad (3.4.2)$$

whose description is presented in Table 3.10.

Variable	Mean	Nr Observations	Standard Deviation	Min	Max
W_Basicness	0.02	7013	0.69	-3.97	4.27

Table 3.10: Descriptive Statistics of Weighted index of Basicness.

Independent Variables

Institutions Given the hypotheses that we try to validate, our main variables relate with the institutional setting where the invention is developed. To capture this institutional setting, we use the information on the type of organization where the inventor(s) is (are) employed at the time of research leading to the patent. In doing this, we totally align the inventor's behavior with his employer organization. Hence, the most important unity of observation for us is the pair (patent, invention organization). To distinguish *individual* research from research in *partnership*, we use the information on the existence of co-inventors, and on their employer organizations.[11] When co-inventors are working for the same organization, we consider it as a single entity of invention organization.

The PatVal survey distinguishes between large firms, medium-sized firms, small firms, private research organizations, government research organizations, universities, other governmental organizations, and other type of organizations. For the purpose of our chapter, we consider two main groups of organizations: Academia and Corporate. We then define the following four dummy variables:

$ACADEMIA$**,** equal to one if the patent is produced within a university, or a government research organization, by one or more inventors (all inventors are in the same organization);[12]

$CORPORATE$**,** equal to one if the patent is produced within a firm, a hospital, a foundation, or a private research organization, by one or more inventors (all inventors are in the same organization);

[11] In empirical terms, a partnership situation is identified by the existence of a collective invention. We are aware that a *collective invention* is different from a *research collaboration.* However, due to data limitations, and with the belief that the distinction between the two concepts does not add much value to our analysis, we follow the literature (e.g. Lechevalier *et al.*, 2006; Cassiman *et al.*, 2007; Sapsalis & van Pottelsbergh, 2007) and consider a *collective invention* as an indicator of a *research collaboration.*

[12] The decision to aggregate government research organizations with universities in Academia has two main causes. First, we do not have much information on the entity of the organizations included in the sample as *government research organizations* and, as such, we follow the classification that is usual in the patent literature (e.g., Fontana *et al.*, 2006). Second, there is empirical evidence that the incentives schemes for researchers' careers in public institutions and in universities are similar, namely in terms of publications (e.g., Jaffe *et al.*, 1998).

$ACAD\_CORP$, equal to one if the patent is produced by (at least) two organizations, the main-inventor being in a university, or a government research organization, and with one (or more) co-inventor(s) in a firm, hospital, foundation, or private research organization;

$CORP\_ACAD$, equal to one if the patent is produced by (at least) two organizations, the main-inventor being in a firm, a hospital, a foundation, or a private research organization, and with one (or more) co-inventor(s) in a university, or a government research organization;

$ACAD\_ACAD$, equal to one if the patent is produced by (at least) two organizations, the main-inventor being in a university, or a government research organization, and with one (or more) co-inventor(s) in another university, or government research organization;

$CORP\_CORP$, equal to one if the patent is produced by (at least) two organizations, the main-inventor being in a firm, a hospital, a foundation, or a private research organization, and with one (or more) co-inventor(s) in another firm, hospital, foundation, or private research organization.

The descriptive statistics on the previous dummy variables are presented in Table 3.11.

Variables	Mean	Nr Observations	Standard Deviation	Min	Max
ACADEMIA	0.03	9176	0.18	0	1
CORPORATE	0.85	9176	0.36	0	1
ACAD_CORP	0.01	9176	0.12	0	1
CORP_ACAD	0.02	9176	0.14	0	1
ACAD_ACAD	0.01	9176	0.07	0	1
CORP_CORP	0.08	9176	0.27	0	1

Table 3.11: Descriptive Statistics of Institutions behind Inventions.

Most patents are produced by inventors employed by Corporate organizations, without co-inventors outside of the organization (85%), or with Corporate co-inventors (8%). 3% of the main-inventors work for Academic institutions and patent inventions alone, while 1% of Academic main-inventors have co-inventors in other Academic institutions. Patents arising from partnerships between Academia and Corporate represent 3% of our total sample (1% have Academic main-inventors and 2% have Corporate main-inventors).

