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RESEARCH OUTPUT FROM UNIVERSITY-INDUSTRY COLLABORATIVE PROJECTS*

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Abstract

We study university projects and research collaboration projects with industry that are supported by government grants. First, we propose a theoretical model to analyze optimal decisions in these ventures. Second, we test our theoretical results with a unique dataset containing academic publications and collaborative research funds for all the academics at the major engineering departments in the UK. We find that universities focus on more basic ventures when they develop projects alone and that the collaboration with firms increases the quantity and quality of the research output only when the firms' characteristics make them valuable partners.

JEL Classification numbers: O32, I23

Keywords: industry-science links, research collaborations, basic versus applied research

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1 Introduction

In the last decades universities have enlarged their entrepreneurial activity in many dimensions, including collaborating with industry in research projects, patenting and licensing, creating science parks, promoting university spin-outs, and investing equity in start-ups (see, for example, Mowery et al., 2004, and Siegel, 2006). Nowadays, the industry considers university-industry collaborative links through joint research, consulting or training arrangements, as important transmission channels (Cohen et al., 2002). As a result, research contracts and joint research agreements are widespread (D'Este and Patel, 2007).

This paper studies the research output of university-industry research collaborations supported by government grants. Project outcomes depend on the type of project and on the level of resources invested by each of the participants. Of particular importance for the partners is the level of basicness or appliedness of the project. Typically, university researchers and laboratories prefer projects of a more basic nature. Firms, in contrast, expect higher benefits from projects that can be more easily applied. Our theoretical analysis makes predictions on the type of research collaboration the participants agree upon and the respective levels of investment. We test our model measuring the direct effect of the partnership characteristics on the type (basic or applied), the number, and the impact of published papers coming out of the project. For comparison purposes, we also study projects that are developed by university researchers only.

In our theoretical model, a university is characterized by the value it allocates to innovative projects, its efficiency in R&D activities, the type of project it prefers (in the basic/applied dimension), and its flexibility to adapt more applied projects to its goals. The firm is also defined by the value, efficiency, most preferred type of project, and flexibility to adapt more basic projects. In our model, the resources that each partner allocates to the venture may depend on its interest in it, namely the type of project to be developed.

The university takes decisions following its own interests when it runs a project by itself. Therefore, it chooses the type of project that it prefers and the level of investment that maximizes its objective function. This investment increases with the value the university allocates to each publication and with its scientific level, and it decreases with the cost of the investment.

When the project is the issue of the relationship between a university and a firm, then the partners need to agree on the definition of the project. In this case, we assume that the participants running the collaborative project reach an efficient agreement. The partnership decides on a type of project that takes into account the interest of both participants and it is chosen to minimize the frictions due to the fact that the university prefers a more basic project than the firm. The project lies closer to the most preferred type to the firm as the value it allocates to the outcome increases and as the cost it suffers from moving away from its ideal project increases (and similarly for the university). Both partners boost their investment when they place more value on the output and when their interests are more aligned. Investment is also increasing in their technical and scientific level and it is decreasing in the costs they suffer. Through the investment decisions, the characteristics of the partners affect the quantity and quality of the research output.

As is apparent from the previous results, when the university develops the project on its own, we expect it to focus on more basic ventures than in a situation where it collaborates with firms. The comparison of the research output obtained in the two scenarios is not so clear. On the one hand, the quantity and quality of the output in collaborative projects should be higher because more partners invest and also because the total worth of the output is higher, as it is valuable for both the university and the firm. On the other hand, there are costs associated to the collaboration, in particular because university researchers and firm employees often have difficulties working together. Therefore, we expect the collaboration with firms to improve the final outcome when the firms' characteristics make them valuable partners while it might be detrimental otherwise.

To test our theoretical findings, we construct a dataset containing academic research output (publications) and collaborative research funds for all the academics employed at the major engineering departments in the UK. We concentrate on the engineering sector, as it has traditionally been associated with applied research and industry collaboration and it contributes substantially to industrial R&D (Cohen et al., 2002). We measure the research output of projects that are scientific in nature and that receive funding from the Engineering and Physical Sciences Research Council (EPSRC), the UK government agency for funding research in engineering and the physical sciences. The EPSRC selects projects based on their scientific content. The grants are run by academic researchers, but they may involve partners from industry. We study the effects of collaborative agreements with the industry by analyzing, within the pool of projects financed with the grants, the publications obtained by the researchers involved in projects with and without industry partners.

For each EPSRC project in which the engineering academics participated, we identified all the articles in the ISI Science Citation Index (SCI) published between 2008-2010 that cite them as a funding source. We take both the normal count and the impact-factor weighted count of publications as measures of quantity and quality of the research output. The characteristics of the project are based on the Patent Board classification, version 2005, developed by Narin et al. (1976), which classifies journals according to their general research orientation. We associate an index taking into account the basic-applied nature of the journal. As proxies for the partners' characteristics, we associate two indices to each university researcher and each firm that reflect the average basicness-appliedness type of his or her past publications and the number and impact of their publications in the period 2002-2007. To be able to perform our analysis with a comparable dataset, we consider projects that generated at least one classified publication, and have researchers and firms with at least one classified publication. We end up with a final, representative sample of 487 research projects, 187 of which are collaborative and 300 non-collaborative.

First, we regress the project's output type with respect to the index of the researchers and the firms. In line with the results in our theoretical exercise, we obtain that the appliedness of the output is increasing in the appliedness of both the university and firm partners. We also find that the effect of the appliedness of the researcher is stronger, which suggests that the results are more valuable for the universities than for the firms and/or that the firms are more flexible than the universities.

Second, we consider the output of the project measured in terms of number of publications and their impact factor. As expected, the effect of funding has a positive and highly significant effect on the number and quality of publications. More efficient university researchers also significantly improve the quantity and quality of the research output. In contrast, the effect of the publications of the firms is more complex: the intercept is negative and the slope is positive. This indicates that, as suggested by the theoretical model, collaboration with firms with poor publication records (which may indicate low level of scientific knowledge and low absorptive capacity) leads to lower scientific output than a project developed by universities alone. However, as the publications of the industry partners increase, the quantity and quality of the research output improves and it becomes higher than the output produced by university projects.

Our theoretical model is related to the contribution by Pereira (2007). She proposes a model to analyze the type of project that is decided in a collaborative agreement. Her objective is to emphasize that the characteristics of partnership agreements are the result of an optimal contract between partners when informational problems are present. She shows how two different structures of partnership governance - centralized and decentralized - may optimally use the type of project to motivate the supply of non-contractible resources. Lacetera (2009) takes the viewpoint of the firm and builds a model to study whether it is optimal for a firm to conduct some research activities in-house or to outsource them to academic organizations. He focuses on the potential value of the commitment due to the outsourcing of the activity and on the discrepancy between scientific and economic value of the projects.

