The Organization of Research Activities in Industry and Academia: Implications for the Commercialization of University Research

by

Nicola Lacetera

Laurea in Economics, Università Bocconi, Milano (2000)

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Signature of Author .....
Sloan School of Management
May 4, 2006

Certified by .....
Rebecca Henderson
Eastman Kodak LFM Professor of Management, MIT
Thesis Supervisor

Certified by .....
Robert Gibbons
Sloan Distinguished Professor of Organizational Economics and Strategy, MIT
Thesis Supervisor

Certified by .....
Philippe Aghion
Robert C. Waggoner Professor of Economics, Harvard University
Thesis Supervisor

Accepted by .....
Birger Wernerfelt
J. C. Penney Professor of Management Science, MIT

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Abstract

This dissertation is composed of three essays.

In the first essay, I build a model of the choice and timing of entry into commercial activities by an academic research team, and analyze the returns and costs of these activities. I compare the behavior and performance of the academic team to an industrial research team. The two teams are assumed to differ in their objectives, governance modes, and incentive systems. I show that, while in some cases academic scientists are more reluctant to commercialize research, in other cases they may commercialize faster than profit-seeking firms would – and perform less basic research. Academic and non-academic scientists also select different projects, and this may explain the good performance of 'academic entrepreneurs' found in several empirical studies. In the light of these results, I interpret the mixed evidence on the success of, and the arguments in favor and against, the involvement of universities into business-related research activities.

In the second essay, I define a model of a firm's choice of whether to conduct research in-house or to outsource it to academic research teams. I exploit the fact that companies and universities have different missions, and model the different authority structures implied by different organizational choices in the conduct of research. Outsourcing a project to a university allows a firm to commit not to terminate or alter a scientifically valuable project before completion. This commitment is potentially valuable for the firm in an environment where scientific value and economic value may not coincide, and scientific workers are responsive to the incentives defined by their community of peers. I then formulate some empirical predictions about the kind of research activities firms will outsource to universities, and activities on which they will exert stronger control. I confront these hypotheses with empirical evidence from a sample of industry-university research agreements, as well as from other analyses and case studies, and find patterns consistent with my model.

In the third essay, I analyze the restrictions on publication and control over the research agenda for universities and other 'open-science' research organizations, in a sample of biotechnology research contracts where the sponsor party is a for-profit company. I find that stronger publication restrictions appear to be more frequent in projects concerning earlier phase research and projects with longer duration. Research teams based in hospitals have significantly lower publication delays. Longer project duration is also strongly correlated with higher authority of the sponsoring firm over the direction of research. Teams in more prestigious research organizations tend to be subjected to lesser control by the sponsor company.

Thesis Supervisor: Rebecca Henderson
Title: George Eastman Kodak LFM Professor of Management, MIT

Thesis Supervisor: Robert Gibbons
Title: Sloan Distinguished Professor of Organizational Economics and Strategy, MIT

Thesis Supervisor: Philippe Aghion
Title: Robert C. Waggoner Professor of Economics, Harvard University

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To Cristiana

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Introduction

This dissertation analyzes the organization of research activities in industry and academia. The main objective is to contribute toward understanding the role of university research in industrial success and, more broadly, in the competitiveness of an economy.

A vast literature in Management and Economics has explored the role of academic research for economic competitiveness and growth (Jaffe 1989, Mansfield 1991, Cohen et al. 2002). Recently, the process of commercialization of academic research, i.e., the involvement of universities in profit-seeking activities, has received great attention (Thursby et al. 2001, Ezkowitz 2004, Shane 2004). However, most studies take universities as 'black boxes', and do not explicitly consider their institutional and organizational features. My endeavor is to begin to open this black box.

This exercise is relevant for public policy analysis, as well as for managerial considerations. From a public policy standpoint, there has been an increased interest, both in the US and in Europe, toward policies aimed at stimulating the involvement of universities into the commercialization of research. However, very little is known about whether 'academic entrepreneurship' is different from 'private firm entrepreneurship'. We need to understand whether universities and academic scientists can offer something that other actors, e.g., firms, cannot replicate. If the commercialization of research takes place in universities the same way as it does in firms, there would be no reason to involve academic organizations in commercially-oriented activities. The institutional and organizational features of universities, such as the peculiar missions and the incentive systems academic researchers respond to, are likely to be among the candidates to explain the specific contribution of academia to the economy.