In our empirical analysis we are including an additional type of partnership, which is not reflected in our theoretical framework, namely between organizations that are institutionally similar: $ACAD\_ACAD$, $CORP\_CORP$. For that reason, the empirical results may bring supplementary interesting information.

Interaction

We use a question in the survey that asks about the importance of interactions between the main-inventor and people outside his (her) employer organization (*outside interactions*), during the process of research. With this question, we construct the following dummy:

$INTERACTION$, equal to one if outside interactions were important for the research leading to the patent.

In the total sample, 41% of the inventors declare that outside interactions were important during the process of research, as shown in the descriptive statistics of Table 3.12.

Variable	Nr Observations	Mean	Standard Deviation	Min	Max
INTERACTION	9591	0.41	0.49	0	1

Table 3.12: Descriptive Statistics on Important Interactions between main-inventors and people outside his (her) organization.

A limitation of the information contained in this question of the survey (hence, in our dummy), is that interactions here asked are the ones between the main-inventor and other people outside main-inventor's employer organization, but apart from co-inventors. For our analysis, we then need some additional information on the answers to this question, specially on how it relates with the existence of co-inventors. Table 3.13 shows that cross tabulation.

	Existence of Co-inventors in...						
	same organization			different organization			
Interaction	nr patents	% Co-inventors	% Interaction	nr patents	% Co-inventors	% Interaction	Total
Yes	1404	34.1	69.1	627	54.3	30.9	2031
No	2713	65.9	83.7	528	45.7	16.3	3241
Total	4117	100	78	1155	100	22	5272

Table 3.13: Cross tabulation of Important Interactions Outside and Co-inventors.

As Table 3.13 shows, the existence of important interactions outside is more frequent, when there are co-inventors in an organization different from the one employing the main-inventor. In fact, when there are co-inventors in the same organization, only in 34.1% of the patents the outside interactions were important, while when there are co-inventors in a different organization, the frequency of important outside interactions increased to 54.3%. Despite the relation between these two questions is not one-to-one, the evidence that they are positively related allows us to cross them. We then consider our dummy $INTERACTION$ as a (rough) proxy for important interactions between the main-inventor and people in the partner organization, apart from co-inventors.

This dummy enables to obtain insights on the validity of our third theoretical hypothesis.

Other controls Our basicness measure relates not only to the basic or applied nature of the patent, but also to its quality. Therefore, it seems reasonable to control for other factors that may affect its quality. For that purpose, we use some of the factors that have been traditionally used in the literature:

$COURT$, equal to one if the patent was ever litigated in a court;

$MONETARY$, equal to one if the main-inventor receives personal monetary compensation expressly because of the production of the patent;

$CLAIMS$, number of claims in the patent;

$FAMILY$, family size of the patent, i.e., number of the set of patents filed with different patenting authorities that refer to the same invention.

Table 3.14 below shows the descriptive statistics for these control variables for the quality of the patent.

Variables	Mean	Nr Observations	Standard Deviation	Min	Max
COURT	0.04	7593	0.20	0	1
MONETARY	0.6	9591	0.49	0	1
CLAIMS	10.85	9055	6.98	1	131
FAMILY	6.98	9057	4.09	1	32

Table 3.14: Descriptive Statistics on control variables for quality of patents.

From Table 3.14 is visible that 4% of the patents were litigated ($COURT$), 60% of the inventors declare that they received monetary rewards related with patenting ($MONETARY$), the average number of claims of patens ($CLAIMS$) is 10.85 with a standard deviation of 6.98, the average family size is around 7 with a standard deviation of 4.09.

In the survey, there is information on whether there is formal collaboration agreements between the employer organization of the main-inventor and other partners, during the research process. From Tables 3.15a and 3.15b below, it is visible that this information may influence our dependent variable, in particular through *basicness* (rather than through *quality*).

With Formal Collaboration Agreements					
Variable	Mean	Nr Observations	Standard Deviation	Min	Max
α	0.2949	1735	0.7358	-1.4781	2.2962
Without Formal Collaboration Agreements					
Variable	Mean	Nr Observations	Standard Deviation	Min	Max
α	-0.0733	6925	0.6039	-2.6474	3.2391

Table 3.15a: Descriptive Statistics on the Composite Index of Basicness, α, crossed with Existence of Formal Collaboration.

The existence of formal collaboration agreements seems to be positively related with a higher basicness.