In terms of evidence, survey studies (e.g., Blumenthal et al., 1986, and Gulbrandsen and Smeby, 2005) report that the choice of research topics of academics whose research is supported by industry were biased by their commercial potential.[1] Some papers have tried to find evidence for this negative (so-called "skewing") effect indirectly: by measuring the effect of industry collaboration on researcher publication patterns. Some papers use patenting and licensing as measures of industry collaboration (Azoulay et al., 2009; Breschi et al., 2008; Calderini et al., 2007; Hicks and Hamilton, 1999; Thursby and Thursby, 2002, 2007; van Looy et al., 2006) while others use collaborative research agreements (Banal-Estañol et al., 2010). On the other hand, Veugelers and Cassiman (2005) also find evidence of a change of behavior in the other side: collaboration with universities lead

[1] As Dasgupta and David (1994) pointed out, the goals and the incentives received from the institution scientists works for shape their preferences in terms of research. The links with the industry, while they have many positive consequences for the economy, have also raised concerns about the detrimental effects that more market-oriented activities may have on pure scientific production. The interests of the industry may divert university researchers from their main duty and some voices have pointed out that the increased secrecy and shifts in research interests may be an important concern.

firms to more basic oriented-research. We depart from these two streams of literature in two dimensions. First, we take into account the type of researchers and firms with which the researcher and the firm collaborate with. Second, we measure the impact a university-industry collaboration has on the specific project.

The literature has also studied the effect of industry collaboration on the quantity and quality of academic research output. Survey studies suggest that industry involvement is linked to higher academic productivity (e.g., Gulbrandsen and Smeby, 2005). Using patenting and licensing as collaboration measures, empirical papers find that patenting either does not affect publishing rates (Agrawal and Henderson, 2002, and Goldfarb et al., 2009) or that the patenting and the quantity and quality of research output are positively related (Azoulay et al., 2009; Breschi et al., 2008; Calderini and Franzoni, 2004; Calderini et al., 2007; Fabrizio and DiMinin, 2008; Stephan et al., 2007; van Looy et al., 2006). Buenstorf (2009), however, stresses that the effect might depend on the type of university-industry relationship. Using collaborative research as measure of industry involvement, Manjarres-Henriquez et al. (2009) and Banal-Estañol et al. (2010) uncover an inverted U-shape relationship between industry collaboration on academic research output. The negative effect of high-collaboration levels is also consistent with the survey results in Blumenthal et al. (1986) and the empirical evidence on NASA-funded academic researchers in Goldfarb (2008).

The rest of the paper proceeds as follows. The next section presents our theoretical framework explaining the preferences and parameters describing the universities and the firms. In Section 3 we describe the characteristics optimal project depending on the researchers, and possibly the firms, that participate in it. We suggest some static comparative results concerning the type of project and the output as a function of whether the project involves an industry partner or not. We describe our database and test our predictions in Section 4. Finally, in Section 5 we conclude.

2 The model

We introduce a simple model to analyze the optimal decisions taken by the participants in research projects that receive financing by the government. We address two questions:

which type of projects they chose and how much investment (effort, know-how and additional resources) they put into the project. Some of the projects only involve university researchers while others include both university researchers and firms. We start describing those projects where only universities participate and later focus on university-industry collaborative projects.

2.1 University projects

We consider a university U (we will refer to the team of university researchers that obtained a project as a university) that has achieved financing I_M to develop a particular research project. The benefits that U obtains from the project depends on several parameters and decisions. One of them is the level of basicness (or alternatively appliedness) of the project. We represent the appliedness by the parameter x, where $x = 0$ corresponds to the most basic project, and the level of appliedness increases with x. We denote university U´s most preferred variety by x_U.

We consider research projects; therefore, we identify the research output as publications. We abstract from other results, such as patents or generation of transfer of know-how. University U gives value v_U to each publication of a project of type x_U.[2] A publication has less value for U if x is different from x_U; the larger the distance $|x - x_U|$, the larger the loss in value. In the spirit of the Hotelling model, we model this loss as "transportation costs" depending on the distance. We assume that the value for U of a research output in a project x is

$$\left(1 - t_U \left(x_U - x\right)^2\right) v_U.$$

The number of publications depends on the investment I_U made by U as well as on the amount I_M obtained from the government. We think of I_U as reflecting the level of involvement of the researchers working on the project, the possible additional financing by the research lab, etc. The number of publications also depends on the parameter δ_U, which describes the efficiency of U. Hence, δ_U measures the scientific level of U, the

[2] We use publications as a one-dimension variable. Since both quantity and quality (impact factor) of the publications matter, we can interpret that one average-quality publication gives v_U to U. A high-quality (high-impact) publication gives a value similar to several average-quality publications.

patents and know-how it owns, the quality of the labs, etc. We assume that the number of results is given by $\delta_U I_U + I_M$. We will also interpret $\delta_U I_U + I_M$ as an index that reflects both the number and the quality of the publications. That is, the resources can be devoted to increase the quantity or the quality of the papers. Both parameters enter in a similar manner in the utility of the participants in the project.

Therefore, the net expected profits of U are

$$\pi_U(x, I_U) = (\delta_U I_U + I_M)\left(1 - t_U (x_U - x)^2\right) v_U - \frac{c_U}{2} I_U^2$$

where the last term reflects the cost of the investment.

2.2 University-industry collaborative projects

Consider now the relationship between firm F and university U who collaborate on a project with government financing I_M. There are important benefits for industrial and academic collaborations. These agreements give firms access to highly qualified scientists and help them keep up-to-date with new ideas and explore the applications of new scientific discoveries. Academics may provide assistance with experimentation, access to the analytic skills of the university, or the use of equipment (e.g., Veugelers and Cassiman, 2005). Universities may also benefit from the access to new questions and research funds. In addition, research partners can exploit economies of scale and scope in the generation of R&D and benefit from the synergies related to exchanging and sharing complementary know-how.

We model the firm's objective function in a similar manner as the university's objective function. We denote F's most preferred type of project by x_F and t_F is the parameter that represents the transportation costs for F. Firms' interests are more applied than universities' interests; therefore, we consider $x_F > x_U$.The impact of a firm's investment depends on the parameter δ_F, which represents the technical and scientific level of F, its absorptive capacity, the level of its human capital, etc. Finally, firm F gives value v_F to each publication of a project of type x_F. We may think of v_F as also reflecting the know-how or applied knowledge acquired during the research that leads to the publication.