Managers also can benefit from this research. Especially in science-based sectors like biotech-

nology, semiconductors and nanotechnology, companies are increasingly building formal ties with academic teams and departments for collaborative research effort. It is therefore important that managers understand what are the opportunities and challenges from such relations; a deeper knowledge of the effects of institutional and organizational differences would be valuable.

The dissertation is composed of three essays. In these essays, I characterize the organizational and institutional features of industrial and academic environments, and explore the consequences of the differences of these environments on variables like the commercial performance of academic entrepreneurs, the development of research collaborations between companies and universities, and the features of these collaborations.

The first essay (Chapter 1) analyzes the choice of academic scientists to commercially exploit their research. I build a model of the timing of entry into commercial activities by an academic research team, and analyze the returns and costs of these activities. In order to focus on the peculiarities of academic entrepreneurship as opposed to industrial entrepreneurship, I compare the behavior and performance of the academic team to an industrial research team. The two teams are assumed to differ in their objectives, governance modes and incentive systems. I show that, while in some cases academic scientists are more reluctant to commercialize research, in other cases they may commercialize faster than profit-seeking firms would – and perform less basic research. I also derive that academic and non-academic scientists enter different sets of commercial projects. This selection mechanism may explain the good performance of 'academic entrepreneurs' found in several empirical studies, since academic research teams tend to enter projects with higher expected returns and likelihood of success. This study helps interpreting the mixed evidence on the success of, and the arguments in favor and against the involvement of universities into business-related research activities. I also identify and discuss a series of implications for empirical analyses of the commercialization of academic research.

In the second essay (Chapter 2), I propose a theory for why firms conduct some research activities in-house and outsource other projects to academic research teams, and for why firms retain different degrees of control over collaborative research projects. Due to the different institutional missions of academic organizations, outsourcing a project to a university allows a firm to commit not to terminate or alter a scientifically-valuable project before completion. This commitment is potentially valuable for the firm in an environment where scientific value

and economic value may not coincide, and scientific workers are responsive to the incentives defined by their community of peers. I build a formal economic model that formalizes these arguments. I then formulate some empirical predictions about the kind of research activities on which firms will exerts stronger control. I confront these hypotheses with empirical evidence from a sample of industry-university research agreements as well as from other analyses and case studies, and find patterns consistent with my model. Finally, I interpret my findings within the current policy debate on the desirability of stronger formal ties between industry and academia.

In the third essay (Chapter 3), I analyze the restrictions on publication (and therefore on the openness of the research) and on the control over the research agenda for universities and other 'open-science' research organizations, when they are sponsored by for-profit companies. I document variation in these provisions, in a sample of research contracts in biotechnology. I find that stronger publication restrictions appear to be more frequent in projects concerning earlier phase research and projects with longer duration. Research teams based in hospitals have significantly lower publication delays. Longer project duration is also strongly correlated with higher authority of the sponsoring firm over the direction of research. Teams in more prestigious research organizations tend to be subjected to lesser control by the sponsor company. I then infer a series of managerial and policy considerations emerging from my findings.

Appendixes A and B at the end of the dissertation offer extensions to the models described in the first two essays.

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Chapter 1

Multiple Missions and Academic Entrepreneurship

1.1 Introduction

The issue of the commercialization of academic activities or 'academic entrepreneurship' – intended as the involvement of academic scientists and organizations in commercially-relevant activities, in different forms[1] – has received great attention over the past thirty years. Several observers have pointed to academic research as an under-utilized resource for a country's competitiveness, because academic research has been too distant from practical applications, and of not easy transferability and applicability (see Slaughter and Rhoades 1996 for an account of these claims). Policy makers intervened with several provisions, such as the 1980 Bayh-Dole Act and the 1986 Federal Technology Transfer Act, in order to stimulate universities to undertake more industrially relevant research. While originally confined to the United States, the role of universities for industrial success has more recently received increasing attention in Europe and Japan (Henrekson and Rosenberg 2000, Geuna et al. 2003, and David 2005), with both policy and managerial implications.

