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Managing Innovations resulting from University-Industry Collaborations

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Managing Innovations resulting from University-Industry Collaborations *

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We consider a policy regime allowing academic institutions to grant industry the intellectual property rights (IPRs) over invention resulting from collaborations. If a firm plays an important role in generating an invention, the researcher offers the IPRs to the firm, as an incentive to collaborate. However, he retains certain domains where he can exploit an invention without having to apply for a license. The choice of these domains involves a tradeoff. In fact, the researcher either induces the firm's effort, by assigning a broad field of use, or he ensures that he can use an invention in other applications, by granting a narrow field of use. The reverse occurs if it is the researcher who plays an important role in generating an invention. The main difference, however, is that if effort were contractible, the firm could reward the researcher for supplying the first best level of effort, because, unlike the researcher, it is not cash constrained. An empirical analysis, based on École Polytechnique Fédérale de Lausanne research contracts, supports the role of broad fields in bolstering a firm's effort, when the latter is important for generating an invention.

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1 Introduction

Joint industry-academic research is recognized to play a significant role in the diffusion of knowledge and as a source of new ideas for both industry and academia.

Survey evidence on European Technology Transfer Offices by Conti and Gaulé (2008) shows that out of 212 respondents, 88 consider industry- sponsored research income more important than licensing income as an indicator of success, 87 consider it equally important and only 37 contend that licensing income is more important than industry-sponsored research income. Similarly, 105 respondents indicated that they spend more time negotiating and managing research contracts than licenses, 42 spend about the same time and 65 spend more time on licenses. In the US, exponents from the industry sector (Thompson, 2003, and Johnson, 2007) point to the importance of university-industry collaboration as a means of transferring technology, as opposed to a business model in which firms "buy" from universities inventions entirely conceived in university laboratories.

An important aspect of industry-sponsored research contracts is the assignment of the intellectual property rights (IPRs) over inventions ensuing from the collaboration between a firm and an academic researcher. In fact, the ex-ante allocation of property rights impacts the willingness of the parties to participate in a project and the effort they devote to it. Academic institutions (and governments if these policies are established at a national level) face a trade-off. On the one hand, assigning the IPRs to a firm is an incentive for the latter to participate in a joint project and fosters the effort it devotes to the project. On the other, retaining the IPRs allows inventions to be used in applications with firms other than that participating in the project, without having to pay a license fee.

In some European countries, such as Sweden and Italy, it is the academic researcher who decides whether to allow firms to retain IPRs over inventions derived from joint collaborations. Others, like Switzerland, leave it up to their academic institutions to choose whether or not the IPRs should be assigned to industry. The situation in the US is different, as universities retain property rights generated from federally funded research.

This study examines a policy regime that allows academic institutions to assign to industry the IPRs deriving from joint collaboration. We distinguish two cases. One in which the firm's effort is more important than the researcher's effort for generating an invention. In this case the IPRs are assigned to the firm and the researcher has to decide the breadth of the field of use in which the industry partner can exercise its rights. The other case is exactly the opposite - the researcher's effort is more important than the firm's effort for the success of a project. The IPRs are therefore assigned to the researcher and the firm has to decide the breadth of the field of use in which the researcher can exercise his rights. In the model there is no conflict of interest between the researcher and his academic institution and, thus, it does not matter whether the IPRs are assigned to the researcher or the academic institution.

We believe this work provides useful insights for those countries and academic institutions that have a similar policy in place. Moreover, it explores an interesting alternative to the US university technology transfer model, as shaped by the Bayh-Dole Act. Recently, some industry sector professionals in the US have raised the concern that American universities might have assumed too rigid a position, especially when managing intellectual property (IP) generated from industry-sponsored research (Thompson, 2003, and Johnson, 2007). Interestingly, Thompson contends that European universities are more successful at encouraging university-industry research because they have more flexible IP policies and in general offer more favorable terms to their industry partners.

In a joint collaboration where the firm's contribution is decisive in generating an invention, the researcher offers the IPRs to the firm as an incentive for the latter to participate in the project.

We find that the researcher grants a broad field of use if the return the firm earns from the extra fields it is assigned is high. In fact, a high return induces the firm to make a greater effort, which in turn has a positive impact on the probability of an invention being generated. The drawback of this choice is that the researcher cannot apply for a license to use an invention in these fields because he is cash constrained. When the return the researcher could earn in these fields compensates for the lower probability of an invention being realized, the researcher should assign a narrow field of use to the firm.

This case corresponds to types of collaboration that are closer to the market than to the researcher's laboratory.

When the researcher's effort is determinant for the success of a project, the firm will renounce ownership of the intellectual property rights, which will be assigned to the researcher. In fact, the latter requires ownership of the IPRs as a condition to participate in the project. The firm's choice regarding the field of use is symmetrical to that the researcher makes when the firm's effort is important for generating an invention.

The main difference in relation to the previous case is that if the researcher's effort were contractible, the firm could offer a contract stating that the researcher should provide the first best level of effort, in exchange for a compensation that allows the latter to break even. This contract is feasible because the firm, unlike the researcher, is not cash constrained. However, it is optimal only if the payoff earned by the firm is not lower than the payoff it would receive if the researcher did not supply the first best level of effort.

This case corresponds to types of collaboration that are closer to the researcher's laboratory than to the market.