The participants must agree on the "variety" x of their project. The pair $F - U$ will define a collaborative project x in the interval $[x_U, x_F]$ since any project more applied than

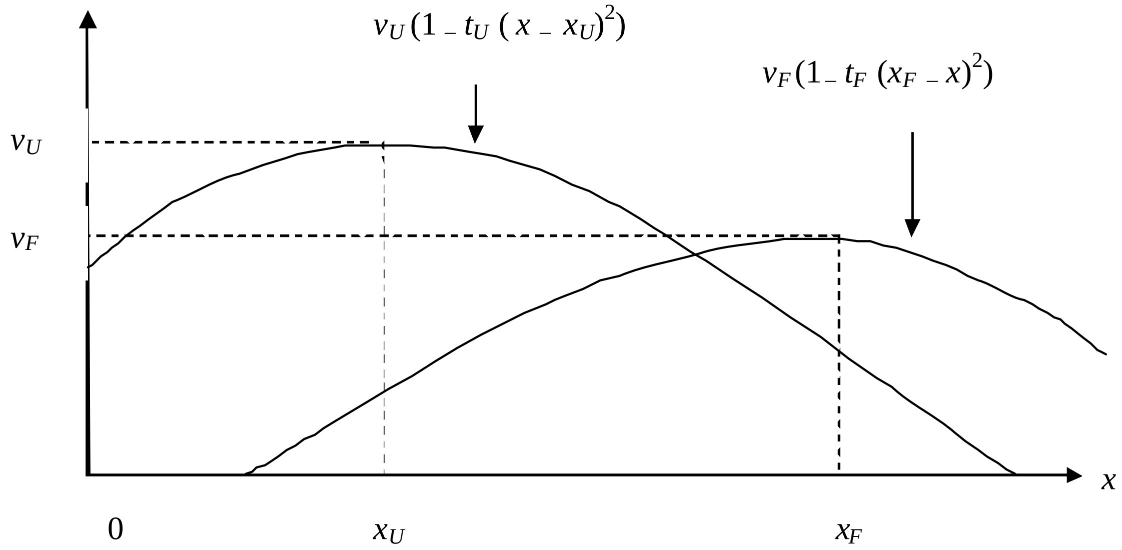

Figure 1: Value of the output for the university and the firm

x_F is dominated for both the firm and the university by the project x_F, and similarly for projects of a more basic nature than x_U.

Figure 1 represents the value of a success for F and U, as a function of the type of project x. We assume that the value of the collaborative agreement is always non-negative for both the firm and the university, which requires that the transportation costs are not too large: $t_U (x_F - x_U)^2 \leq 1$ and $t_F (x_F - x_U)^2 \leq 1$.

In the collaborative projects, the number of publications depends on the investment made by both participants, I_U and I_F, in addition to I_M. We assume that this number is given by $\delta_F I_F + \delta_U I_U + I_M$. Therefore, the net expected profits of F and U from the collaborative projects are respectively

$$\begin{aligned} \pi_F(x, I_F, I_U) &= (\delta_F I_F + \delta_U I_U + I_M) \left(1 - t_F (x_F - x)^2\right) v_F - \frac{C_F}{2} I_F^2 \\ \pi_U(x, I_F, I_U) &= (\delta_F I_F + \delta_U I_U + I_M) \left(1 - t_U (x - x_U)^2\right) v_U - \frac{C_U}{2} I_U^2 \end{aligned}$$

where $\frac{C_F}{2} I_F^2$ represents the cost of investment I_F for F and $\frac{C_U}{2} I_U^2$ the cost of I_U for U. We allow the university's cost of the investment to reflect the difficulties that researchers often encounter when they work with firms: $C_U \geq c_U$.[3] Indeed, there is evidence that research collaboration often carries coordination costs due, among others things, to the difference in culture, priorities and values of universities and firms (e.g., Dasgupta and David, 1994; Champness, 2000; Cummings and Kiesler, 2007; and Lacetera, 2009).

Our model of university-industry collaboration is similar to the proposal by Pereira (2007), although we introduce two modifications: we consider a quadratic form for the transportation costs and we add the term I_M to reflect the financing that the project receives from the government. Hence the collaborative agreement is defined by the parameters identifying the firm F, the vector $(x_F, v_F, t_F, \delta_F, C_F)$, and the ones identifying the university U, the vector $(x_U, v_U, t_U, \delta_U, C_U)$.

3 Optimal projects

3.1 Optimal university projects

The university chooses the type of project x and the level of investment I_U that maximizes its profits $\pi_U(x, I_U)$, possibly taking into account the level of government financing I_M. Given that U does not have to reach any compromise, it will select the type of project that best suits its interest, x_U, and the level of investment that maximizes its profits. Proposition 1 states the characteristics of the optimal university project.

Proposition 1 *The optimal university project $P^o = (x^o, I_U^o)$, when U has characteristics $(x_U, v_U, t_U, \delta_U, c_U)$, is*

$$\begin{aligned} x^o &= x_U \\ I_U^o &= \frac{\delta_U}{c_U} v_U. \end{aligned}$$

As it was expected, the level of university investment I_U^o increases with the value it allocates to each publication, v_U and with its scientific level δ_U, while it decreases with the cost of the investment, c_U.

[3]The cost C_F can also reflect the difficulties that firms face when working with university researchers. Given that we will not analyze projects carried out by firms alone, this effect is without consequence.

Proposition 1 also allows the easy calculation of the number of publications $N^o = \delta_U I_U^o + I_M$, as a function of the exogenous variables:

$$N^o = \frac{\delta_U^2}{c_U} v_U + I_M.$$

As explained before, N^o reflects the quantity and quality of publications. For convenience, we will refer to it as number of publications.

We state the variation of N^o with respect to the exogenous variables in Corollary 1.

Corollary 1 *The number of publications N^o increases with the value of each research output v_U and with the university scientific level δ_U, as well as with the amount of the grant I_M. It decreases with the investment cost c_U.*

3.2 Optimal collaborative projects

The participants F and U in any collaborative project will reach an agreement that we denote $A = (x, I_F, I_U)$ in terms of type of project x and investment levels (I_F, I_U). In addition, F and U may set a monetary transfer $T \in \mathbb{R}$ (we take the convention that T is a transfer from F to U, which can be positive or negative). Therefore, a collaborative agreement starts with the signing of a contract (A, T) between F and U.

Given that it is possible to transfer expected profits from the firm to the university and vice-versa through T, F and U have incentives to sign an optimal agreement, $A^* = (x^*, I_F^*, I_U^*)$, which corresponds to the vector $A = (x, I_F, I_U)$ that maximizes the joint profits $\Pi(x, I_F, I_U) \equiv \pi_F(x, I_F, I_U) + \pi_U(x, I_F, I_U)$ with respect to the terms of the agreement.[4] The firm and the university will indeed sign the agreement if the joint profits $\Pi(x^*, I_F^*, I_U^*)$ are higher than the sum of their outside opportunities. The transfer T will be fixed so that each partner obtains at least its outside opportunity.

Next proposition provides the optimal agreement $A^* = (x^*, I_F^*, I_U^*)$.

[4] We abstract from moral hazard issues concerning the free-riding problem that may arise in collaborative agreements (see, for example, Pérez-Castrillo and Sandonis, 1996, for the moral hazard problem linked to the disclosure of know-how in Research Joint Ventures; Pereira, 2007, for university-firm collaborations; and Lerner and Malmendier, 2010, for cases where the funding can be diverted to other projects).

Proposition 2 *The optimal agreement* $A^* = (x^*, I_F^*, I_U^*)$ *for* F *and* U*, with characteristics* $(x_F, v_F, t_F, \delta_F, C_F)$ *and* $(x_U, v_U, t_U, \delta_U, C_U)$ *respectively, is*

$$\begin{aligned} x^* &= \frac{t_F v_F}{t_F v_F + t_U v_U} x_F + \frac{t_U v_U}{t_F v_F + t_U v_U} x_U \\ I_F^* &= \frac{\delta_F}{C_F}\left(v_F + v_U - \frac{t_F v_F t_U v_U}{t_F v_F + t_U v_U}\left(x_F - x_U\right)^2\right) \\ I_U^* &= \frac{\delta_U}{C_U}\left(v_F + v_U - \frac{t_F v_F t_U v_U}{t_F v_F + t_U v_U}\left(x_F - x_U\right)^2\right). \end{aligned}$$

The optimal type of the project x^* in the collaborative agreement lies closer to the optimal firm's type x_F (and farther from x_U) as the firm's value v_F increases (or v_U decreases) and also as the cost t_F of moving from its ideal project increases (or t_U decreases). The reaction of the optimal investment levels with respect to the exogenous parameters is provided in Corollary 2.