The increasing interest in academic entrepreneurship has stimulated a broad and lively

[1] Industry-university collaborations, university-based venture funds, university-based incubator firms, start-up founding by academicians, double appointments of faculty members in firms and academic departments, etc. The same definition of academic entrepreneurship is used by other authors, such as Henrekson and Rosenberg (2000) and Franklin et al. (2001).

debate among scholars, and data from numerous sources have been collected to analyze empirically the process of academic involvement in commercialization, and its economic and social consequences. Positions on the economic impact of the commercialization of academic research vary greatly. On the one hand, some scholars argue that the direct involvement of academic scientists in industrially-relevant activities would solve some imperfections in the transmission of knowledge, and will also motivate researchers to undertake projects with greater economic and social relevance (Gibbons et al. 1994, Zucker and Darby 1995, Ezkowitz 2004).[2] On the other hand, some observers are skeptical about the ability of academics to manage commercial activities, while still abiding by the rules and missions of academia and more generally of the scientific community. These rules are seen as standing in marked contrast with the profit seeking approach that characterizes commercial activities (Dasgupta and David 1994, Stern 1995, Nelson 2004).

Like the theoretical and policy debates, so the available empirical evidence is controversial. A few studies document the success of academic entrepreneurs both when they start their own companies and when they collaborate with existing firms (Zucker and Darby 1995, Cockburn and Henderson 1998, Nerkar and Shane 2003, Rothaermel and Thursby 2005, Agrawal 2006, among others). Other evidence shows that commercial ventures involving academic scientists are often not successful (Kenney 1986, Lerner 2004, Lowe and Ziedonis 2006).

Despite the vast attention directed toward the issue, the state of the debate is still incomplete. In particular, very little is known about whether academic entrepreneurship is *different* from private-firm entrepreneurship. A deeper understanding of this point is not only of intellectual interest but also of relevance for policy makers and managers. In order to evaluate the role of universities in the successful commercialization of research, and to strike an 'appropriate' balance between research activities and commercially-oriented activities, we need to understand to what extent universities and academic scientists offer something that other actors, e.g. 'pure' firms, cannot replicate.[3] If the commercialization of research takes place in universities the same

[2] As reported by David (2005), the European Commission has repeatedly stated that universities have the potential to be more effective than European industry in high tech sectors.

[3] These considerations are relevant also in relation to the internal organization of firms and to the provision of 'academic' incentives to company scientists, e.g. bonuses and promotions based on their recognition in the community of peers (see Henderson and Cockburn 1994, Stern 2004): to what extent, and under which circumstances, are these incentives beneficial? What kinds of behavior do they induce, that standard, 'monetary'

manner that it does in firms, there will be no reason to involve academic organizations in entrepreneurial activities. Moreover, since some forms of academic entrepreneurship occur through collaborations with companies, managers need to understand the organizational and institutional peculiarities of universities in order to evaluate properly the returns from collaborations, and to anticipate the behavior of their academic partners.

This essay analyzes the differences between academic and industrial entrepreneurs through a study of two key decisions of academic scientists who have the opportunity to undertake commercially-relevant work: the decision whether to undertake the commercial opportunity, and the timing of entry into the commercial venture. I build an economic model of the decision to commercialize research, of the timing of entry by an academic research team into commercially-oriented activities, and of the returns and costs associated with these activities. In order to identify the peculiarities of academic entrepreneurship, I compare the outcomes obtained by the academic team with those of an industrial research team facing the same choices. The model is based on three key ingredients that characterize the research process: the assumption of the cumulative nature of knowledge (i.e. current knowledge production builds on previous knowledge), the presence of different forms of scientifically-valuable knowledge, and the consideration of the institutional differences among the organizations performing research. The simultaneous consideration of these three characteristics of the research process is novel to the Economics and Management literature on Science and Innovation. I model cumulativeness by assuming that the cost of performing commercially-oriented activities (development, commercialization, and so forth) is lower if a team has previously performed some pre-commercial (or fundamental) research. Fundamental research therefore has an investment value. I also assume that the research teams choose among different types of fundamental research that are more or less applicable to practical problems. In accordance with an institutional approach to the analysis of science (as introduced in Sociology by Merton (1957, 1973), in Economics by Dasgupta and David 1994, and in the managerial literature by Gittelman and Kogut 2003), academic and industrial teams are assumed to differ in the objectives they pursue, in the incentive systems to which they respond, and in the organizational structure within which they perform research activities. In particular, I assume that academic scientists derive direct benefit from

incentives are not able to induce?

the performance of fundamental research with no direct economic value, for example, that in the form of publications and peer recognition. The benefit, in turn, may depend upon the type of fundamental research that is performed, if some types of research are more consistent with the way the reward and recognition system works in the scientific community. Moreover, just like industrial actors, academic scientists respond to economic incentives. Academic entrepreneurs are therefore characterized as entrepreneurs with multiple affiliations and missions. Research activities have for academics both an investment value and an immediate consumption value.