With Formal Collaboration Agreements					
Variable	Mean	Nr Observations	Standard Deviation	Min	Max
AQuality	1.0001	1356	0.3863	0.3108	2.2127
Without Formal Collaboration Agreements					
Variable	Mean	Nr Observations	Standard Deviation	Min	Max
AQuality	0.9873	5463	0.3866	0.0031	2.2406

Table 3.15b: Descriptive Statistics on the Average Quality of the patents crossed with Existence of Formal Collaboration.

The existence of formal collaboration agreements does not seem to cause much change in terms of the average quality of the patents.

As Tables 3.16a and 3.16b evidence, the existence of formal collaboration agreements adds information neither captured by the interaction of the main-inventors with outside people, nor by the inventing institutions.

	Formal Collaboration Agreements						
	Yes			No			
Interaction	nr patents	% Formal	% Interaction	nr patents	% No Formal	% Interaction	Total
Yes	1121	64.6	33.9	2181	31.5	66.1	3302
No	614	35.4	11.5	4745	68.5	88.5	5359
Total	1735	100	20.0	6926	100	80.0	8661

Table 3.16a: Cross tabulation of Important Outside Interactions and Existence of Formal Collaborations.

From Table 3.16a, the existence of formal collaboration agreements appears positively related with important outside interactions.

	Formal Collaboration Agreements				
	Yes		No		
Institution	nr patents	% Institution	nr patents	% Institution	Total
ACADEMIA	118	39.7	179	60.3	297
ACAD_ACAD	26	57.8	19	42.2	45
ACAD_CORP	92	72.4	35	27.6	127
CORPORATE	1050	14.3	6280	85.7	7330
CORP_CORP	315	45.4	377	54.5	692
CORP_ACAD	134	78.8	36	21.2	170
Total	1735	20.0	6926	80.0	8661

Table 3.16b: Cross tabulation of Existence of Formal Collaborations and Institutions.

From Table 3.16b, it is visible that the existence of formal collaboration agreements is higher when there are partnerships with organizations different from the one employing the main-inventor: in Academia, partnerships are associated with higher frequencies of formal collaboration (57.8% and 72.4%, depending whether co-inventors are from Academia or Corporate, respectively); and similarly for Corporate inventions under partnerships (formal collaborations present frequencies of 45.5% and 78.8%, depending on the co-inventon is with Corporate or Academia, respectively). Moreover, the highest frequency of formal collaboration agreements exist when partnership involve different types of institutions: 72.4% of the patents arising from ACAD_CORP register formal collaboration agreements; while for CORP_ACAD, 78.8% of the patents are associated with formal agreements. Nevertheless, it is interesting to notice that the existence of partnerships and formal collaborations are capturing different effects, since their relation is not 1-1.

Given the results from this descriptive analysis on the existence of formal collaboration agreements, we decide to include as a control in our analysis, the following dummy:

$FORMAL$**,** equal to one if there was a formal collaboration agreement (involving well defined contracts among parties) during the research leading to the patent, between the employer organization and other partner, 0 otherwise (informal or no collaboration agreement).

Table 3.17 shows the descriptive statistics of this dummy.

Variable	Nr Observations	Mean	Standard Deviation	Min	Max
FORMAL	8661	0.2	0.4	0	1

Table 3.17: Descriptive Statistics on the Existence of Formal Collaboration Agreements.

Finally, we also control for the country of the main-inventor and for the technological class of the patent.

The technological patent classification follows the ISI-INIPI-OST, based on the EPO IPC classes. ISI-INIPI-OST is a technology-oriented classification system jointly elaborated by the German Fraunhofer Institute of Systems and Innovation Research (ISI), the French Patent Office (INIPI), and the Observatoire des Science et des Techniques (OST). It distinguishes among 30 technologies and 5 higher-level technology areas (macro classes) based on the International Patent Classification (IPC).[13] Table 3.18 describes the composition of the dataset by these macro technological classes.

Technological Classes	DE	DK	ES	FR	HU	IT	NL	UK
Electrical engineering	13	8	9	14	14	16	25	17
Instruments	10	12	7	12	11	9	10	15
Chemistry, Pharmaceutical	20	24	22	15	43	16	21	20
Process engineering	25	28	28	26	14	26	25	22
Mechanical engineering	32	29	34	33	19	33	20	27

Table 3.18: Descriptive Statistics on Macro Technological Classes, per country.

