RESEARCH OUTPUT FROM UNIVERSITY-INDUSTRY COLLABORATIVE PROJECTS*

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Abstract

We study collaborative and non-collaborative projects that are supported by government grants. First, we propose a theoretical framework to analyze optimal decisions in these projects. Second, we test our hypotheses with a unique dataset containing academic publications and research funds for all the academics at the major engineering departments in the UK. We find that the type of the project (measured by its level of appliedness) is increasing in the type of both the university and firm partners. Also, the quality of the project (number and impact of the publications) increases with the quality of the researcher and firm, and with the affinity in the partners' preferences. The collaboration with firms increases the quality of the project only when the firms' characteristics make them valuable partners.

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Biographical statements

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1 Introduction

In the last three decades universities have enlarged their entrepreneurial activity in many dimensions, including patenting and licensing, creating science parks, promoting university spin-outs, investing equity in start-ups, and collaborating with industry in research projects (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 channels of knowledge transfer (Cohen et al., 2002). As a result, research contracts and joint research agreements are widespread (D'Este and Patel, 2007).

Collaborative projects have important benefits both for industry and academia. They 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 provide assistance with experimentation, access to the analytic skills of the university, or the use of equipment (e.g., Veugelers and Cassiman, 2005). Academic researchers 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 the exchange of complementary know-how.

In terms of production of research output, however, collaboration with industry has ambiguous effects. On the one hand, industry involvement might delay or suppress academic publication, endangering the "intellectual commons" and the practices of "open science" (Nelson, 2004, and Dasgupta and David, 1994). Industry collaboration might also "skew" the type of research projects towards more applied contents (Florida and Cohen, 1999). Faculty participating in knowledge and technology transfer activities, on the other hand, claim that industry collaboration improves research outcomes (Lee, 2000).

This paper studies the research output of university-industry research collaborations supported by government grants. We first provide a theoretical framework describing the process that leads to the outputs of collaborative and non-collaborative research projects. The process includes the negotiation of the type of the project in which partners will work on, as well as the investment levels each partner devotes in to the project. Our theoretical framework ends up making predictions on the characteristics of the outputs, such as type and quantity of publications, as a function of the characteristics of the partners, such as efficiency and preferences. We then test our model and measure empirically the impact of the characteristics of the partners on the outcome of each specific project.

In our theoretical framework, project outcomes are defined by type (degree of basicness or appliedness) and quality (quantity and impact of the publications). Typically, university researchers and laboratories prefer projects of a basic nature. Firms, in contrast, expect higher benefits from projects that can be more easily applied. In a non-collaborative project, the researcher takes decisions taking into account her preferences only. In collaborative projects, the partnership decides on a type of project taking into account the interest of both participants. Through the investment decisions, the characteristics of the partners affect the quality of the research output. Both partners boost their investment when they place more value on the output and when their technical and scientific level are higher. Investment is also increasing when their interests are more aligned.

We expect a non-collaborative project to focus on more basic ventures than a collaborative project. In fact, the type of collaborative project is a weighted average of the preferences of project participants. The scientific level of the participants should not affect the type of project but its quality only. The quality of collaborative projects is not necessarily greater than the quality of non-collaborative projects. On the one hand, the quantity and impact of the output in collaborative projects should be higher because more partners invest. 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 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 evaluates projects based on their scientific content, as well as their potential impact on the current or future success of the UK economy.

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 and 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 quality of the project. As a measure of type, we use the Patent Board classification, version 2005, developed by Narin et al. (1976), which classifies journals according to their general research orientation. As proxies for the partners' characteristics, we use the average basicness-appliedness type and the number and impact of their publications in the period 2002-2007. Our final, representative sample includes 487 research projects, 187 of which are collaborative and 300 are non-collaborative.

Our dataset allows us to take into account not only the effect of the existence or the number of industrial partners but also the type of firms with which university researchers collaborate. Moreover, it allows us to directly measure the impact of the collaboration with industry on the outcome of a specific research project.

First, we regress the project's output type with respect to the type 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. Also, the type of project is not influenced by the scientific level of the researchers or the firms.