The results of the model can be summarized as follows. While in some cases academic scientists are more reluctant to move to commercially-relevant activities, in other cases they move even faster than profit-seeking firms would. On the one hand, academic scientists derive direct benefits from the performance of pre-commercial research; this reduces the likelihood that academic scientists will move to commercially-oriented research. On the other hand, if the kind of basic research that scientists are more motivated to perform in academia is not easily applicable to commercially-relevant research, then academic scientists, despite the consumption value they derive from performing basic research, may find the investment value too low, and may soon prefer to move to commercially-relevant activities. On the contrary, industrial researchers have incentives to perform fundamental research more easily applicable to commercial problems (for example, research that is multidisciplinary or research that is idiosyncratic to a particular problem); this makes the cost-reducing investment in fundamental research more profitable. The timing of entry, moreover, determines also the costs and, therefore, the commercial profitability of the research effort: the later the entry, the lower the costs of transition from fundamental to commercial research. Two implications emerge from these findings. First, a trade-off between the timing of entry into commercialization and cost-effectiveness exists, and different organizations solve it differently. Second, academic scientists tend to enter commercial projects with higher revenues, or a greater probability of success, than do industrial actors, because they derive positive utility also from not entering commercial activities while continuing to do fundamental research or, equivalently, their opportunity cost of undertaking commercial activities is higher. Therefore, a self-selection mechanism is present: academic and non-academic teams move different types of projects from the lab to the market. In addition, when the same type of projects is undertaken, there are different incentives to invest in a given

type of research, and this will also impact the expected commercial profitability of the project.

This analysis helps to reconcile the contrasting evidence regarding the outcomes of the commercialization of academic research, as well as the arguments in favor of and against the academic involvement in commercial activities. The model identifies, for example, both the environmental conditions and project types that would encourage an academic research team to produce a greater (and, possibly, socially desirable) amount of research before moving to commercialization, *and* the cases in which an academic research team would be too slow or too fast in moving to commercialization, and more or less effective in performing both fundamental research and commercially-oriented work. Moreover, the results of my analysis imply that some of the existing evidence for the success of academic entrepreneurs needs to be taken with caution because of the self-selection mechanism mentioned above: the commercial ventures into which academicians enter are different from those undertaken by companies. More precisely, empirical tests should try to tease apart the effect of the different abilities of academic scientists, of the selection into different projects, and of the potentially different incentives to invest in a given type of research for a given project.

In Section 1.2, I review the literature on the commercialization of academic research and elucidate the limits of the existing debate and evidence. In Section 1.3 I offer an informal description of the main features of the model. I also position my work within a recent tradition of theoretical analyses of the organization of research in academia. Section 1.4 is dedicated to the formal description and analysis of the model. In Section 1.5, I both provide intuitions behind the formal results, and relate the findings to the existing literature and available empirical evidence. Section 1.6 discusses the managerial and policy insights from my findings. Section 1.7 outlines the theoretical extensions of the analysis and proposes empirical strategies and settings for assessing the plausibility of the assumptions and for testing the results of the model. Section 1.8 offers a concluding summary.

1.2 Current debate and literature

1.2.1 Review

Several authors claim that because universities perform fundamental science, because this basic knowledge is increasingly important in high-technology sectors and more generally in the knowledge economy, and because knowledge may be hard to transfer, it is desirable to involve directly academic organizations and scientists into commercially-oriented activities. Moreover, these scientists would be 'disciplined' by such commercial involvement, since they would choose research projects still of scientific value, but also with practical applications. Academic scientists would therefore strike a virtuous compromise between the production of scientifically-relevant knowledge, and the translation of this knowledge into economic and social value (see for example Gibbons et al. 1994, Zucker and Darby 1995, Stokes 1997, Ezkowitz 2004, and Agrawal 2006).

A vast empirical literature has provided evidence consistent with these claims. Several studies have shown that the presence of academic scientists in start-up and young, science-intensive companies, such as in biotech and semiconductors, has a positive impact on the innovative and financial performance of these firms (Zucker and Darby 1995, Zucker et al. 1998, Torero et al. 2001, Nerkar and Shane 2003, Shane 2004, Stephan et al. 2004, Rothaermel and Thursby 2005, Toole and Czarnitzki 2005). Other works have found that the direct involvement of academicians positively affects the innovativeness and profitability also of large, established firms (Zucker and Darby 1997, Cockburn and Henderson 1998). Some scholars showed that the 'reproduction' of academic incentives within the firm – by tying company scientists' bonuses and promotions to their standing in the scientific community, for example – positively affects the innovative performance of firms (see for example Henderson and Cockburn 1994). Taken together, these results and claims imply that there is a special role for academic scientists and academic incentives in the performance of commercially-relevant research that builds on the fundamental discoveries that these scientists have already achieved.