In this chapter we use the same technological classes, but based on the more disaggregated technological classification composed by 30 classes.

[13] For the concordance between ISI-INIPI-OST technological classes and EPO IPC classes see Hinze *et al.* (1997).

3.5 Empirical Analysis

With the variables proposed in the previous section, we try to validate our three hypotheses. For that, we use two alternative (complementary) methodologies: first, using descriptive statistics on the difference in means of the weighted index of basicness; second, employing regression analysis.

3.5.1 Difference in Means

In Table 3.19 below, we present the differences in the means of the Weighted Basicness, $W - Basicness$, for the different institutions behind the inventions and for the total sample.

	ACADEMIA	CORPORATE	ACAD_CORP	CORP_ACAD	ACAD_ACAD
ACADEMIA					
CORPORATE	0.95**				
ACAD_CORP	0.03	-0.93**			
CORP_ACAD	0.29**	-0.66**	0.26**		
ACAD_ACAD	-0.59**	-1.54**	-0.62**	-0.88**	
CORP_CORP	0.76**	-0.20**	0.73**	0.47**	1.35**

Note: ** significant at the 5% level. Values= mean WBasic(column) - mean WBasic(row).

Table 3.19: Differences in Means of W-Basicness according to Institutions, for total sample.

The results in Table 3.19 are coherent with our first prior: patents with Academic main-inventors have, on average, a higher index of basicness than the ones with Corporate main-inventors. This is verified whether Academic main-inventors: do not have co-inventors outside their organizations ($ACADEMIA$), have Academic co-inventors ($ACAD\_ACAD$), or have Corporate co-inventors ($ACAD\_CORP$); and the comparison is either with Corporate inventors alone ($CORPORATE$), with Corporate main-inventors and Academic co-inventors ($CORP\_ACAD$), or with Corporate main-inventors and Corporate co-inventors ($CORP\_CORP$).

When the main-inventor is Academic and (s)he has a Corporate co-inventor ($ACAD\_CORP$), on average the index of basicness is not significantly different from the one when inventions are from Academia alone ($ACADEMIA$). This result does not confirm our second theoretical hypothesis, from which we would expect a reduction on the average basicness, due to the existence of Corporate co-inventors. Nevertheless, when we compare Academic main-inventions and a Corporate co-inventor ($ACAD\_CORP$) with Academic main-inventions and an Academic co-inventor ($ACAD\_ACAD$), the basicness index in the first context is smaller [$mean(ACAD\_CORP) - mean(ACAD\_ACAD) = -0.62$]. From this result, it seems that having a Corporate co-inventor, rather than an Academic, is associated with a less basic invention. This is aligned with Hypothesis 2.

Regarding Corporate main-inventors, the data also seems to confirm our second prior.

When Corporate main-inventors have Academic co-inventors, the average basicness: is higher than when there are no co-inventors at all
$[mean(CORPORATE) - mean(CORP\_ACAD) = -0.66]$, and is also higher than when co-inventors are also Corporate
$[mean(CORP\_ACAD) - mean(CORP\_CORP) = 0.47]$.

It is interesting to notice that when patents arise from partnerships between Academic organizations, the average basicness is higher than when they are produced by Academia alone $[mean(ACADEMIA) - mean(ACAD\_ACAD) = -0.59]$.

In a schematic way, our results show the following ranking for basicness of patents:

$$\begin{aligned} & WBasicness(ACAD\_ACAD) > WBasicness(ACADEMIA) = \\ = \; & WBasicness(ACAD\_CORP) > WBasicness(CORP\_ACAD) > \\ > \; & WBasicness(CORP\_CORP) > WBasicness(CORPORATE). \end{aligned}$$

In order to infer on our third hypothesis, we split the total sample in two sub-samples, according to the variable $INTERACTION$. Tables 3.20a and 3.20b, below, show the results for the differences in the means of $W - Basicness$, for each sub-sample.