Corollary 2 *Both investments* I_F^* *and* I_U^* *are increasing in the values* v_F *and* v_U *and decreasing in the transportation costs* t_F*,* t_U *and in the distance between the most preferred types of project* $(x_F - x_U)$*. Moreover,* I_F^* *is increasing in the firm's technical and scientific level* δ_F *and decreasing in the cost* C_F*. Similarly,* I_U^* *is increasing in the university's scientific level* δ_U *and decreasing in the cost* C_U*.*

Finally, we can compute the number of research outputs $N^* = \delta_F I_F + \delta_U I_U + I_M$ that comes out of the research collaboration under the optimal agreement:

$$N^* = \left(\frac{\delta_F^2}{C_F} + \frac{\delta_U^2}{C_U}\right)\left(v_F + v_U - \frac{t_F v_F t_U v_U}{t_F v_F + t_U v_U}\left(x_F - x_U\right)^2\right) + I_M.$$

Corollary 3 shows the effect of changes in the exogenous parameters on the number of publications N^*.

Corollary 3 *The number of publications* N^* *increases with the value of each research output* v_F *and* v_U*, with scientific and technical level* δ_F *and* δ_U*, as well as with the amount of the grant* I_M*. It decreases with the investment costs* C_F *and* C_U *and with the distance* $(x_U - x_F)$*.*

3.3 Research outcomes in university versus collaborative projects

The two main elements decided by the participants in a project are first, the type of project, that is, its degree of appliedness and second, the level of investments, which influences the number of publications achieved in the project.

The comparison between the type of project that we expect when the university develops one alone, x^o, versus a situation where the university collaborates with firms, x^*, is immediate: $x^o < x^*$. That is, there are no reasons for U to deviate from its most preferred type in a university undertaking while the type of project in a collaborative agreement reflects the interest of both the university and the firm.

The analysis of the comparison of the number of publications by the university and collaborative projects shows that a trade-off may exist. On the one hand, there are two clear reasons that suggest that collaborative projects should be more productive than university projects. First, both partners invest in a collaborative project. This effect is reflected in the presence of the term $\left(\frac{\delta_F^2}{C_F} + \frac{\delta_U^2}{C_U}\right)$ in N^* while the corresponding term is $\frac{\delta_U^2}{c_U}$ in N^o. Second, both partners are interested in the project, which increases the value of each publication from v_U in N^o to $\left(v_U + v_F - \frac{t_F v_F t_U v_U}{t_F v_F + t_U v_U}\left(x_F - x_U\right)^2\right)$ in N^*. On the other hand, as argued above, for the university, collaborative projects tend to be more difficult to develop than university projects. We have reflected this additional cost in the difference between c_U and C_U.

We should expect N^* to be higher than N^o whenever δ_F is high enough and/or whenever $v_F - \frac{t_F v_F t_U v_U}{t_F v_F + t_U v_U}\left(x_F - x_U\right)^2$ is high enough. In fact, if the second term is large, $N^* > N^o$ for any δ_F while $N^* < N^o$ when $v_F - \frac{t_F v_F t_U v_U}{t_F v_F + t_U v_U}\left(x_F - x_U\right)^2$ is small and δ_F is low. We draw the two possible cases as a function of the parameter δ_F in Figure 2. The one on the right accounts for the cases having C_U significantly higher than c_U, v_U much above v_F, high transportation costs and high distance among preferred project, $\left(x_F - x_U\right)$. These reasons lead to the fact that for low levels of δ_F the output of a collaborative project is inferior to a non-collaborative one.

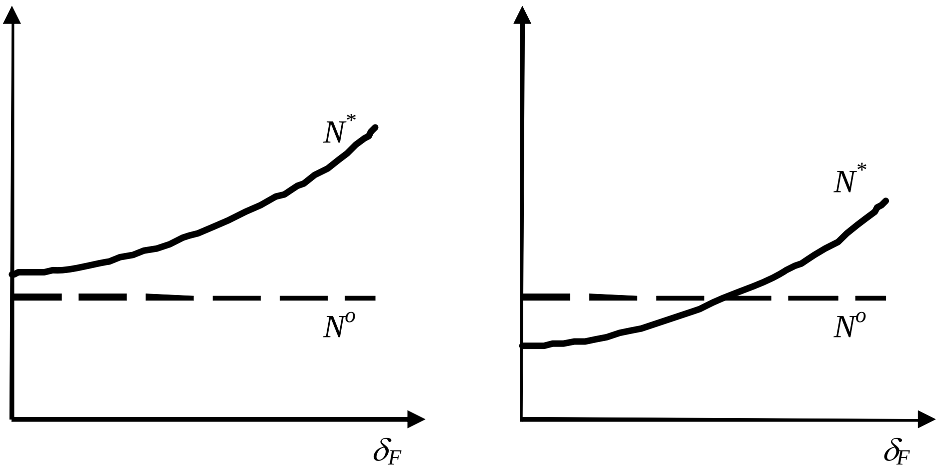

Figure 2: Number of research outputs in university and collaborative projects

4 Empirical evidence

4.1 Data and descriptive statistics

Our research projects are based on grants given by the Engineering and Physical Sciences Research Council (EPSRC), the main UK government agency for funding research in engineering (amounting to around 50% of overall funding of engineering department research projects). Some of these grants include one or more firms as industry partners and are considered "collaborative grants". As defined by the EPSRC, "Collaborative Research Grants are grants led by academic researchers, but may involve other partners. Partners generally contribute either cash or 'in-kind' services to the full economic cost of the research." The EPSRC encourages research in collaboration with the industry. As a result, around 35% of EPSRC grants presently involve partners from industry. These mediated partnerships allow for a comprehensive and homogeneous insight into the dynamics of university-industry collaborations.

Our starting point is the uniquely created longitudinal dataset in Banal-Estañol et al. (2010), which contains information on all researchers employed at the engineering departments of 40 major UK universities between 1985 and 2007. We identify all their articles in the ISI Science Citation Index (SCI) that named the EPSRC as a funding source. The Web of Knowledge has been systematically collecting information on funding sources from the acknowledgements since 2008. We consider only those articles that specify the grant number codes. Of course, some publications have been funded by multiple EPSRC funds and some EPSRC projects generate more than one publication.