Other scholars are skeptical about the ability of academic scientists (and, more broadly, of academic organizations) to manage commercial activities efficiently. These scholars claim that academic scientists are part of a peculiar institutional environment, the scientific community,

whose mission is the production and timely diffusion of scientifically-relevant knowledge. The priority rule for rewards and recognition, the disciplinary organization of research and discipline-based evaluation, and the open diffusion of the results of research are key instruments toward the efficient accomplishment of the mission. The simultaneous presence of multiple missions (i.e. the addition of commercial incentives to academic ones) would eventually generate tensions and, then, cannot be sustained. Academic scientists, for example, would need to give priority to one or the other environments to which they are affiliated. One the one hand, they might delay or forego commercial opportunities. On the other hand, they may instead focus on commercialization, thus 'rushing' to commercial activities and neglecting their academic duties. Academic scientists would therefore be unable to balance the performance of scientifically-relevant research and commercially-oriented activities (among others, see Dasgupta and David 1994, Stern 1995, Heller and Eisenberg 1998, and Nelson 2004).

In fact, we see these tensions in some historical examples of research with commercial potential conducted by universities, as well as in several more recent cases and large-sample studies. Historical cases of important discoveries show that, even when academic researchers had accumulated a good deal of the relevant knowledge required to obtain economically profitable results, with awareness of the economic relevance of these results, commercial research labs working 'in parallel' to the academic labs reached the results faster. Examples include the discovery of the transistor and the synthesis of human insulin.[4]

Regarding more recent case studies, Kenney (1986) provides examples in which commercial activities performed by academic researchers produced poor results. Argyres and Liebeskind (1998) document that several attempts by universities to generate companies have been received with diffidence by private investors, because the institutional and organizational arrangements were not deemed as economically promising. Lerner (2004) reports on the difficulties that academic organizations encountered when they directly engaged in sponsoring industrial research activities (see also Bok 2003).

As for large-sample evidence, Doutriaux (1987) finds that companies involving academics are likely to grow faster if the academics give up on their commitments with the university.[5]

[4] See for example Nelson (1962), Braun and Macdonald (1978), Hoddeson (1980), Bray (1997) for the invention of the transistor; and Hall (1987), Stern (1995), and McKelvey (1996) for synthetic insulin.

[5] In the language of Franklin et al. 2001, they are not academic entrepreneurs any longer, and they are instead

Audretsch (2000) argues, and empirically shows that academic researchers tend to undertake entrepreneurial activities in later stages of their lives than do non-academics, who respond to different incentives and have different priorities. Academic entrepreneurs would therefore delay or forgo the introduction of some innovations. A survey by Hall et al. (2000) reveals that the involvement of university partners in research projects tends to delay commercialization. Lowe (2002) finds that academic researchers start their companies around early stage discoveries, when still basic research has to be performed and extra-work is needed in order to make the discoveries profitable. Calderini et al. (2004) find that academic scientists with very high quality publications are less likely to appear as inventors in patents assigned to firms. The authors hint at an 'adverse selection' process, in which firms generally collaborate with academic scientists of lower quality. Lowe and Ziedonis (2006), while showing that university start-ups tend to perform no worse (and possibly better) than new entrepreneurial activities started by established firms, also show that the presence of academic inventors among the founders of a company negatively affects some performance indicators. Interestingly, Rothaermel and Thursby (2005), while finding that incubator firms with an active involvement of academicians have lower rates of failure, also find that these firms take longer to be 'promoted', i.e. to exit from the incubator and become independent companies. With reference to licensing activities, Jensen and Thursby (2001) find that the academic research disclosed to Technology Transfer Offices (and that will be commercialized in the form of licenses) is most often in very early stages. At the same time, many potentially profitable discoveries are never disclosed and stay 'shelved' in the labs of academic professors.