Empirical evidence based on a sample of industry-sponsored research contracts concluded by researchers at the École Polytechnique Fédérale de Lausanne

(EPFL)[1], provides some support for the case of the firm's effort being determinant for the success of a project. The contracts we chose govern collaborations between academic researchers and industry on very applied projects, where the firm's effort is likely to be more important. The empirical findings show that there is a positive relationship between the breadth of the field of use and the effort supplied by the firm. The result is consistent with the idea, suggested by the theoretical model, that the researcher can foster the firm's effort by assigning a broad field of use, when the firm's participation is important for the success of the project.

Our analysis contributes to the debate on the conditions under which firms should be assigned the IPRs over inventions generated by university-industry collaborations (Aghion and Tirole, 1994). Moreover, by highlighting the disadvantages of assigning a firm a broad field of use, our analysis also contributes to the theory of hold-ups (Klein at al. 1978, Hart and Moore 1988, Green and Scotchmer 1995, Ziedonis 2004). For our definition of university-industry collaboration we take inspiration from Jensen et al. (2003), Lacetera (2006) and from the notion of "research push" adopted by Callaert et al. (2006). Our assumption of a cash constrained researcher very much resembles that of a cash constrained research unit made by Aghion and Tirole (1994). Similarly to these authors, we find that the existence of a cash constraint on the researcher may cause inefficiency. However, in our model the inefficiency derives from the fact that the researcher may refrain from assigning a broad field of use to foster the firm's effort because he cannot afford a license to use the invention in other projects.

The paper is organized as follows. Section 2 introduces a model analyzing the choice an academic researcher makes regarding the field of use when deciding to involve a firm in a project and offering the IPRs to the latter. The underlying assumption is that the firm's effort is determinant for the realization of an invention. Section 3 analyzes the opposite case in which a firm has to choose regarding the field of use when deciding to involve a researcher in a project and offering the IPRs to the latter. We assume that the researcher's contribution is determinant for the realization of an invention. Section 4 presents the empirical findings based on a sample of EPFL research contracts. Section 5 concludes.

[1] EPFL is one of Europe's leading institutions in the fields of science and technology and is the world's 18th university in the field of "Engineering/Technology and Computer Sciences" according to the 2008 academic ranking of world universities by Shanghai Jiao Tong University.

2 Model with firm contributing more than researcher to an innovation

2.1 Model setup

A researcher asks a firm to collaborate in a research project and offers a contract. The firm is required to provide financial means as well as expertise and instrumentation. For the moment, we assume that the contribution made to the project by the firm is more important for generating an invention than that made by the researcher. This is the case with more applied projects that are closer to the market than to the researcher's laboratory.

The contract also contains a definition of the intellectual property rights regime. We assume that the firm stipulates the ownership of the IPRs as a condition for participating in a project. This is justified on the grounds that the firm's intervention is important for the success of the project.

The benefit of being assigned the IPRs lies in the possibility of making ex-post "decisions that were not contracted ex-ante" (Baker et al., 2002). In fact, by granting the IPRs to the firm, the researcher relinquishes his control over the use the firm makes of any invention generated during the project.

The researcher, however, wants to make sure he will be able to use the invention in other projects with commercial value, without having to apply to the firm for a license. This is in fact the return he expects from the collaboration. Therefore, if an invention can be exploited in a number of different fields, the researcher will retain at least some of them. The question is how to split the fields of use between the researcher and the firm.

In the model, we rule out the possibility that the decision regarding the field of use is entirely made ex-post, once an invention has been generated. In reality, because the IPRs are assigned ex-ante to the firm, its ex-post bargaining power will be so high that the researcher will find it difficult to restrict the domain within which the firm can exercise its rights.

There are n fields of use in which an invention can be marketed. These fields can be exploited either by the firm or by the researcher, but they cannot be exploited by both parties at the same time. In each field, an invention yields a return, R_i, if exploited by the firm, and a return, V_i, if exploited by the researcher.

The researcher assigns $k - j$ fields (with $k > j$) to the firm, because the latter requires them, together with the IPRs, as a condition for participating in the project. These fields constitute a natural complement to the IPRs and without them the firm would not earn any return. The researcher retains $n - k$ fields that represent the compensation for the effort he devotes to the project. Finally, he makes a decision concerning the remaining j fields based on whether he derives greater utility from exploiting them or from assigning them to the firm and thus inducing it to make a greater effort. Although both the researcher and the firm would realize a positive return on these fields, it is not clear ex-ante which party makes the highest return. In fact, an exogenous event may occur during the course of the project that affects the characteristics of the invention being produced. This, in turn, has an impact on the parties' returns, including those from the j fields. We assume that such an event can occur with a positive probability. However, at the end of the project the characteristics of the invention are revealed and the parties discover the return they can earn by exploiting the j fields.

During the development phase, an invention is realized with a positive probability, $p(e, I)$. We assume that this probability is strictly concave and increases with the levels of effort supplied by the researcher (e) and the firm (I)[2]. However, the impact of the firm's effort on the probability of an invention being generated is greater than the impact of the researcher's effort.