We analyze the articles that acknowledge an EPSRC project as a funding source in the period 2008-2010, as well as the publications of the researchers and firms of those projects in the period 2002-2007. We use the normal count of publications as proxy of the project's research output or input. We do not discount for the number of EPSRC funding sources of each publication as we do not have funding information about non-EPSRC sources. As a second measure, we also consider the "impact-factor-weighted" sum of publications, with the weights being the impact attributed to the publishing journal. To compute it, we use the SCI Journal Impact Factor (JIF), a measure of importance attribution based on the number of citations a journal receives to adjust for relative quality. Though not a direct measure for quality, the JIF represents the impact attributed to a particular journal by peer review. As the JIF of journals differs between years, and journals are constantly being added to the SCI, we use the closest available to the date of publication.

As an indicator of the type of publication we use the Patent Board (formerly CHI) classification (version 2005), developed by Narin et al. (1976) and updated by Kimberley Hamilton for the National Science Foundation (NSF). Based on cross-citation matrices between journals, it characterizes the general research orientation of journals, distinguishing between (1) applied technology, (2) engineering and technological science, (3) applied and targeted basic research, and (4) basic scientific research. Godin (1996) and van Looy et al. (2006) reinterpreted the categories as (1) applied technology, (2) basic technology, (3) applied science, and (4) basic science; and grouped the first two as "technology" and the last two as "science". Following their definition, we define the level of appliedness of a set of articles as the number of publications in the first two categories divided by the number of publications in the four categories. Some of the articles were published in journals that had not been classified and are therefore discarded in the calculation of level of appliedness.

Our data set consists of projects with at least one classified publication in the project output, at least one in the university input and at least one in the firm input. This left us with a final sample of 487 research projects, 187 of which are collaborative (involving at least one industrial partner) and 300 are non-collaborative. For ease of comparison, we keep the same sample throughout the paper.

Project output Tables 1 and 2 provide descriptive statistics of the output of the project. Our sample set of publications citing at least one of the 487 EPSRC projects up to December 31, 2010, contains 1,286 publications once we concentrate on the projects on engineering, having the reference number of the project and having appeared in a journal that is in one of the four categories explained above. The average number of publications in a research project in the period 2008-2010 is 2.64 but the dispersion is high, with a standard deviation of 3.35. The most prolific project generated 47 recorded publications. If we take the sum of the impact factors of the journals in which the publications are published, projects have an average of 7.91 but again dispersion is high.

As we can see in the first four columns of Table 2, projects contain on average a non-negligible amount of publications in each of the four categories. Categories 2 and 3 have the highest number of publications (0.78 and 0.63 on average) and category 1, the lowest (0.16 on average). The average level of our measure of appliedness is around 0.52. However, there is large difference in this level between university and collaborative projects: the average level of appliedness is 0.62 for the 187 projects that include firms while it is only 0.45 for the 300 university projects.

University input We use the information on all the articles published by 1066 the matched researchers in the last five years of the database (2002-2007).[5] We consider again the total number of publications, the impact-factor-weighted sum of publications and the total number of publications of each orientation category.

As shown in Table 1, the average researcher in our database published 22.98 articles over the five-year period. The total impact factor of the average researcher is over 56.

[5]Most entries in the SCI database include detailed address data that helps to identify institutional affiliations and unequivocally assign articles to individual researchers. Publications without address data had to be ignored. However, this missing information is expected to be random and to not affect the data systematically.

As shown in Table 2, the average publication of the average researcher is more applied (0.58) than the average publication coming out of the project (0.52). This is probably due to the fact that past publications might also contain outputs from contract research and other collaborative projects with industrial partners.

We consider the average of the researchers in each project because we do not have information about some of the researchers in the same project (they are not in the dataset because they might be from other universities or from fields outside engineering). However, the number of missing researchers per project is small: the average number of researchers in our sample is 2.18 while it is 2.37 if we would also include those for whom we do not have information.

Government funding and firm input We also match our database with that of the EPSRC. The EPSRC database contains information on start year and duration of the grant, total amount of funding, names of principal investigators and coinvestigators, and names of the (potentially multiple) partner organizations. Most of the partner organizations are private companies but in some cases they can also be government agencies or other (mostly foreign) universities. We consider the private companies only. We collected information on all the unique articles published by the employees of these companies between 2002 and 2007. We consider again the total number of publications, the impact-factor-weighted sum of publications, the total number of publications of each orientation category. For each of these variables, we also compute the average of all the industrial partners in each project. We use the same measure of appliedness for the project partners as the one we use for the project output and for the project researchers.

We have 187 projects that have at least one firm research partner. Of those, the average number of partners is more than three. In each project, the average number of publications of the firm partners over the five-year period is more than 1,000. If weighted by the journal impact factor, the number is above three thousand. The quantity and the quality of the research output of the firm is a combined measure of firm size and scientific level of the average researcher in the firm.

Notice that the publications of the firms are less applied than those of the researchers (0.55 versus 0.58). This may be due to the difficulties that industry researchers face to publish their most applied work, due to a requirement of secrecy. The appliedness index of the publications that researchers involved in collaborative projects is 0.63, superior to the ones running non-collaborative ones (0.55). Therefore, we only observe the outcome of their research that is of a more basic nature, with less perspectives of industrial application.

4.2 Regression results

Table 3 provides the results on the type of the output of the project. We regress the level of appliedness of the output of the project on the average level of appliedness of the researchers and on the average level of appliedness of the firms. We allow the effect of the researcher to differ in collaborative and non-collaborative projects. We report both the regressions which do not and those that do take logs of all the variables. In the latter, the coefficients can be interpreted as elasticities.

As predicted by the theory, the appliedness of the output is increasing in the appliedness of both university and firm partners. Both effects are highly significant but the effect of the appliedness of the researcher is stronger. As we can see in the second column, an increase in one percentage point in the appliedness of the researchers increase the appliedness of the project by 0.71 percentage points. The same increase in the appliedness of the firms increases the appliedness of the output by 0.2 percentage points. The effect of the researcher is not significantly different in collaborative and non-collaborative projects.

As a robustness check, we perform the same regression using the number of publications in category 1 with respect to the total classified number of publications. Again, the appliedness of the output increases with the appliedness of both the university and firm partners. The effects are less strong but all except one are still highly significant. Using this measure, the effect of the researcher is significantly stronger in collaborative projects. For the same change in the level of appliedness of the researcher, the output is more applied.

Table 4 provides the results on the quantity and quality of the output of the project. Using both the normal count and the impact-factor-weighted count of publications, we regress the count of publications of the project on the total funding, on the average count of publications of the researchers and on the total count of publications of the firm partners. As a robustness check, we also include the same regression with the average number of the publication partners in Table 5. We allow for an intercept on the number of publications of the firm to separate collaborative with non-collaborative projects (non-collaborative projects are the only ones that have a zero publication number).

As expected, the effect of funding is positive and highly significant in all the regressions in Table 4. More efficient university researchers also significantly improve the quantity and quality of the research output. An increase in one percent in the publication researcher record increase the count of publications by 0.066 percentage points and the weighted count by 0.247 percentage points.

The effect of the publications of the firms is curvilinear, as the intercept is negative and the slope is positive. The effects are highly significant in the four columns except for the case in which we take logs in the normal count of publications. As a result, having firms with poor publication records is worse than having no firm partner at all. However, as the publications of the firm partners increase, the quantity and quality of the research output improves. Figure 3 plots the predicted values for the count of publications. The effect of having partners with a mean count of firm publications is not positive nor negative. Similar effects are obtained if we use the average number of publications of the set of firm partners instead of the total, as we can see in Table 5, although the effects are less significant.