1.2.2 Discussion

The positions and the evidence previously described witness the richness of the debate and the research on academic entrepreneurship. However, there are three particular issues, among others, that the existing literature has not satisfactorily explored. First, those studies that express concerns about the ability of academic organizations to undertake successfully entrepreneurial activities offer a very stylized view of the activities of companies and universities. A purely institutional approach, which typically characterizes skeptical views, implies both that firms

'surrogate' entrepreneurs.

never perform fundamental research, and that universities never perform commercially-related activities. Neither is true. In particular, profit-seeking companies perform scientifically-valuable research within their boundaries and through their own scientists. What makes this fundamental research more applicable to practical problems? A more detailed analysis of the role of fundamental research, of the various types of scientifically-relevant research that organizations perform, and more generally of the nature of scientific knowledge, is in order.

Second, most of those who see the commercialization of academic activities with favor basically exclude a peculiar role for universities in the commercialization process. The concept of 'academic entrepreneur' these works refer to, both in theoretical and quali-quantitative analyses, rarely has any connotation specific to the academic environment. The academic entrepreneur is represented as an individual (or a team) with some ideas or scientific discoveries that can be marketed. However, why do we need to assume that this inventor is an academician? Why cannot these ideas emerge outside of the academic environment? A better understanding of the differential impact of academic entrepreneurship, as opposed to other forms of entrepreneurship, requires some precise characterization of the institutional and organizational features of academia, to which university scientists are subject. We also need an institutional benchmark or counter-factual against which to evaluate the commercial activities of academic organizations. What are the objectives of academic organizations and, more generally, of the scientific community? How are universities organized, and how are academics rewarded? The institutional approach outlined in the previous section offers important insights for the characterization of the *academic* entrepreneur. Moreover, if university involvement in commercially-relevant activities were so crucial, we should not have observed so many failures, or so much diffidence by investors; nor should we see company labs developing their own relevant fundamental research and 'outperforming' academic labs working on similar topics, without necessarily replicating exactly the incentives and rules of academia.

The third reason for dissatisfaction concerns the state of empirical research. The existing studies lack a common definition of performance; it is, therefore, difficult to compare potentially contrasting results. Most likely, the impact of academic entrepreneurs should be evaluated along a range of performance measures rather than with respect to one-dimensional measures. Another problem in existing empirical studies is a conceptual one. From the point of view of

the single scientist or research lab, undertaking commercially-related activities (founding a firm, licensing research results, keeping a stable relation with a company, and so on) is a *choice* to be weighed against such alternatives as spending more time in other academic activities. Inferring any causal relationship between scientist involvement and performance in absence of these corrections for selectivity (indeed missing in the existing studies) would be misleading, for both descriptive and normative purposes.[6] This selection problem is related to the importance of properly characterizing *academic* entrepreneurship, i.e. including in the analysis considerations on the peculiarities of the academic institutional environment.

1.3 Modeling academic entrepreneurship

1.3.1 Informal description of the model

The study I propose is meant to address the issues raised in the previous section. The objective is to characterize and analyze the behavior of academic organizations when they have the option to undertake commercially-relevant activities. The analysis is conducted through a model of the decision to undertake commercially-oriented activities by an academic research team, of the timing of entry into commercialization, and of the returns and costs related to these activities. I then compare the behavior and performance of the academic team to an industrial research team. A summary of the basic features of the model follows.

1. I model three key aspects of the research process. First, I consider knowledge as cumulative: current knowledge production builds on previous knowledge. This is captured by assuming that the cost of performing commercially-oriented activities (development, commercialization, etc.) is lower if a team has previously performed some pre-commercial (or fundamental) research. Fundamental research has therefore an investment value. Second, I allow for the pres-

[6] Consider the following examples. Lenoir (1997) describes the creation of Varian Associates in the late 1940s by some Stanford physicists and engineers, for the development of Nuclear Magnetic Resonance instrumentation. He reports that Felix Bloch, a leading theoretical physicist at Stanford, decided to get involved with the company only a few years after its foundation, when the company was already growing and in good health. Murray (2004) reports the case of an academic scientist who decided to join a firm which had developed some of his research, only after the firm was able to raise money from a range of sources. Was the direct involvement of Bloch in Varian Associates causing the good financial performance? Or did Bloch joined the company once its prospects began to look good? Was the anonymous scientist described by Murray causing the firm to be able to raise money, or did the scientist made a commitment to the firm only after learning the quality of the firm and its optimistic prospects?

ence of different forms of scientifically-valuable knowledge, more or less applicable to practical problems. Third, the academic and the industrial teams are assumed to differ in the objectives they pursue, in the incentive systems to which they respond, and in the organizational structure in which they perform research activities. In particular, I assume that academic scientists derive direct benefit from the performance of fundamental research with no direct economic value: for example, publications and peer recognition. The benefit, in turn, may depend on the type of fundamental research that is performed, since some types of research are more consistent with the way the reward and recognition system works in the scientific community. By modeling these aspects of the research process, I integrate institutional views and considerations on the nature of scientific knowledge.