Second, we consider the output of the project measured in terms of number of publications and their impact factor. As expected, funding has a positive and highly significant effect on the number and impact of publications. More efficient academic researchers also significantly improve the 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 researchers alone. However, as the publications of the industry partners increase, the quality of the project improves and it becomes higher than that of non-collaborative projects. Finally, our regression confirms that the quality of the project is higher when the interest of the researcher and the firm are more aligned.

The rest of the paper proceeds as follows. In Section 2, we do a brief literature review. Section 3 presents our theoretical framework, which develops the hypotheses 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 Literature Review

Our theoretical framework is related to the work of 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.[1] 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.[2] Some papers have

[1] Using survey data, Pereira and García-Fontes (2011) empirically test the influence of the type of inventor on the level of basicness of the patent. Patents invented by academic researchers seem to be more basic than those arising from corporate researchers. More interestingly for our purposes, in case of a partnership, the identity of the organization employing the main inventor is important. When the main inventor is employed by a firm, patents show a basicness index that is smaller than when the main-inventor is an academic researcher (although it is higher than when all inventors are firms' researchers).

[2] As Dasgupta and David (1994) pointed out, the goals and the incentives received from the institution

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 firms to more basic research-oriented.

The literature has also studied the effect of industry collaboration on the quantity and impact of academic research output. In their report for the National Academy of Sciences, Merrill and Mazza (2010) conclude that the majority of studies have not found evidence of negative effects of industrial collaboration (or commercially related faculty activity) on the publication counts and citation counts. 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 impact 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-shaped relationship between industry collaboration and 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).

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.

Although our objective is not to evaluate the EPSRC program, we do obtain some conclusions on the outcome of the program. In this sense, our paper is related to the literature that evaluate projects and programs in terms of creation of knowledge, measured by the publications obtained by the researchers involved (see, for instance, Cozzens et al. 1994). Bozeman et al. (2001) provide an alternative model for evaluating science and technology programs that takes into account not only the immediate outcomes from scientific projects but it also pays attention to the researchers' career trajectories.

Based on an analysis of longitudinal bibliometric data, Ponomariova and Boardman (2010) analyze the effect of the collaboration of university faculty with firms in a university research center. They find that during the years in which university researchers are affiliated with the center, they are more likely to be more productive, to produce more papers with industrial collaborators, and to produce more interdisciplinary research.

Recent studies emphasize the importance of knowledge creation for the emerge of entrepreneurship. The contributions by Audretsch et al. (2006) and Acs et al. (2009) propose the "knowledge spillover theory of entrepreneurship" in which the creation of new knowledge expands the technological opportunity set. An important implication of this theory is that an increase in the stock of knowledge is expected to positively impact the degree of entrepreneurship. They also test empirically the theory and show that entrepreneurial opportunities are not exogenous but they are created by a high presence of knowledge spillovers. Therefore, programs like the one offered by the EPSRC not only contribute to an increase in the level of knowledge and publications but also, indirectly, to the emergence of entrepreneurial activity. In this sense, our study contributes to a better understanding of programs that help increase university entrepreneurship.[3]

Our paper highlights that the level of firms' scientific publications has a strong positive influence on the outcome of the research programs. In their influential paper, Cohen and Levinthal (1990) argue that a firm's absorptive capacity is critical to its innovative capabilities and influences its innovation decisions, in particular concerning the participation in cooperative R&D ventures. The past record of publications of a firm is a clear signal of its absorptive capacity and also of its ability to contribute to a research program. Accord-

[3] See Rothermael et al. (2007) for a detailed analysis and taxonomy of the literature that analyzes university entrepreneurship.

ing to our results, this ability is crucial not only for the firm but also for the university researchers involved in collaborative projects.

3 The theoretical framework

To analyze the output of research projects that have received government financing, we introduce a simple framework to analyze the participants' decisions.[4] The projects are aimed at financing research; therefore, we focus on the decisions leading to academic publications. We abstract from other outputs, such as patents or transfer of know-how.

We focus on two characteristics of the project: type and quality. The *type* is defined as the level of appliedness (or alternatively basicness) of the research developed in the project. The difference between a basic project and an applied one is not its scientific content or its originality but the potential applicability of the results. Typically, academic researchers are more inclined to solve general puzzles, whose potential application for the industry, at least in the short run, is small (basic research). Industry, and by consequence, firms that are involved in research tend to be interested in more applied questions. The *quality* is related to the level of the research developed in the project. We will measure the quality of the project through both the count of the publications obtained in the project and their impact factor.