Without loss of insight we assume that the researcher will devote a fixed amount of effort to the project, $\bar{e}$. This amount is no greater than the residual effort after he has accomplished his two main academic tasks of teaching and conducting basic research. On the contrary, the effort provided by the firm, I, varies with expected returns. The assumption regarding e allows us to focus on the researcher's role in spurring the firm's effort by choosing the appropriate breadth for the field of use. Relaxing this assumption would not significantly impact the results of the model.

The levels of efforts e and I are not contractible. However, even if I were contractible, the academic researcher could not compensate the firm for supplying the first best level of effort, because he is cash constrained.

Throughout the model we make the assumption that there is no conflict of interest between an academic institution and its researcher. This implies that the academic institution and the researcher represent a sole partner during negotiations with industry.

The interaction between the academic researcher and the firm is extended over six stages:

1. The researcher asks a firm to collaborate in an applied project. He offers a contract assigning the IPRs to the firm and defining a regime for the fields of use.

2. The firm may accept or decline the offer. If it accepts, both the researcher and the firm will invest in effort.

3. An invention occurs with a positive probability.

4. The uncertainty regarding the characteristics of the invention is revealed and the parties discover the returns they could derive from the j fields.

[2] e and I are measured in dollars.

5. The firm exploits the invention in the fields assigned to it, and the researcher does so in the remaining fields.

6. Payoffs are realized.

2.2 The first best

In this section, we merge the two entities (the researcher and the firm) and find the levels of effort that maximize the sum of their payoffs. In line with the standard approach in contract theory, we will define this case as our first best. In each field, if $R_i \geq V_i$, the firm will exploit the invention; conversely, if $V_i \geq R_i$, the researcher will do so.

The ex ante payoff of the merged entity is:

$$VFB = p(\overline{e}, I) * [\sum_{i=1}^{n} \max(R_i, V_i)] - \overline{e} - I$$

The researcher devotes a fixed level of effort to the project, $\overline{e}$. The firm however chooses a level of effort, I^*_{FB}, that maximizes VFB. In our first best, it does not matter how the n fields are assigned. In fact, the firm and the researcher are a sole entity and there is no need for the researcher to utilize the j fields as a lever to foster the firm's effort.

2.3 The case of no uncertainty

We depict this case as a situation in which the parties do not encounter any uncertainty regarding the value they could derive by exploiting an invention in the j fields. This is a benchmark case against which a situation involving uncertainty will be assessed.

Payoffs When the researcher retains $n - k + j$ fields, his payoff is:

$$U_N = p(\overline{e}, I) * \sum_{i=k-j+1}^{n} V_i - \overline{e}$$

The firm's payoff, when exploiting the remaining $k - j$ fields, is:

$$\Pi_N = p(\overline{e}, I) * \sum_{i=1}^{k-j} R_i - I$$

When the researcher renounces the j fields and assigns them to the firm, he requires a compensation, T. Therefore, his payoff is:

$$U_B + T$$

where: $U_B = p(\overline{e}, I) * \sum_{i=k+1}^{n} V_i - \overline{e}$.

The firm's payoff is:

$$\Pi_B - T$$

where: $\Pi_B = p(\bar{e}, I) * \sum_{i=1}^{k} R_i - I$.

Whether the firm is assigned $k-j$ or k fields, it will choose a level of effort that maximizes its expected payoffs. Moreover, we assume that:

$$[p(\bar{e}, I(\sum_{i=1}^{k} R_i)) - p(\bar{e}, I(\sum_{i=1}^{k-j} R_i))] * \sum_{i=1}^{k} R_i \geq I(\sum_{i=1}^{k} R_i) - I(\sum_{i=1}^{k-j} R_i) \quad (1)$$

This assumption guarantees that the firm, if assigned the j fields, will find it profitable to provide a level of effort $I(\sum_{i=1}^{k} R_i) \geq I(\sum_{i=1}^{k-j} R_i)$.

Researcher's decision concerning the allocation of the fields of use
When deciding about the fields of use, the researcher will adopt the following rules:

1. Allocate $k-j$ fields to the firm;
2. Retain $n-k$ fields;
3. Assign the j fields to the firm if:

$$\Pi_B - \Pi_N \geq U_N - U_B \quad (2)$$

Otherwise, retain the j fields.

Condition (2) in rule 3 is the result of a bargaining game between the researcher and the firm. The researcher is willing to give up the j fields if the upfront payment, T, he receives is at least equal to $U_N - U_B$. The firm is willing to accept the j fields if the payment it has to make is no greater than $\Pi_B - \Pi_N$. Combining the two conditions, we obtain that the j fields are assigned to the firm if $\Pi_B - \Pi_N \geq U_N - U_B$.

From condition (1) we derive that $\Pi_B - \Pi_N \geq 0$. This implies that $U_B - U_N \geq 0$ is sufficient for an agreement to be reached assigning the j fields to the firm.

The upfront fee, T, the firm has to pay to acquire the j fields has no effect on its expected returns and on the effort it furnishes. Therefore, if assigned the j fields, the firm will furnish a greater effort, because its expected returns are higher.

If $\sum_{i=k-j+1}^{k} (R_i - V_i) < 0$, the researcher may still find it profitable to assign the j fields to the firm, provided that the gain in terms of a greater probability of an invention being generated outweighs the loss $\sum_{i=k-j+1}^{k} V_i$ incurred from relinquishing the j fields.