2. The model compares the performance of academic entrepreneurs to the performance of other types of entrepreneurs or companies who do not formally rely on university-based knowledge and scientists. I perform the comparison by analyzing how same problem is solved by an academic team and by an industrial team. I take the two teams (and more generally the academic and industrial environment) to be differing in the objectives and incentives to which the scientists respond. For example, in the industrial environment the scientists respond to (or are rewarded on the basis of) commercial incentives only, and do not attribute any consumption value to performing fundamental research. Academic scientists, as mentioned in the previous point, also receive a direct benefit from the performance of research.[7] Apart from this difference, I keep all of the other characteristics of the problem as being the same, regardless of the institutional environment. The driver of the different behavior and outcomes of academic and non-academic teams is therefore the multiplicity of missions and incentives academics respond to, when they get involved in projects with commercial value.

3. I analyze the returns from commercialization and the costs of these activities. Moreover, the model has a dynamic structure that allows me to study another relevant dimension: the timing of commercialization. Therefore, I consider multiple measures of performance.

[7] To a large extent, the model can also be applied to, say, only industrial research teams, responding to different incentive structures to which a firm can in some way commit. However, also for its greater policy relevance, I will focus on the case of a university-based team, and will compare it to a company-based team, thus identifying the organizational location with different incentive structures.

1.3.2 Relation to the existing theoretical literature

The model builds on a recent tradition of theoretical works that have focused on the performance of commercially-relevant research by universities. Some of these works (Jensen and Thursby 2001, Jensen et al. 2003, Dechenaux et al. 2003, and Mazzoleni 2005) study university licensing, and focus on such issues as the agency relationships between the single scientist, the university and the Technology Transfer Office, and the relationship between appropriability of research and the different types of licenses (exclusive or non-exclusive) arranged by universities. Jensen et al. (2003) model the positive impact that the performance of additional research can have on the expected commercial returns, and my model shares this aspect with them. However, a limit of these works is that the scientist-inventors in the models have no clear institutional and organizational connotations; thus their behavior is not easily distinguishable from the behavior of non-academic scientists faced with the same research problem. If this is the case, then it is not clear why we need universities to be involved in such commercialization activities.[8] My framework is different in that it models such peculiar characteristics of the academic environment as the peculiar mission and incentive system. Other works, such as Lacetera (2005) and Aghion et al. (2005), do model the peculiar characteristics of agents belonging to the scientific community, but assume that there is no response, by academic scientists, to other forms of incentives. My model considers the simultaneous presence of multiple missions and institutional rules in academia, as a consequence of the possibility for academicians to undertake commercial activities, as in Beath et al. (2003). Finally, I apply the model both to an academic team and to a company team, thus making possible a comparison with the 'benchmark' actor (a firm).

[8] Moreover, while the analysis of the relations between scientists and the Technology Transfer Office is important, it is not the only relevant one. For example, Jong (2006) points out that, while Stanford University had a sophisticated technology transfer infrastructure, its scientists were much less entrepreneurial, at least in the biotechnology sector, than their colleagues at UC San Francisco, where there was not a comparable technology transfer infrastructure. It turns out, moreover, that some of the characteristics that Jong underlines as potentially explaining the entrepreneurial success of UCSF scientists, are also present in my model – in particular the attitude toward interdisciplinary research.

1.4 The model

1.4.1 Set up

The academic team

Environment An academic team has the opportunity to complete an economically valuable research project, given the amount of knowledge available and the amount of research performed up to that moment, which we call period 0. There are two periods, $t = 0$ and $t = 1$.[9] In period 0 the team faces the following choice set: it can perform some additional fundamental research (with no direct economic applications, but with novel scientific content), and possibly move to completion and commercial application in the following period, or it can move to commercially-relevant activities right away in period 0. Commercial activities include both the time spent writing a business plan to market the product, and the performance or supervision of development and marketing activities.[10] These activities are supposed to be directly performed, at least to some extent, by the scientists themselves. More precisely, what will be relevant is that the academic scientists have authority over the kind of activities (commercial versus scientific) that are performed. Unlike research activities, commercial activities have no scientific value: they do not get any recognition or attention in the scientific community. The team can also stay idle. If the team chooses to perform additional fundamental research, it also chooses how 'applicable' to the commercial project the fundamental research will be. For example, and according to a number of studies, fundamental research is more applicable if it is multidisciplinary.[11] One could also think of applicability as being related to the degree of specificity and tacitness of the fundamental research: the more tailored the research is to a given project, the higher the applicability to that issue. In the terminology of Stokes' (1997), the team decides whether the fundamental research is going to be more into the Bohr's quadrant, performed without any interest for practical applications, or more into the Pasteur's quadrant, aimed at producing both scientifically-valuable and practically-useful results.