We address two questions: which type of project the partners choose? and how high is the quality of the project? We consider first projects that involve university researchers only and then those that include both academic researchers and firms.

3.1 Non-collaborative projects

Let us consider a university researcher (or a team of university researchers), that we denote by U, that has obtained funding I_M for a research project on her own. The benefits that U obtains from the project depend on its type and quality, through the impact of the results of the project in her CV and academic career, or the consideration by peers in her

[4]See Banal-Estañol et al. (2011) for the details of the theoretical model that formally develops the ideas presented in this section.

field.

The type of project, that is, its level of appliedness, can be represented by a parameter x. Researchers may have different preferences over this dimension. We denote U´s most preferred type by x_U. Projects have less value for U if x is different from x_U; the larger the distance between the type x and her most preferred type x_U, the larger the loss in value.[5]

We represent the quality of the project by an index that reflects both the number and the impact of the publications derived from the project. Resources can be devoted to increase this index. The quality depends on the "effort" allocated by the researcher as well as on the amount I_M obtained from the government. The effort can refer to the level of involvement of the researcher, the possible additional financing by the research lab, etc. Moreover, the quality of the project also depends on the efficiency (or ability) of U.

In terms of predictions, the researcher selects the type of project that best suits its interest, x_U. Moreover, we predict that the level of the researcher's dedication to the project is increasing with the value she allocates to the output, with her scientific level, and with the level of government financing I_M.

We now state the testable hypotheses on the type and quality of a non-collaborative project.

Hypothesis 1 *The type of a non-collaborative project is more applied as the level of appliedness of the researcher increases.*

Hypothesis 2 *The quality of a non-collaborative project increases with the scientific level of the researcher as well as with the amount of the grant.*

3.2 University-industry collaborative projects

Consider now a project with government financing I_M led by a researcher U in collaboration with a firm F. We denote F's most preferred type of project by x_F and we consider that firms' preferences are more applied than universities': $x_F > x_U$. A firm values the

[5] In Banal-Estañol et al. (2011), we present a model in the spirit of the Hotelling model and describe this loss as "transportation costs" depending on the distance.

quality of the project because it reflects the know-how or applied knowledge acquired during the research that leads to the publications. Firms, as academic researchers, suffer a cost from moving from their ideal point in terms of research. The firm may invest in the project is several ways, including financial resources as well as firm's researchers effort. The level of investment may depend on the technical and scientific level of F, its absorptive capacity, the level of its human capital, etc.

The participants in a collaborative project must agree on a type x. One expects that they will compromise on a project less applied than x_F and less basic than x_U and agree on the one best suited for the partnership. The type chosen will be a weighted average of the optimal types for the researcher and the firm, where the weights depend on the value the partners allocate to the outcome of the project and also on the difficulties encountered when moving from the ideal project.

The partners must also reach an agreement as to the level of their investment.[6] At the optimal agreement, their investment is increasing in their technical and scientific level and they are decreasing in the distance between the most preferred types of project $(x_F - x_U)$.

Hypothesis 3 and 4 state the testable effect of changes in the exogenous parameters on the type and quality of collaborative projects.

Hypothesis 3 *The type of a collaborative project is more applied as the level of appliedness of the firm and the researcher increases.*

Hypothesis 4 *The quality of a collaborative project increases with the scientific and technical level of the firm and the university researcher, as well as with the amount of the grant, and decreases with the distance between the level of appliedness of the researcher and that of the firm.*

[6] In our discussions 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).

3.3 Research outcomes in university versus collaborative projects

According to our previous discussion, it is immediate that collaborative projects are more applied than non-collaborative ones. 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 researcher and the firm.

The analysis of the comparison of the quality of collaborative and non-collaborative projects shows a trade-off. On the one hand, there are two reasons that suggest that collaborative projects should be more productive. First, both partners invest in a collaborative project while only the researcher works on a non-collaborative one. Second, both partners are interested in the project, which increases the value of each publication. On the other hand, researchers and firms often encounter difficulties when they work with each other. 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).[7] This tends to decrease the academic researchers' investment.