In the last two columns of Table 4, we include the number of firms as an additional regressor. The linear effects of the scientific level of the researchers and firms are similar. Here, the intercept is still negative but insignificant, but the new continuous variable of the number of firms is negative and highly significant. The interpretation of this result is that, for a given number of publications of the firm partners, collaborating with less would be better. This is again consistent with our theory, which would suggest higher costs if a researcher collaborates with more firms.

5 Conclusion

In this paper, we provide both a theoretical analysis and empirical evidence on the types, quantity and quality of the outcomes of university-industry collaborative projects. Our theoretical model posits that the project type takes into account the interests of both universities and firms and minimizes the frictions between the university's basic interests and the firm's applied interests. Projects are more basic if universities attach greater value to the project or suffer more from developing an applied project. Similarly, projects are more applied if firms attach greater value to the project or suffer more from collaborating in a basic project. We also show that participant investment levels are greater when their output valuations increase and when their interests are more aligned. Investment is also increasing in their technical and scientific level and decreasing in the costs they suffer. Through the investment decisions, the characteristics of the partners affect the quantity and quality of the research output.

The empirical evidence supports the theoretical predictions. The level of appliedness of the project output is significantly affected by the level of appliedness of the university participants and the level of appliedness of the firm participants. More basic researchers generate more basic output and more applied firms generate more applied output. We find no difference on the effect of researchers in collaborative and non-collaborative agreements. We also find the projects in which more prolific researchers and more prolific firms work generate more and better publications.

In comparison, our theoretical results show that universities should produce more basic outputs if they do not collaborate with industry. But, the effect of industry collaboration on the project's quantity and quality of the research output can have two opposite effects. On the one hand, collaboration increases investment levels, both because partners bring resources and because the academics have more incentives to invest. On the other hand, having collaborative partners increases the cost of the project because they might find difficulties in working together. Industry partners therefore improve project outcomes only if they are valuable partners.

Again consistent with the theory, our empirical evidence shows that firm partners with low publication records decrease the quantity and quality of the project output whereas those with high levels improve project outcomes. According to our linear model, collaborating with firms which have publication records below the mean is worse than not collaborating with any firm. This means, again taking our model at face value, that collaborating with 80% of the firms in our sample decreases the number of publications of the project. Collaborating with firms, of course, can also have other advantages besides the impact on the publication numbers.

Still, one of the main contributions of this paper is to emphasize the importance of taking into account the type of firms with which university researchers collaborate, and not only the number of firms. Emphasizing collaboration with the right type of firm should be a beneficial policy. Our empirical analysis suggests that collaborating with large firms that have a high average scientific level improves the research output of government grants.

6 Appendix

Proof of Proposition 1. The university solves the following program:

$$\underset{x,I_U}{Max}\left[(\delta_U I_U + I_M)\left(1 - t_U\left(x - x_U\right)^2\right)v_U - \frac{c_U}{2}I_U^2\right]$$

It is immediate that $x^o = x_U$ and

$$\frac{\partial \Pi}{\partial I_U} = \delta_U\left(1 - t_U\left(x - x_U\right)^2\right)v_U - c_U I_U.$$

Therefore, the FOC $\frac{\partial \Pi}{\partial I_U} = 0$ implies $I_U^o = \frac{\delta_U v_U}{c_U}$. ■

Proof of Proposition 2. The optimal agreement A^* solves the following program:

$$\underset{x,I_F,I_U}{Max}[(\delta_F I_F + \delta_U I_U + I_M)\left(\left(1 - t_F\left(x_F - x\right)^2\right)v_F + \left(1 - t_U\left(x - x_U\right)^2\right)v_U\right)$$
$$-\frac{C_F}{2}I_F^2 - \frac{C_U}{2}I_U^2].$$

The objective function is concave in its arguments. Taking derivatives of Π with respect to the endogenous variables, we obtain

$$\begin{aligned}\frac{\partial\Pi}{\partial x} &= (\delta_F I_F + \delta_U I_U + I_M)\, 2(t_F\,(x_F - x)\, v_F - t_U\,(x - x_U)\, v_U),\\ \frac{\partial\Pi}{\partial I_U} &= \delta_U\left(\left(1 - t_F\,(x_F - x)^2\right) v_F + \left(1 - t_U\,(x - x_U)^2\right) v_U\right) - C_U I_U,\\ \frac{\partial\Pi}{\partial I_F} &= \delta_F\left(\left(1 - t_F\,(x_F - x)^2\right) v_F + \left(1 - t_U\,(x - x_U)^2\right) v_U\right) - C_F I_F.\end{aligned}$$

From the first derivative with respect to x we see that the solution is always interior and defined by

$$x^* = \frac{t_F v_F}{t_F v_F + t_U v_U} x_F + \frac{t_U v_U}{t_F v_F + t_U v_U} x_U.$$

From the derivative with respect to I_U and I_F, we obtain the optimal levels of investment that, taking into account the optimal type of project x^*, can be written as:

$$\begin{aligned}I_F^* &= \frac{\delta_F\left(1 - t_F\,(x_F - x^*)^2\right) v_F + \left(1 - t_U\,(x_U - x^*)^2\right) v_U}{C_F}\\ I_U^* &= \frac{\delta_U\left(1 - t_F\,(x_F - x^*)^2\right) v_F + \left(1 - t_U\,(x^* - x_U)^2\right) v_U}{C_U}.\end{aligned}$$

After easy calculations, we obtain the expressions for I_F^* and I_U^* in the Proposition.

Finally note that the investments are positive and the second-order conditions hold. ■

Proof of Corollary 2. Denoting $Y = v_F + v_U - \frac{t_F v_F t_U v_U}{t_F v_F + t_U v_U}(x_F - x_U)^2$, the derivatives for $i = F, U$ are $\frac{\partial I_i^*}{\partial \delta_i} > 0$, $\frac{\partial I_i^*}{\partial C_i} < 0$ and $\frac{\partial I_i^*}{\partial Y} > 0$. Moreover, $\frac{\partial Y}{\partial (x_F - x_U)} = -2\frac{(t_F v_F)^2 v_U}{(t_F v_F + t_U v_U)^2}(x_F - x_U) < 0$, $\frac{\partial Y}{\partial t_U} = -\frac{(t_F v_F)^2 v_U}{(t_F v_F + t_U v_U)^2}(x_F - x_U)^2 < 0$ and $\frac{\partial Y}{\partial v_U} = 1 - \frac{(t_F v_F)^2 t_U}{(t_F v_F + t_U v_U)^2}(x_F - x_U)^2 \geq 1 - \frac{(t_F v_F)^2}{(t_F v_F + t_U v_U)^2} > 0$. The derivatives $\frac{\partial Y}{\partial t_F}$ and $\frac{\partial Y}{\partial v_F}$ are similar. ■

Proof of Corollary 3. The proof is immediate after Corollary 2. ■

References

[1] Agrawal, A. and Henderson R. (2002): "Putting patents in context: Exploring knowledge transfer from MIT", *Management Science* 48, 44-60.