Similarly, if $\sum_{i=k-j+1}^{k}(R_i - V_i) \geq 0$, the researcher may find it profitable to maintain the j fields if the value he would derive compensates for the loss in terms of a lower probability of an invention being generated.

Regardless of which partner is assigned the j fields, the probability of an invention being generated is lower than in the first best. In fact, the firm chooses a level of effort that maximizes its own payoff and not the sum of the payoffs of the merged entity.

2.4 The case of uncertainty

We now analyze a situation in which the parties are uncertain regarding the returns they will be able to generate by exploiting the j fields.

When deciding on the field of use, the researcher has two options. First, he can assign a broad field of use, which encompasses all k fields. In this way, the firm can earn a higher return and provide a greater effort than if it were assigned only $k - j$ fields. This, in turn, has a positive impact on the probability of an invention being generated. The drawback is that the researcher renounces the possibility of making a return from the j fields. Therefore, as compensation, he asks the firm to pay an upfront fee that extracts the expected surplus, $E\Pi_B - \Pi_N$, that the firm derives from the j fields [3]. Thus, the researcher's payoff is $EU_B + T$ and the firm's payoff is $E\Pi_B - T$. T is the payment the researcher requires for assigning the additional j fields. EU_B and $E\Pi_B$ are expected values since the researcher and the firm do not know with certainty the returns they can realize from the j fields.

In the model, since the researcher is cash constrained, when he renounces the j fields he cannot apply for a license ex-post if he learns that $\sum_{i=k-j+1}^{k}(V_i - R_i) \geq 0$.

As a second option, the researcher can assign a narrow field of use. Therefore, he allocates only the $k - j$ fields that the firm requires as a condition for participating in the project and retains the remaining $n - k + j$ fields. If, ex-post, the parties realize that $\sum_{i=k-j+1}^{k}(R_i - V_i) \geq 0$, the firm will pay a fee to the researcher to exploit the j field. Because the fee is paid ex-post, it impacts the expected returns of the firm and, thus, its decision regarding the amount of effort to provide. To prevent the researcher from assigning the j fields ex-post to another partner generating the same returns as the firm, the latter requires that the contract should include a clause stating that if $\sum_{i=k-j+1}^{k}(R_i - V_i) \geq 0$, the researcher assigns the j fields to the firm.

We assume that the event $\sum_{i=k-j+1}^{k}(V_i - R_i) \geq 0$ occurs with a probability d, while the event $\sum_{i=k-j+1}^{k}(V_i - R_i) < 0$ occurs with a probability $1 - d$.

The researcher's ex-ante payoff when he assigns a narrow field of use is[4]:

[3] E designates expected value because the firm does not know with certainty the return it can make from the j fields.

[4] We designate the researcher's payoff with U_{NU} where the subscript stands for narrow in the case of uncertainty. E represents expected value. In fact, the researcher is uncertain regarding the value he can derive from the j fields.

$$U_{NU} = p(\overline{e}, I) * [\sum_{i=k+1}^{n} V_i + d * \sum_{i=k-j+1}^{k} EV_i + (1-d) * EM] - \overline{e}$$

With a probability d, the researcher will exploit the j fields, while with probability $1-d$ he will assign them to the firm in exchange for a payment M.

The firm's ex-ante payoff is:

$$\Pi_{NU} = p(\overline{e}, I) * [\sum_{i=1}^{k-j} R_i + (1-d) * \sum_{i=k-j+1}^{k} (ER_i - EM)] - I$$

If the firm is assigned a narrow field of use, it estimates ex-ante that it will be able to exploit the j fields with a probability $1-d$. Therefore, its payoff includes the expectation that with a probability $1-d$ it will realize a value $\sum_{i=k-j+1}^{k} R_i$ in exchange for a payment, M, to the researcher. This in turn has an impact on the level of effort the firm provides.

Ex-post, the researcher will require the payment, M, to extract all the firm's surplus. Therefore, $M^* = \sum_{i=k-j+1}^{k} R_i$. This is possible because the researcher has a greater bargaining power deriving from the retention of the j fields.

Proposition 1 *The researcher will assign a broad fields of use to the firm if $d \leq \overline{d}$.*

$\overline{d}$ is equal to:

$$\frac{[p(\overline{e}, I(\sum_{i=1}^{k} ER_i)) - p(\overline{e}, I(\sum_{i=1}^{k-j} R_i))] * (\sum_{i=k+1}^{n} V_i + \sum_{i=1}^{k} ER_i)}{p(\overline{e}, I(\sum_{i=1}^{k-j} R_i)) * [\sum_{i=k-j+1}^{k} (EV_i - ER_i)]} - \\ - \frac{[I(\sum_{i=1}^{k} ER_i) - I(\sum_{i=1}^{k-j} R_i)]}{p(\overline{e}, I(\sum_{i=1}^{k-j} R_i)) * [\sum_{i=k-j+1}^{k} (EV_i - ER_i)]} \tag{3}$$

Proof. *The researcher assigns a broad field of use if $U_B + T \geq U_{NU}$.*

Substituting:

U_B with $p(\overline{e}, I(\sum_{i=1}^{k} ER_i)) * \sum_{i=k+1}^{n} V_i - \overline{e}$;