No Interaction	ACADEMIA	CORPORATE	ACAD_CORP	CORP_ACAD	ACAD_ACAD
ACADEMIA					
CORPORATE	1.00**				
ACAD_CORP	0.23	-0.76**			
CORP_ACAD	0.24*	-0.75**	0.01		
ACAD_ACAD	-0.89**	-1.89**	-1.13**	-1.14**	
CORP_CORP	0.85**	-0.15**	0.62**	0.60**	1.75**

Note: ** significant at the 5% level; * significant at the 10% level. Values= meanWBasic(column)-meanWBasic(row).

Table 3.20a: Differences in Means of W-Basicness according to Institutions, for the sub-sample of Non-Important Interactions.

Interaction	ACADEMIA	CORPORATE	ACAD_CORP	CORP_ACAD	ACAD_ACAD
ACADEMIA					
CORPORATE	0.81**				
ACAD_CORP	-0.05	-0.91**			
CORP_ACAD	0.33**	-0.53**	0.38		
ACAD_ACAD	-0.28	-1.13**	-0.23	-0.61**	
CORP_CORP	0.66*	-0.20**	0.71**	0.33**	0.94**

Note: ** significant at the 5% level; * significant at the 10% level. Values= meanWBasic(column)-meanWBasic(row).

Table 3.20b: Differences in Means of W-Basicness according to Institutions, for the sub-sample of Important Interactions.

Once we split our sample in two sub-samples, we still find evidence on our Hypothesis 1: whenever main-inventors are from Academia, the average basicness is higher than when main-inventors are Corporate. The only exception is when we consider partnerships between different institutions: the average basicness of patents from $ACAD\_CORP$ is not significantly different from the basicness associated with $CORP\_ACAD$, whether there are or not important interactions.

As far as the second hypothesis is concerned, most of the results for the sub-samples are in line with what we obtain for the total sample as a whole. The only qualitative divergence that we register now is that, when interactions become important, the difference of basicness between $ACAD\_CORP$ and $ACAD\_ACAD$ decreases from -1.13 (Table 3.20a) to a value that is not significantly different from zero (Table 3.20b). Nevertheless, this is a sign favouring our Hypothesis 3: once interactions increase, Academia does not need to distort that much the basicness of the project in order to give incentives to a Corporate partner. The reverse part of the third hypothesis also seems to hold in our data: when interaction increases, the basicness of the patents arising from partnerships between Corporate main-inventors and Academic get closer to the basicness of the patents where no Academic inventors are involved. This is visible either through the distance between $mean(CORPORATE)$ and $mean(CORP\_ACAD)$, that becomes shorter with interaction (the difference changes from -0.75 to -0.53), or through the distance between $mean(CORP\_ACAD)$ and $mean(CORP\_CORP)$ that also decreases with interaction (from 0.60 to 0.33).

The result that partnerships between Academics organizations produce more basic patents than Academics individually also appears here as significative, with or without important interactions.

3.5.2 Regression Analysis

To discuss the coherence between our theoretical priors and the data, we make use of a second type of statistical tool: regression analysis. In this case, we define the following regression:

$$\begin{aligned}(W - Basicness)_i \; = \; & a_0 + a_1 CORPORATE_i + a_2(ACAD\_CORP)_i + \\ & + a_3(CORP\_ACAD)_i + a_4(ACAD\_ACAD)_i + \\ & + a_5(CORP\_CORP)_i + a_6 FORMAL_i + \\ & + a_7 COURT_i + a_8 MONETARY_i + a_9 CLAIMS_i + \\ & + a_{10} FAMILY_i + aX_i + \varepsilon_i, \end{aligned} \tag{3.5.1}$$

where the index $i = 1, ..., 7864$ states for the patents in the survey, X denotes a vector of other characteristics of the patents, namely country of the main-inventor and the technological class, a is the coefficient vector associated with X, and ε is a random variable. Excluding the dummy $ACADEMIC$ from the regression, the value of a_0 corresponds to the weighted-basicness of the patents with Academic inventors (one or more inventors, but all work in the same organization).

We estimate (3.5.1) using an OLS methodology with robust standard errors. This estimation enables the assessment of Hypotheses 1 and 2, namely through the inference of coefficients a_0 till a_5. As before, to infer on Hypothesis 3, we make use of the dummy $INTERACTION$ to separate our sample in two sub-samples: first, with patents whose main-inventors declare non-important interactions, i.e., $INTERACTION = 0$; second, with patents where interactions are considered important, $INTERACTION = 1$.