[2] Azoulay, P., Ding, W., and Stuart, T. (2009): "The Impact of Academic Patenting on The Rate, Quality and Direction of (Public) Research Output", *The Journal of Industrial Economics* 57(4), 637–676.

[3] Banal-Estañol, A., Jofre-Bonet, M., and Meissner, C. (2010): "The Impact of Industry Collaboration on Research: Evidence from Engineering Academics in the UK", Working Paper City University London.

[4] Blumenthal, D., Gluck, M., Louis, K.S., Stoto, M.A., and Wise, D. (1986): "Universityindustry Research Relationships in Biotechnology: Implications for the University", *Scienc*e 13 June, 232 (4756), 1361 - 1366.

[5] Breschi, S., Lissoni F., and Montobbio, F. (2008): "University patenting and scientific productivity. A quantitative study of Italian academic inventors", *European Management Review* 5, 91-110.

[6] Buenstorf, G. (2009): "Is commercialization good or bad for science? Individual-level evidence from the Max Planck Society", *Research Policy* 38(2), 281-292.

[7] Calderini, M. and Franzoni C. (2004): "Is Academic Patenting Detrimental to High Quality Research? An Empirical Analysis of the Relationship between Scientific Careers and Patent Applications", Bocconi University: Cespri Working Paper No. 162.

[8] Calderini, M., Franzoni, C., and Vezzulli, A. (2007): "If star scientists do not patent: an event history analysis of scientific eminence and the decision to patent in the academic world", *Research Policy* 36, 303-319.

[9] Champness M. (2000): "Helping industry and universities collaborate", *Research Technology Management* 43(4), 8–10.

[10] Cohen, W.M., Nelson R.R., and Walsh J.P. (2002): "Links and Impacts: The Influence of Public Research on Industrial R&D", *Management Science* 48, 1-23.

[11] Cummings, J. and Kiesler, S. (2007): "Coordination costs and project outcomes in multi-university collaborations", *Research Policy* 36(10), 1620-1634.

[12] D'Este P. and Patel, P. (2007): "University-Industry linkages in the UK: What are the factors underlying the variety of interactions with industry?", *Research Policy* 36, 1295-1313.

[13] Dasgupta, P. and David, P. (1994): "Towards a New Economics of Science", *Research Policy* 23(5): 487-522.

[14] Fabrizio, K. and DiMinin, A. (2008): "Commercializing the Laboratory: Faculty Patenting and the Open Science Environment", *Research Policy* 37, 914-931.

[15] Geuna, A. and Nesta, L. J. J. (2006): "University patenting and its effects on academic research: The emerging European evidence", *Research Policy* 35, 790-807.

[16] Godin, B. (1996): "The state of Science and technology indicators in the OECD countries", Research Paper, Statistics Canada.

[17] Goldfarb, B. (2008): "The effect of government contracting on academic research: Does the source of funding affect scientific output?", *Research Policy* 37, 41-58.

[18] Goldfarb, B., Marschke, G., and Smith, A. (2009): "Scholarship and inventive activity in the university: complements or substitutes?", *Economics of Innovation and New Technology* 18 (8), 743-756.

[19] Gulbrandsen, M. and Smeby, J.C. (2005): "Industry Funding and University Professors' Research Performance", *Research Policy* 34, 932-950.

[20] Hicks, D. and Hamilton, K. (1999): "Does University-Industry Collaboration Adversely Affect University Research?", *Issues in Science and Technology* 74-75.

[21] Lacetera, N. (2009): "Different Missions and Commitment Power in R&D organizations: Theory and Evidence on Industry-University Alliances", *Organization Science* 20(3), 565-582.

[22] Lerner, J. and Malmendier, U. (2010): "Contractibility and the Design of Research Agreements", *The American Economic Review* 100(1), 214-246.

[23] Manjarres-Henriquez, L., Gutierrez-Gracia, A., Carrion-Garcia, A., and Vega-Jurado, J. (2009): "The effects of university—industry relationships and academic research on scientific performance: Synergy or substitution?", *Research in Higher Education* 50(8), 795-811.

[24] Mowery, D. C., Nelson, R. R., Sampat B. N., and Ziedonis A. A. (2004): *Ivory Tower and Industrial Innovation. University-Industry Technology Transfer Before and After the Bayh-Dole Act*, Stanford University Press: Palo Alto, CA.

[25] Narin, F., Pinski G., and Gee H. (1976): "Structure of the Biomedical Literature", *Journal of the American Society for Information Science*, 25-45.

[26] Pereira, I. (2007): "Business-Science Research Collaboration under Moral Hazard", Working Paper Universitat Autonoma de Barcelona.

[27] Pérez-Castrillo, D. and Sandonis, J. (1996): "Disclosure of know-how in research joint ventures", *International Journal of Industrial Organization* 15(1), 51-79.

[28] Siegel, D. S. (ed.) (2006): *Technology Entrepreneurship: Institutions and Agents Involved in University Technology Transfer*, Vol. 1. Edgar Elgar: London.

[29] Stephan, P., Gurmu, S., Sumell, A.J., and Black, G. (2007): "Who's Patenting in the University?", *Economics of Innovation and New Technology* 61, 71-99.

[30] Thursby, J. and Thursby, M. (2002): "Who is Selling the Ivory Tower: the Sources of Growth in University Licensing", *Management Science* 48, 90-104.

[31] Thursby, J. and Thursby M. (2007): "Patterns of Research and Licensing Activity of Science and Engineering Faculty." In: R. Ehrenberg and P. Stephan (eds.): *Science and the University*. Madison: University of Wisconsin Press.

[32] van Looy, B., Callaert, J., and Debackere, K. (2006): "Publication and patent behaviour of academic researchers: Conflicting, reinforcing or merely co-existing?", *Research Policy* 35, 596-608.

[33] Veugelers, R. and Cassiman, B. (2005): "Cooperation between Firms and Universities. Some empirical evidence from Belgian manufacturing", *International Journal of Industrial Organization* 23, 355–379.