T^* with $p(\overline{e}, I(\sum_{i=1}^{k} ER_i)) * \sum_{i=1}^{k} ER_i - I(\sum_{i=1}^{k} ER_i) - [p(\overline{e}, I(\sum_{i=1}^{k-j} R_i)) * \sum_{i=1}^{k-j} R_i - I(\sum_{i=1}^{k-j} R_i)]$;

U_{NU} with $p(\overline{e}, I(\sum_{i=1}^{k-j} R_i)) * [\sum_{i=k+1}^{n} V_i + d * \sum_{i=k-j+1}^{k} EV_i + (1-d) * EM] - \overline{e}$;

M^* with $\sum_{i=k-j+1}^{k} R_i$;

and solving for d, we obtain the condition above. ■

The probability of an invention being generated affects the value a researcher can derive from all the fields he retains. Therefore, if, by renouncing the j fields, the researcher obtains in exchange a significant increase in the probability of an invention being generated, then he will assign a broad field of use. The range of parameters for which this choice is optimal increases in $\sum_{i=k-j+1}^{k} ER_i$ and decreases in $\sum_{i=k-j+1}^{k} EV_i$.

We have assumed that the researcher and the firm do not incur any verification cost to discover ex-post whether $\sum_{i=k-j+1}^{k}(R_i - V_i) \geq 0$ or vice versa. However, in reality these costs are positive and may reduce the range of parameters over which a narrow field of use is optimal.

3 Model with researcher contributing more than firm to an innovation

3.1 Model setup

This case is symmetrical to the one we considered in the previous section. A firm is willing to collaborate with a researcher in a research project and offers a contract. The contribution made by the researcher to the project is more important for generating an invention than that made by the firm. This is indeed true for more basic research projects that are closer to the researcher's laboratory than to the market.

The contract the firm offers to the researcher contains a definition of the IPR regime. The researcher stipulates ownership of the intellectual property rights as a condition for participating in the project. Since we made the assumption that the researcher and his academic institution are a sole partner, it does not matter whether the IPRs are assigned to the researcher or the academic institution. The firm, however, has to make sure that it can retain at least some of the fields in which the invention can be marketed. Thus, it will assign to the researcher the $n-k$ fields stipulated by the latter as a condition for participating in the project; it will retain $k-j$ fields and make a decision on the remaining j fields, depending on whether it derives greater utility by exploiting them or by assigning them to the researcher and thus inducing greater effort from the latter.

Again the parties are uncertain as to the returns they could make by exploiting the j fields.

The impact of the researcher's effort on the probability of an invention being generated is greater than the impact of the firm's effort. Without loss of insight we assume that the firm will supply to the project a fixed amount of effort $\overline{I}$. The effort provided by the researcher, e, however varies according to the expected returns. In any case, it cannot be greater than the residual effort after the researcher has accomplished his two main academic tasks of teaching and conducting basic research.

The main difference in relation to the setup in the previous section is that the firm is not cash constrained. Therefore, if the researcher's effort were contractible, the firm could offer the researcher an ex-ante compensation for providing the first best level of effort.

3.2 The first best

As before, we merge the two entities (researcher and firm) and find the levels of effort that maximize the sum of their payoffs. In each field, if $R_i - V_i \geq 0$, the firm will exploit the invention; otherwise the researcher will do so.

The ex-ante payoff of the merged entity is:

$$VFB = p(e, \overline{I}) * [\sum_{i=1}^{n} \max(R_i, V_i)] - e - \overline{I}$$

The researcher provides a level of effort, e^*_{FB} that maximizes VFB. Conversely, the firm chooses a fixed level of effort, $\overline{I}$.

3.3 The case of no uncertainty

In the absence of any uncertainty regarding the returns the firm and the researcher can derive from the fields j, the firm will assign the latter to the researcher if:

$$[p(\overline{I}, e(\sum_{i=k-j+1}^{n} V_i)) - p(\overline{I}, e(\sum_{i=k+1}^{n} V_i))] * \sum_{i=1}^{k-j} R_i \geq p(\overline{I}, e(\sum_{i=k+1}^{n} V_i)) * \sum_{i=1}^{k} R_i \quad (4)$$

Because the researcher is cash constrained, he does not pay any fee to the firm in exchange for the j fields.

This option is optimal for the firm if the surplus it realizes from the remaining $k-j$ fields compensates for the loss incurred from relinquishing the j fields. We assume the following condition:

$$[p(\overline{I}, e(\sum_{i=k-j+1}^{n} V_i)) - p(\overline{I}, e(\sum_{i=k+1}^{n} V_i))] * \sum_{i=k-j+1}^{n} V_i \geq e(\sum_{i=k-j+1}^{n} V_i) - e(\sum_{i=k+1}^{n} V_i)$$

Therefore, if assigned the j fields, the researcher will supply the level of effort $e(\sum_{i=k-j+1}^{n} V_i)$, with $e(\sum_{i=k-j+1}^{n} V_i) > e(\sum_{i=k+1}^{n} V_i)$.

If the researcher's effort were contractible, the firm could offer a contract to the researcher stating that the researcher should supply the first best level of effort in exchange for an upfront transfer, A. The researcher will accept the offer if the payment, A, suffices for him to break even. In the same contract the firm will assign the j fields to the researcher if the $\sum_{i=k-j+1}^{k} V_i \geq \sum_{i=k-j+1}^{k} R_i$.