The results for the estimation of regression (3.5.1) with sub-sample of non-important interactions are given in Table 3.21.

Variables	Coefficients	Standard Errors	T-ratios
Constant	0.5943**	0.0841	7.0666
CORPORATE	−0.8571**	0.0749	−11.4433
ACAD_CORP	−0.1106	0.1555	−0.7113
CORP_ACAD	−0.3116**	0.1283	−2.4287
ACAD_ACAD	0.8421**	0.2203	3.8225
CORP_CORP	−0.7658**	0.0829	−9.2376
FORMAL	0.1452**	0.036	4.0333
COURT	−0.0663	0.0483	−1.3727
MONETARY	0.068**	0.0187	3.6364
CLAIMS	0.0022	0.0016	1.3750
FAMILY	0.0095**	0.0027	3.5185
Nr Observations= 3449 $R^2 = 0.26$			

Note: ** significant at the 5% level. Dependent variable: W-Basicness.

Table 3.21: Regression results for sub-sample with INTERACTION=0.

The results are in line with our prior Hypothesis 1: comparing with Academic patents, Corporate patents present a smaller basicness (basicness is reduced by 0.8571 when we compare $CORPORATE$ and $ACADEMIA$ inventions). A similar conclusion is obtained when we compare inventions patented by Corporate partnerships ($CORP\_CORP$) with Academic inventions: again, basicness is reduced for Corporate (by 0.7658 in our index). It is interested to notice that also here it appears that patents arising from Academic partnerships have an estimated basicness higher than patents coming from Academic individual research.

As far as our Hypothesis 2, the values estimated do not seem to evidence our conjecture regarding $ACAD\_CORP$ (the level of basicness of the patents arising from these partnerships is not significantly different from the one arising from $ACADEMIA$ alone).

Table 22 presents the results of the estimation for the sub-sample with patents with important interactions during research.

Variables	Coefficients	Standard Errors	T-ratios
Constant	0.6054**	0.1273	4.7557
CORPORATE	−0.6228**	0.1058	−5.8866
ACAD_CORP	−0.0231	0.1621	−0.1425
CORP_ACAD	−0.3576**	0.131	−2.7298
ACAD_ACAD	0.2746	0.2441	1.1249
CORP_CORP	−0.5649**	0.1143	−4.9423
FORMAL	0.2009**	0.0372	5.4005
COURT	−0.1449	0.0935	−1.5497
MONETARY	0.1028**	0.032	3.2125
CLAIMS	0.0086**	0.0023	3.7391
FAMILY	0.0105**	0.0049	2.1429
Nr Observations= 2105 $R^2 = 0.23$			

Note: ** significant at the 5% level. Dependent variable: W-Basicness.

Table 3.22: Regression results for sub-sample with INTERACTION=1.

The new set of results is in accordance with Hypothesis 1. Corporate patents are less basic than Academic ones. In particular, comparing with patents from Academic inventors and no partnership ($ACADEMIA$): patents with Corporate inventors and no partnership ($CORPORATE$) have a reduction in basicness of 0.6228; patents with Corporate inventors and coming from a partnership between Corporate organizations ($CORP\_CORP$) show a reduction in basicness of 0.5649; patents with Corporate main-inventor but under a partnership with Academia ($CORP\_ACAD$) also show a reduction in basicness of 0.3576.

As far as Hypothesis 2 is concerned, we again find evidence that the basicness index for patents from partnerships between Academia and Corporate, but with Academic main-inventors ($ACAD\_CORP$) is not significantly different from the one of Academic individual inventions.

The discussion over Hypothesis 3 requires the comparison of the two sets of estimations, and specially of the coefficients associated with variables $ACAD\_CORP$ and $CORP\_ACAD$. Therefore, comparing Tables 3.21 and 3.22, we cannot reject that patents with Academic main-inventors and Corporate co-inventors ($ACAD\_CORP$) are as basic as patents from Academic individual invention. This result does not contradict our predictions in Hypothesis 3. In fact, even when there is no important interactions (Table 3.21), our data detects no reduction on the basicness index. Therefore, once increasing the importance of interaction, and as expected, the basicness index for this type of partnerships does not change. Regarding the patents also under partnerships of both types of institutions, but having Corporate main-inventors ($CORP\_ACAD$), the comparison of the estimated coefficients for the two sub-samples is also in agreement with our third hypothesis. Indeed, once interactions become important, we detect a reduction in the basicness index of these type of patents, thus leading the outcome of the partnership closer to the expected preferences of Corporate main-inventors.