Therefore, we should expect the quality of a collaborative project to be higher than that of a non-collaborative project whenever the research level of the firm is high enough and/or its interest in basic research is strong enough. In fact, if the interest of the firm in basic research is strong, then we expect the quality of a collaborative project to be always higher. However, the quality may be lower when the collaboration costs are high and the firm's scientific ability is low. To make our point clearer we draw the two possible cases as a function of the parameter of firm's ability in producing scientific research in Figure 1. The one on the right accounts for the cases where there are serious difficulties for the researchers to collaborate with firms. In these cases, the output of a collaborative project is inferior to that of a non-collaborative project for low levels of firm's research ability.

[Insert Figure 1 around here]

[7] Okamura and Nishimura (2011) empirically find that public R&D subsidy improves coordination in university-industry research collaboration.

Hypothesis 5 states the expected relation between the types of collaborative versus non-collaborative projects. Hypotheses 6 and 7 reflect the two possibilities with respect to the comparison between the quality of the two types of projects.

Hypothesis 5 *The type of a collaborative project is more applied than that of a non-collaborative project.*

Hypothesis 6 *The quality of a collaborative project is always higher than that of a non-collaborative project.*

Hypothesis 7 *The quality of a collaborative project is higher than that of a non-collaborative project only when the firm's ability is high enough.*

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 more than 50% of overall funding of engineering department research projects). EPSRC "supports excellent, long term research and high quality postgraduate training in order to contribute to the economic competitiveness of the UK and the quality of life of its people." One of the main missions of the EPSRC is "promoting an enterprising culture of adventure and excitement in which people seize opportunities and make things happen."

Some of the EPSRC 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.

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 acknowledged 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 $2008 - 2010$. We use the normal count of publications as proxy of the project's research output. 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 We measure the type of the project defined in the theoretical framework using the type of the publications in the basic-applied space. The quality of the project is measured with the number and impact factor of the publications. Tables 1 and 2 provide descriptive statistics of the two characteristics of the project.

Our final sample set of publications citing at least one of the 487 EPSRC projects up to December 31, 2010, contains $1,286$ publications. 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 (0.79 and 0.67 on average) and category 1, the lowest (0.17 on average). The average level of the measure of appliedness of the projects outcome is around 0.52, 0.62 on average for the 187 projects that include firms and 0.45 for the 300 non-collaborative projects.

[Insert Tables 1 and 2 around here]

University input As a proxy for the type and scientific level of the $1,066$ matched researchers, we use the type, count, and impact-factor-weighted sum of their publications in the last six years of the database $(2002-2007)$.[8] As shown in Table 1, the average researcher in our database published 22.98 articles over the five-year period. The total

[8]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.

impact factor of the average researcher is over 56. 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 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 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 type for the project partners as the one we use for the project output and for the researchers.

We have 187 projects that include 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 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

(0.56 versus 0.58). This may be due to the difficulties that industry researchers face to publish their most applied work, because of a requirement of secrecy. The appliedness index of the publications of the researchers involved in collaborative projects is 0.63, superior to the ones running non-collaborative projects (0.55).

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 in the project 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.

[Insert Table 3 around here]

As predicted by hypotheses 1 and 3, the appliedness of the output is increasing in the appliedness of both university and firm partners. Both effects are highly significant. The effect of the researcher is not significantly different in collaborative and non-collaborative projects. In particular, the last two results also support Hypothesis 5: collaborative projects are indeed more applied than non-collaborative ones. The addition of the coefficients of the type of the researcher and the firm is close to one in column 1, which is in accordance with the prediction of the theory since the type of the project is a weighted average of the types of researcher and firm. We can also see 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, that the firms are more flexible than the universities, and/or that the index of the researchers is more accurate than that of the firms. 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.

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.

Finally, we also show that the type of project is not influenced by the quality of the researchers or the firms. In the last two columns, we regress the level of appliedness of the output on the normal count of publications of the researchers and firms in the project. None of the variables appear as significant, independently if we consider basic publications those of categories 1 and 2 or category 1 only.

Table 4 provides the results on the quality 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).

[Insert Tables 4 and 5 around here]

As predicted by hypotheses 2 and 4, the effect of funding is positive and highly significant in all the regressions in Table 4. More efficient university researchers also significantly improve the 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, in accordance with Hypothesis 4. 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 quality of the research output improves (the slope of the total account, or total weighed account, of firms' publications is significantly positive). Therefore, our empirical results support Hypothesis 7 and rejects the alternative Hypothesis 6. Figure 2 plots the predicted values for the count of publications as a function of the publications of the average researcher and the firm. 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.