A contract requiring the researcher to provide the first best level of effort is optimal for the firm if the payoff it obtains is not lower than the payoff it would receive if the researcher did not supply the first best level of effort.

3.4 The case of uncertainty

When there is uncertainty regarding the returns that either party can derive from the j fields, the firm has the choice between assigning a narrow field of use to the researcher, i.e. the $n-k$ fields, or granting a broad field of use, i.e. the $n-k+j$ fields.

If the researcher is assigned a narrow field of use, he cannot pay an ex-post fee to obtain the j fields because he is cash constrained. Conversely, if he is assigned a broad field of use, the firm can, ex-post, acquire the fields j and pay him a fee that is at least equal to the researcher's forgone return. The firm will seek to acquire these fields provided that $\sum_{i=k-j+1}^{k}(R_i - V_i) \geq 0$.

Once again, to prevent the researcher from assigning, ex-post, the j fields to another partner generating the same returns as the firm, the latter includes in the contract a clause stating that if $\sum_{i=k-j+1}^{k}(R_i - V_i) \geq 0$, the researcher will assign the j fields to the firm.

Similarly to what we have seen above, the firm's choice between a narrow and a broad field of use depends on the expectation that, ex-post, $\sum_{i=k-j+1}^{k}(R_i - V_i) \geq 0$ or vice versa. Therefore, the higher the probability, d, of the return the researcher realizes from the j fields being greater than that which the firm can derive, the more the firm will tend to assign a broad field of use.

Moreover this choice is convenient when the difference between the probability of an invention being generated if the researcher is assigned the j fields and if he is not is high.

If the researcher's effort were contractible, the firm could offer a contract to the researcher with a compensation for supplying the first best level of effort. The researcher would accept if the compensation sufficed for him to break even. The same contract will assign the j fields to the researcher if $EV_i \geq ER_i$.

Again, requiring that the researcher provides the first best level of effort is optimal for the firm if the payoff it obtains is not lower than the payoff it would receive if the researcher did not supply the first best level of effort.

4 Empirical test of the importance of the breadth of the field of use

In this section we present some empirical evidence of the importance of the field of use based on a sample of research contracts negotiated by academic researchers at the École Polytechnique Fédérale de Lausanne (EPFL). EPFL technology transfer policy prescribes that when a researcher collaborates with a firm and an invention results, the firm has the priority right to file a patent application(s) in its name and at its cost. The firm then grants a license to the researcher with a right to sub-license outside the domain reserved to the firm. For inventions that are generated principally in university laboratories, the IPRs are usually assigned to EPFL. Licensing contracts are then negotiated with firms to commercialize these inventions.

Discussions with technology transfer professionals at EPFL revealed important insights into why firms push to retain the IPRs ensuing from university-industry collaborations. According to them, firms perceive the assignment of the IPRs as "fair compensation" for their effort in a research project. Moreover, when the IPRs are assigned to them, firms can control the process of writing and filing patents. Also, most firms believe that when a patent is assigned to them, the underlying invention receives better protection than if the patent were assigned to the university. Finally, ownership of IPRs allows firms "to make decisions ex-post that were not contracted ex-ante" (Baker at al., 2004).

While firms find it profitable to own IPRs over university-industry inventions, the consensus among EPFL professors is divided. We interviewed a number of EPFL professors to discover the pros and cons of a policy that assigns to industry the IPRs derived from joint collaboration. Some of them contended that assigning the IPRs to a firm acts as an incentive for the latter to market university research results. Moreover, it is a way of reducing the time and financial resources required to file a patent and the transaction costs arising from the management of joint intellectual property. However, a few professors expressed some concerns with regard to this policy. In particular, one professor cited a case in which a firm retained the IPRs over the research results derived from a collaboration and did not commercialize the invention. The professor applied for a license to found a startup that would commercialize the invention but the firm refused. Another claimed that assigning the IPRs to firms prevents a researcher from conducting further research in a field close to the field of use assigned to the firm. In fact once the IPRs are assigned to a firm in a pre-defined domain, the firm not only acquires an asset in the form of the ownership rights over the invention but also a dominant position in negotiations with the researcher. Therefore, it becomes more difficult for the researcher to prove that the type of applied research he conducts, although it may be close to it, does not impinge on the field of use of the firm. This in turn discourages the researcher from pursuing further research in domains that are adjacent to the field of use granted to the firm.

The contracts in our sample belong to a special category. For a given amount of effort supplied by the firm, the federal government offers to pay for the effort supplied by the academic researcher. This subsidy is generally granted for projects involving small to medium-sized Swiss firms (or subsidiaries of multinational companies based in Switzerland), as a means of promoting local economic development[5]. The nature of the projects involved is usually very applied. The

[5] In our sample firms with fewer than 50 employees constitute 55% of the total.

federal authorities select them on the basis of detailed business plans and require the firms to market any result ensuing from the collaboration with academic researchers. This case very much resembles the one analyzed in the model where the firm's effort is more important than the researcher's effort for the success of a project.

We examined 152 contracts signed during the period 2000-2008. Each contains a precise definition of the field of use in which the firm will exercise its property rights. Moreover, it includes a specification of the money value of the effort devoted to the project by the firm. As we have seen in the theoretical model, when a researcher is cash constrained, there is no difference between a contractible and non-contractible effort by the firm. In fact, even if the effort were contractible, the researcher could not reward the firm with a cash transfer for supplying the first best level of effort. Thus, the researcher will have to foster the firm's effort by choosing the correct breadth for the field of use.