As far as the other independent variables are concerned, when there are no important interactions outside, $CLAIMS$ and $COURT$ show up insignificant. When interactions are relevant, only $COURT$ shows up as insignificant. All the remaining controls seem important to explain our weighted index of basicness.

3.6 Conclusion

Using contract theory, it can be shown (Chapter 2 of this dissertation) that in the collaborative research process conducting to a patent, the governing partner may choose a type of research, which is not its most preferred one. This distortion is an incentive tool for the other party in the partnership, when it lacks capacity to commit on the allocation of resources. In practice, this means that Corporate organizations may end up producing more *basic* patents if they are partnering with Academia, in order to give incentives for the academic partners to exhert a higher amount of effort. This higher effort translates in a larger probability of success for the common project. Conversely, Academic institutions may choose to develop more *applied* patents to motivate Corporate partners for the common research. In this paper we try to validate these conjectures. As such, we construct an index of the *basicness* of patents, and we use simple empirical techniques to check whether the identity of the organizations that are involved in the research process conducting to the patent is a significant explanatory factor for different levels of basicness. Our empirical results confirm our priors.

In general, Academic inventors produce more basic patents than Corporate inventors. When a patent is a co-invention between both types of institutions, we also find evidence of possible intermediate levels of basicness, but always closer to the interests of the main-inventor. For the case of Corporate main-inventors with Academic co-inventors, patents show a basicness index that is smaller than when only Academic inventors are involved, but higher than when only Corporate inventors exist. For the symmetric situation of Academic main-inventors with Corporate co-inventors, we do not find an intermediate level of basicness, but rather an index that is not significantly different from the one when all inventors are Academic. Although this last evidence is not exactly our prior, it does not contradict the theoretical framework in which we build. In fact, as stated in the previous chapter, a distortion in the most preferred project of the governing party may not occur when the other party (the co-inventor) is not sufficiently important for the success, or when the expected benefit of such success is not significantly high to compensate the cost of the distortion.

Despite building on the theoretical work of Chapter 2, the current chapter treats the argument of incentives behind the distortion of the project in a different manner. Rather than focusing in verifiability and contractibility of efforts (resources), here we consider the capacity of the parties to commit on a certain allocation of effort to the common project. We then take such capacity of commitment as positively related with the importance of interaction between partners, and check whether this interaction is associated with different levels of basicness. Anticipating that the higher the interaction between partners, the easier it is to enforce an ex-ante agreement on the allocation of resources, we expect that higher interaction to be associated with a basicness index that is closer to the interests of the main-inventors. Our data seems to confirm such expectation. When Corporate main-inventors have Academic co-inventors, the more important the interaction, the closer it is the basicness from the level where only Corporate inventors exist. For the reverse situation of Academic main-inventors and Corporate co-inventors, interaction also makes the basicness index become closer to the level when co-invention is between two Academic organizations.

With the simple econometric techniques developed in this chapter, we are able to find empirical signs reinforcing the argument that the outcome of research can be the result of an optimal contract between the parties involved. Future work on trying different (possible alternatives) technical specifications, namely in terms of the composite index of basicness and regression analysis, can be useful as robustness checks of our results.

In the question that we analyze here, there may be some potential problems of endogeneity. We try to see how the institutional framework of the research affects the project developed. Nevertheless, it may be that both institutions and project are the result of a decision taken in a previous stage: with whom (and if) they want to establish a partnership. Further theoretical work on this question of partner selection (in a previous stage of decisions) may bring interesting insights.

The present work also offers some evidence for another potential line of future theoretical developments: the role of interactions between partners in their contractual relationship. In fact, not only different levels (or types) of interaction may lead to different outcomes of the partnership, but also the parties may anticipate such effects and adjust the initial design of the partnership.

In case the level and intensity of interaction between partners in research becomes an important determinant for their capacity of commitment, it is possible to discuss policy implications. Policy measures affecting that interaction would have an impact on the efficiency of partnerships.

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