[Insert Figure 2 around here]

In the third block of 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.

In the last two columns of Table 4, we include the distance between the level of appliedness of the firm and that of the researchers in the project. Independently of the use of logs or not, the coefficient is negative and significant. Therefore, the empirical results support the last prediction in Hypothesis 4: larger differences between the collaborating partners decrease the quality of the output coming out of the project.

5 Conclusion

In this paper, we provide both a theoretical analysis and empirical evidence on the type and the quality of university-industry collaborative projects. Our theoretical framework posits that the project type takes into account the interests of both university researchers and firms. It also stresses that investment of the project are increasing in the partners' technical and scientific level and in the affinity of their interests. Through the investment decisions, the characteristics of the partners affect the quality of the research output.

According to our theory, university researchers should produce more basic outputs if they do not collaborate with industry. But, the effect of industry collaboration on the project's 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.

The empirical evidence supports the theoretical predictions. 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 that the projects in which more prolific researchers and more prolific firms work generate more and better publications.

Again consistent with the theory, our empirical evidence shows that firm partners with low publication records decrease the 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, taking our empirical 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 record.

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 firms that have a high average scientific level and that have similar interest to the researchers, improves the research output of government grants. Therefore, in the evaluation of research proposals, policy makers and managers of programs that fund research may want to take into account not only the scientific level of the university researchers and the interest of the project, but also the scientific level of the firms, as measured in particular by their past record of publications, and the affinity of the partners' past publication records.

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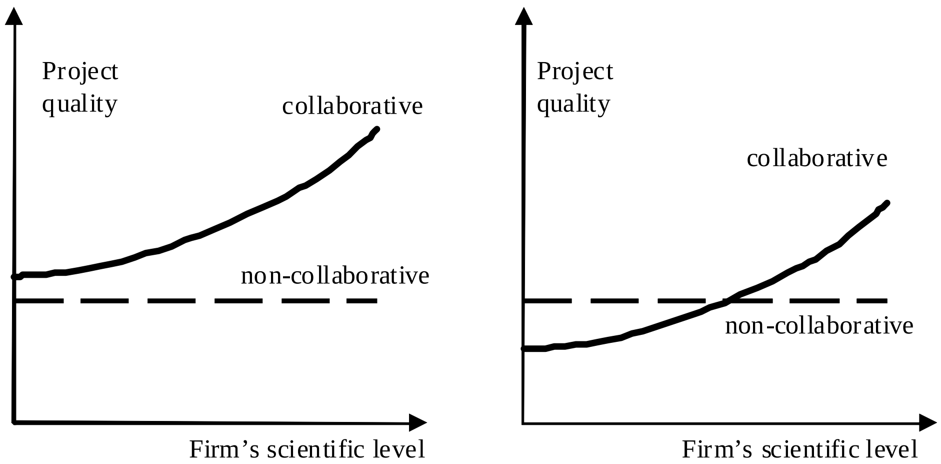