4.1 Econometric model

Our dependent variable is the effort supplied by the firm to a joint collaboration. We model the firm's effort (INDUSTRY_E) as a function of the breadth of the field of use and other controls.

The specification of the model is a two-equation recursive system. In the first equation we analyze the factors affecting the breadth of the field of use (USE_BR). Specifically, we need to measure the impact of the expected returns, the firm derives from the project, on the breadth of the field of use. In fact, as we have seen from the model, the researcher assigns a broad field of use to the firm if the returns the latter can make are high. We proxy the firm's expected returns with a variable capturing the scope of the project (PROJECT_SCOPE). The underlying logic is that if a project concerns the development of a large number of the components of the final product being commercialized, the firm will derive a high value from the project. Conversely, if the project concerns the development of a small part of the final product being commercialized, the value the firm derives from the project is most likely to be low.

We measure the breadth of the field of use by an index capturing the number of industry sectors in which a product can be marketed. This index ranges from 1 (narrowest) to 4 (broadest)[6]. Its distribution is shown in the appendix. An example of a narrow field of use would be "gas sensors for medical applications" since this field allows commercial applications in the medical sector only. Conversely, "polymer reaction engineering" is an example of a broad field of use since it allows applications in a greater number of industry sectors. Our measure for the scope of the project is an index ranging once again from 1 (narrowest) to 4 (broadest). An example of a broad scope would be "power-electronic gear boxes for turbogenerators" in relation to a project on power generation, whereas

[6] The analyses concerning the breadth of the field of use and the scope of the project were conducted with the help of a PhD student in civil engineering at the Georgia Institute of Technology, Atlanta, US

an example of a narrow scope is "magnetic oscillator" in relation to a project on watch construction.

We control for whether the industry partner is a startup (STARTUP), the year of foundation of the firm (FOUNDATION), and the size of the firm measured by the number of its employees. We classified the sample of firms according to the following size categories: 1-50, 51-100, 101-500, 501-1000 and >1000. For each of these categories we built a corresponding dummy[7].

Moreover, we control for whether the academic researcher is cash constrained with a variable GRANT that measures the amount of grant money received by the researcher in the five years preceding the conclusion of the contract[8].

With the variable DURATION we control for the duration of a research contract. Finally, we include in our regressions field fixed effects (basic science, small-scale engineering, large-scale engineering, computer science, biotechnology) and year fixed effects.

Table 1: Summary Statistics

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
INDUSTRY_E	1.41	0.61	0	3.34	152
USE_BR	2.32	1.22	1	4	152
PROJECT_SCOPE	2.3	1.21	1	4	152
STARTUP	0.16	0.37	0	1	152
DURATION	24.26	10.26	6	68	152
FOUNDATION	1971.57	43.31	1793	2007	152
GRANT	6.5	3.56	0	10.49	152
D_50	0.55	0.5	0	1	152
D_100	0.08	0.27	0	1	152
D_1000	0.05	0.22	0	1	152
D_1000_PLUS	0.12	0.32	0	1	152

Results

Figure 2 shows the results of the regression. In the first column we present a simple OLS regression of INDUSTRY_E over USE_BR and other controls. As predicted by our model, the coefficient on USE_BR is positive and significant at the 1% significant level. The coefficient is robust to various combinations of the controls.

In the second and third columns we present our two-equation system. We use two-stage least squares with robust standard errors. In the first stage we regress USE_BR on PROJECT_SCOPE and controls. In the second stage we regress INDUSTRY_E on the estimated value of USE_BR and controls. We

[7]The dummies are: D_50, D_100, D_500, D_1000, D_1000_PLUS.

[8]INDUSTRY_EFFORT and GRANT were measured in Swiss Francs and converted into real terms by dividing for the consumer price index available for the years in which the contracts were signed. Both variables are expressed in log.

avoid using nonlinear specifications in the first stage such as ordered logit or probit because the second stage estimations would not be consistent unless the functional form in the first stage were exactly right (Angrist and Krueger, 2001).

In the first stage, the coefficient on PROJECT_SCOPE is positive and significant at the 1% level. This suggests that the greater the scope of the project, the higher the firm's expected return from using the project's result and, thus, the greater the rationale for a broad field of use. In the second stage, the coefficient on USE_BR is positive and significant at the 1% level, confirming our model prediction. The coefficient for GRANT is positive and significant at the 10% level. This suggests that less cash constrained academic researchers may be more willing to assign a broad field of use because they have less difficulty in paying for a license later on. The coefficient for DURATION is positive and significant at the 1% level. Thus, the greater the length of a project, the greater the effort supplied by the firm. The coefficients for STARTUP, D_50 and D_1000 are all positive and significant, indicating a positive relationship between effort and either small or large firms.