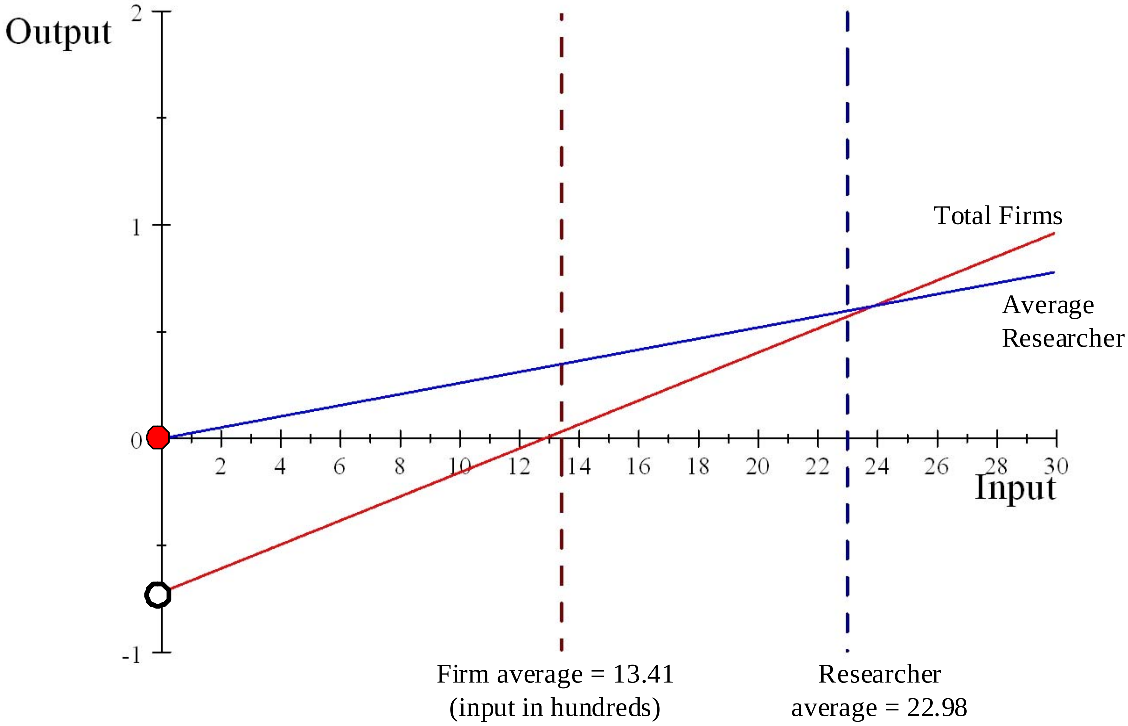

Figure 3: Predicted count of publications as a function of the count of publication of the average researcher of the project as well as a function of the total count of publications of the firm partners. The count of the publications of the firm in the horizontal axis has been divided by 100. In vertical, we plot the mean count of researchers and firms for all projects.

	Normal count (output)	Weighted-count (output)	Count (average researchers)	Weigthted count (average researchers)	Number firm partners (if any)	Count (x100) (total firm partners)	Weighted count (x100) (total firm partners)	Count (x100) (average firm partners)	Weighted count (x100) (average firm partners)	Grant funding (£000)
Observations	487	487	487	487	187	187	187	187	187	487
Mean	2.641	7.915	22.983	56.660	3.401	13.413	35.88	4.111	10.702	723.190
Median	2	3.878	18	40.049	2	4.53	5.242	1.46	2.342	288.248
St dev	3.351	15.118	18.219	57.152	3.709	24.713	90.356	6.552	25.121	1492.19
Min	1	0.203	0.5	0.103	1	0.01	0.012	0.006	0.008	0
Max	47	223.055	99	341.283	31	153.57	614.965	39.245	172.261	18000

Table 1. Project output and inputs

	Count type 1 (output)	Count type 2 (output)	Count type 3 (output)	Count type 4 (output)	Count no type (output)	Appliedness (output)	Appliedness (university)	Appliedness (firms)
Observations	487	487	487	487	487	487	487	187
Mean	0.168	0.789	0.671	0.501	0.511	0.516	0.584	0.556
Median	0	1	0	0	0	0.5	0.630	0.552
St dev	0.510	1.105	1.181	1.654	1.186	0.469	0.322	0.263
Min	0	0	0	0	0	0	0	0
Max	5	12	10	22	15	1	1	1

Table 2. Type of publications

We measure the level of appliedness as the number of publications of types 1 and 2 divided by the number of publications of types 1, 2, 3 and 4.

	Appliedness output (1+2/1+2+3+4)	Appliedness output (1+2/1+2+3+4) (all in logs)	Appliedness output (1/1+2+3+4)	Appliedness output (1/1+2+3+4) (all in logs)
Appliedness researchers	0.807***	0.708***	0.550***	0.247***
	[0.061]	[0.111]	[0.063]	[0.043]
Interaction (collaborative)	-0.037	0.288	0.196**	0.105*
	[0.090]	[0.196]	[0.093]	[0.059]
Appliedness firms	0.246**	0.199***	0.025	0.156***
	[0.096]	[0.051]	[0.107]	[0.056]
Constant	0.002	-1.243***	0.012	-4.123***
	[0.038]	[0.278]	[0.014]	[0.326]
Observations	487	487	487	487
R-squared	0.351	0.168	0.27	0.129

Standard errors in brackets

*** p<0.01, ** p<0.05, * p<0.1

Table 3. Appliedness of output as a function of the appliedness of researchers and firms

	Count (output)	Weighted count (output)	Count (output) (all in logs)	Weighted count (output) (all in logs)	Count (output)	Weighted count (output)
Total grant funding (£000)	0.001***	0.003***	0.142***	0.178***	0.001***	0.003***
	[0.000]	[0.000]	[0.023]	[0.034]	[0.000]	[0.000]
Av count (researcher)	0.026***		0.066*		0.024***	
	[0.008]		[0.034]		[0.008]	
Av weighted count (researcher)		0.074***		0.247***		0.071***
		[0.011]		[0.039]		[0.011]
Intercept total count (firms)	-0.744**		-0.182*		-0.288	-0.249
	[0.321]		[0.103]		[0.370]	[1.583]
Slope total count (firms) (x100)	0.019**		0.034		0.026***	0.037***
	[0.009]		[0.024]		[0.010]	[0.011]
Intercept total weighted count (firms)		-2.728**		-0.479***		
		[1.342]		[0.147]		
Slope total weighted count (firms) (x100)		0.031***		0.060*		
		[0.011]		[0.031]		
Number of firms					-0.167**	-0.830***
					[0.068]	[0.287]
Constant	1.772***	2.280**	-0.185	-0.193	1.759***	2.236**
	[0.258]	[1.032]	[0.166]	[0.236]	[0.257]	[1.024]
Observations	487	487	487	487	487	487
R-squared	0.117	0.189	0.09	0.157	0.128	0.203

*** p<0.01, ** p<0.05, * p<0.1
Standard errors in brackets

Table 4. Project outcomes

	Count (output)	Weighted count (output)	Count (output) (all in logs)	Weighted count (output) (all in logs)
Total grant funding (£000)	0.001***	0.003***	0.144***	0.183***
	[0.000]	[0.000]	[0.023]	[0.033]
Av count (researcher)	0.026***		0.066*	
	[0.008]		[0.034]	
Av weighted count (researcher)		0.074***		0.244***
		[0.011]		[0.039]
Intercept av count (firms)	-0.721**		-0.191*	
	[0.331]		[0.100]	
Slope av count (firms) (x100)	0.056		0.047	
	[0.036]		[0.030]	
Intercept av weighted count (firms)		-2.649*		-0.547***
		[1.356]		[0.141]
Slope av weighted count (firms) (x100)		0.093**		0.097***
		[0.040]		[0.036]
Constant	1.764***	2.261**	-0.167	-0.124
	[0.259]	[1.034]	[0.167]	[0.237]
Observations	487	487	487	487
R-squared	0.114	0.185	0.091	0.162

*** p<0.01, ** p<0.05, * p<0.1
Standard errors in brackets

Table 5. Project outcomes.