Figure 1: Quality in collaborative and non-collaborative projects

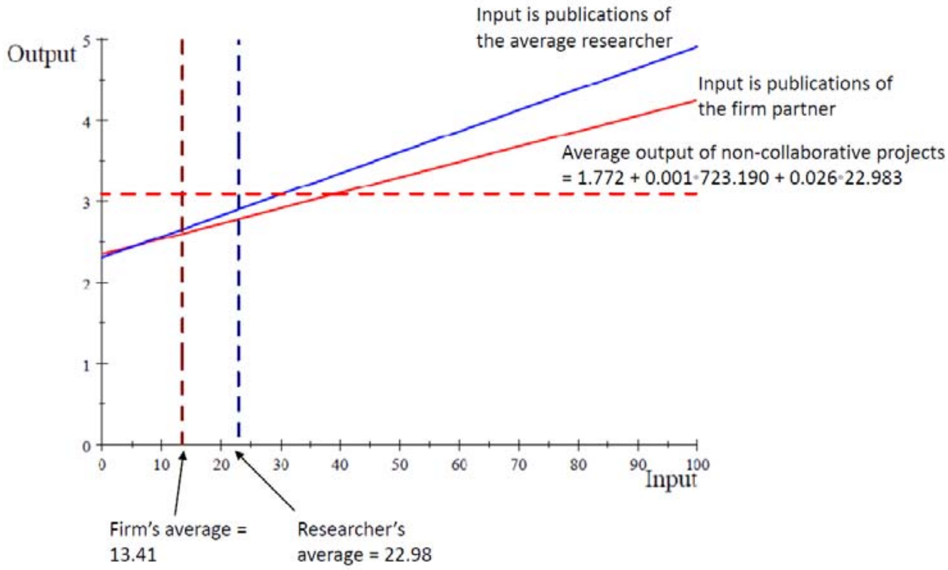

Figure 2: Predicted count of publications as a function of the count of publications of the average researcher of the project as well as a function of the total count of publications of the firm partners. For each line, all the other variables are kept at the predicted effect of the average value. In horizontal dased line, we plot the predicted publications of a project without any partner. The count of the publications of the firm in the horizontal axis has been divided by 100. In vertical lines, 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 quality and scientific level of partners

	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 output (1+2/1+2+3+4)	Appliedness output (1/1+2+3+4)
Appliedness researchers	0.807***	0.708***	0.550***	0.247***	0.784***	0.547***
	[0.061]	[0.111]	[0.063]	[0.043]	[0.070]	[0.067]
Interaction (collaborative)	-0,037	0,288	0.196**	0.105*	0.024	0.207**
	[0.090]	[0.196]	[0.093]	[0.059]	[0.116]	[0.100]
Appliedness firms	0.246**	0.199***	0,025	0.156***	0.322***	0.046
	[0.096]	[0.051]	[0.107]	[0.056]	[0.112]	[0.130]
Av count (researcher)					0.000	0.000
					[0.001]	[0.001]
Intercept total count (firms)					-0.116	-0.016
					[0.091]	[0.034]
Slope total count (firms) (x100)					0.002	0.001
					[0.001]	[0.001]
Constant	0,002	-1.243***	0,012	-4.123***	0.016	0.011
	[0.038]	[0.278]	[0.014]	[0.326]	[0.054]	[0.022]
Observations	487	487	487	487	487	487
R-squared	0,351	0,168	0,27	0,129	0.356	0.271

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

Table 3. Appliedness of output as a function of the appliedness and publications 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)	Count (output)	Weighted count (output)
Total grant funding (£000)	0.001***	0.003***	0.142***	0.178***	0.001***	0.003***	0.001***	0.003***
	[0.000]	[0.000]	[0.023]	[0.034]	[0.000]	[0.000]	[0.000]	[0.000]
Av count (researcher)	0.026***		0.066*		0.024***		0.022***	
	[0.008]		[0.034]		[0.008]		[0.008]	
Av weighted count (researcher)		0.074***		0.247***		0.071***		0.066***
		[0.011]		[0.039]		[0.011]		[0.012]
Intercept total count (firms)	-0.744**		-0.182*		-0,288	-0,249	-1.114***	
	[0.321]		[0.103]		[0.370]	[1.583]	[0.386]	
Slope total count (firms) (x100)	0.019**		0,034		0.026***	0.037***	0.021**	
	[0.009]		[0.024]		[0.010]	[0.011]	[0.009]	
Intercept total weighted count (firms)		-2.728**		-0.479***				-4.505***
		[1.342]		[0.147]				[1.681]
Slope total weighted count (firms) (x100)		0.031***		0.060*				0.033***
		[0.011]		[0.031]				[0.011]
Number of firms					-0.167**	-0.830***		
					[0.068]	[0.287]		
Distance appliedness researchers firms							-0.768*	-3.571*
							[0.450]	[2.042]
Constant	1.772***	2.280**	-0,185	-0,193	1.759***	2.236**	2.284***	4.737***
	[0.258]	[1.032]	[0.166]	[0.236]	[0.257]	[1.024]	[0.395]	[1.742]
Observations	487	487	487	487	487	487	487	487
R-squared	0,117	0,189	0,09	0,157	0,128	0,203	0.122	0.194

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

Table 4. Quality of the project as a function of the partner's scientific level and distance in types

	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 in terms of publications.