Table 2: Regression Results

VARIABLES	(1) INDUSTRY_E	(2) USE_BR	(3) INDUSTRY_E
USE_BR	0.10a		0.26a
	[0.03]		[0.10]
STARTUP	0.36b	0.07	0.37a
	[0.14]	[0.28]	[0.14]
DURATION	0.02a	0.00	0.02a
	[0.00]	[0.01]	[0.00]
FOUNDATION	-0.00	-0.00	-0.00
	[0.00]	[0.00]	[0.00]
LGRANT	0.03b	0.01	0.02c
	[0.01]	[0.03]	[0.01]
D_50	0.21c	-0.49	0.27b
	[0.12]	[0.29]	[0.13]
D_100	-0.15	-0.23	-0.13
	[0.22]	[0.39]	[0.21]
D_1000	0.41c	-0.99	0.50b
	[0.23]	[0.62]	[0.23]
D_1000_PLUS	0.12	-0.37	0.18
	[0.16]	[0.35]	[0.16]
PROJECT_SCOPE		0.39a	
		[0.08]	
Constant	3.18	6.82	2.16
	[2.64]	[5.06]	[2.52]
FIELD FE	YES	YES	YES
TIME FE	YES	YES	YES
Observations	152	152	152
R^2	0.337	0.283	0.258

a: p<0.01, b: p<0.05, c: p<0.1

Robust standard errors in brackets

5 Concluding Remarks

The phenomenon of university-industry technology transfer has been widely studied with special attention to the US model according to which universities retain the IPRs derived from federally funded research.

This study adopts a different perspective and examines a policy regime allowing firms to retain the IPRs over inventions generated from collaboration with academia. This is often the case in European academic institutions when the contribution a firm makes to a project is more important than that of the researcher.

When the firm's participation is determinant for generating an invention, the researcher will offer the ownership of the intellectual property rights to the firm as a lever to induce the latter to collaborate in a project. However, he will retain some domains where he can exploit an invention without having to apply to the firm for a license. Our analysis reveals that the researcher's choice regarding which domains should be retained results from solving a trade-off between inducing the firm's effort, by assigning a broad field of use, and using the project's results in the largest number of applications, by granting a narrow field of use. If the expected returns the firm can realize from the extra domains assigned to it are high, then a broad field of use is the optimal choice. In fact, higher expected returns translate into greater effort by the firm and, therefore, into a higher probability of an invention being generated. On the other hand, when the value the researcher can derive from these domains is sufficiently high to compensate for a lower probability of an invention being realized, then assigning a narrow field of use is optimal.

This case is consistent with collaborations on more applied projects that are closer to the market that to the researcher's laboratory.

When the researcher's effort is determinant for the success of a project, the firm will renounce ownership of the intellectual property rights, which will be assigned to the researcher. In our model there is no conflict of interest between the researcher and his academic institution and, therefore, it does not matter whether the IPRs are assigned to the researcher or the academic institution. The choice the firm makes regarding the field of use is symmetrical to the one the researcher has to make when the firm's effort is determinant for the success of a project. However, if the firm assigns a broad field of use it can apply for a license ex-post, because, unlike the researcher, it is not cash constrained.

Moreover, if effort were contractible, the firm could offer a contract to the researcher stating that the researcher should provide the first best level of effort in exchange for upfront compensation. This contract is feasible because the firm is not cash constrained. However, it is optimal only if the payoff the firm earns is not lower than the payoff it would receive if the researcher did not supply the first best level of effort.

This case is consistent with collaborations on basic applied projects that are closer to the researcher's laboratory than to the market.

We provided some empirical evidence for the case of the firm's effort being more important than the researcher's effort for the success of a project. The results indicate a positive relationship between the breadth of the field of use and the effort supplied by a firm.

Our study highlights the importance of carefully defining ex-ante the field of use in which a partner will exercise its property rights. Survey evidence from

Cockburn (2007) shows that one of the most frequent motivations for wanting to restructure license deals among license partners lies in an inappropriate definition of field of use restrictions. We believe that partners definitely experience greater remorse in the case of research collaborations, where negotiations concerning field of use take place before an invention is generated. Moreover, remorse is likely to affect parties, such as academic researchers, who, on the one hand, are often cash constrained and, on the other, have the potential to use the results of a project in several other applications.

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6 Appendix

Table 3: Distribution of USE_BR and PROJECT_SCOPE

	USE_BR		PROJECT_SCOPE	
	Freq.	%	Freq.	%
1	54	35.53	55	36.18
2	37	24.34	35	23.03
3	19	12.50	23	15.13
4	42	27.63	39	25.66
Total	152	100.00	152	100.00

Table 4: Correlation Coefficients

		1	2	3	4	5	6	7	8	9	10
INDUSTRY_E	1										
USE_BR	2	0.20									
PROJECT_SCOPE	3	0.25	0.35								
STARTUP	4	0.17	-0.04	-0.04							
DURATION	5	0.32	0.04	0.09	-0.13						
FOUNDATION	6	-0.02	-0.11	0.03	0.31	0.00					
GRANT	7	0.13	0.05	0.03	-0.11	-0.04	0.02				
D_50	8	0.07	-0.12	0.05	0.36	-0.16	0.51	-0.07			
D_100	9	-0.18	0.04	0.01	-0.06	-0.03	-0.12	0.09	-0.33		
D_1000	10	0.06	-0.06	0.14	-0.10	0.00	-0.25	-0.01	-0.26	-0.07	
D_1000_PLUS	11	0.07	0.04	-0.08	-0.16	0.20	-0.33	0.16	-0.41	-0.11	-0.09