[9] Appendix A at page 171 begins to sketch an infinite (discrete) time version of the model.

[10] Kelvin Gee (2001), a pharmacologist at the University of California - Irvine, offers some examples of these commercially related activities, which he has directly performed while keeping his academic position.

[11] See, among others, Rosenberg (1994), Stern (1995), Brewer (1999), Llerena and Meyer-Kramer (2003), Rinia et al. (2001), Carayol and Thi (2003), Boardman and Bozeman (2004). Several practitioners I interviewed stressed the importance of multidisciplinary research for the industrial application of basic knowledge.

Examples Consider a case where the current state of knowledge can lead to the development and commercialization of a particular technical device. Developing the device is plausibly more effective if knowledge from several disciplines is brought together in order to complete the project. For example, investing in this multidisciplinary, pre-commercial knowledge may prevent or solve problems that can emerge both in the development and in the use of the innovation. However, scientists can also opt for proceeding along well-defined disciplinary paths, for example with a focus on the properties of a given material. Researchers at Purdue University in the 1940s struggled with this dilemma, when they had to decide how to proceed in their research effort on semiconductors: they faced the choice of proceeding through single-disciplinary paths (explore in more detail the properties of materials like germanium – see Bray 1997), or trying to converge several lines of research and explore the practical implications of the available knowledge, as researchers at Bell Labs eventually did with the discovery of the transistor. Or, consider research in biology and the possibility of bringing some findings to pharmacological applications. Again, this is typically going to be easier if a research team has accumulated, through pre-commercial research, knowledge from other disciplines, such as chemistry and physiology. Alternatively, scientists may just explore biological properties through their single-disciplinary lenses. Academic scientists engaged in the research on synthetic insulin in the 1970s faced similar choices when they could move their research from the labs to pharmacological applications (Stern 1995). I will return to the transistor and the synthetic insulin cases (as well as to other examples) at several points of this essay.

Commercial returns If the team moves to commercial activities, there is a probability $p \in (0,1)$ that the project will be completed (economic returns are earned at completion). If the team performs research in period 0 and the completion is successful, the team earns a return $R > 0$, and there are no more choices to be made. The academic team, therefore, cares about the completion of the project and about receiving extra-revenues from commercialization of their research.[12] Let us define

$$pR = \text{Expected (gross) return from commercial activities} \tag{1.1}$$

[12] Financial rewards for academic scientists can be substantial. See Stephan and Everhart (1998).

Choice set in period 1 If the team does not move to commercial activities in period 0, or does move but fails to complete these activities, it has in period 1 the same choice set as in the previous period. Notice that in period 1 the team has a probability of commercial success equal to p, but no extra-attempts if the project is not successfully completed.

To summarize, the academic team u, in period 0, chooses $a_0^u \in \{s, c, \emptyset\}$. The superscript u stands for 'university'; s stands for 'fundamental research' (or 'science'); and c for 'commercially-related research activities'. The symbol $\emptyset$ indicates that the team stays idle for that period. The choice set a_1^u in period 1 is the same, unless the team has chosen c in period 0 and the project has been successfully completed.[13] There is no discounting between the two periods.

Commercialization costs and applicability of research The cost of commercial activities is borne only once, when the team enters commercialization (i.e. chooses c for the first time). I call this cost C_c^u and I assume:

$$\frac{\partial C_c^u}{\partial \gamma^u} < 0, \tag{1.2}$$

where γ^u measures the level of applicability of the fundamental research to commercial research. γ^u is chosen by the team each time it undertakes fundamental research. If the team enters commercialization in the second period ($t = 1$) after having performed fundamental research in the first period, the cost of commercialization activities declines with the level of applicability of the

[13] The assumption that there are no actions in the last period, if commercialization is undertaken in $t = 0$ and is successful, is a restrictive one. We could expect, for example, the academic team to perform some additional research after the project is completed, if doing this brings extra-utility, or to receive extra commercial returns from one additional period of commercialization. Jensen et al. (2003) make an assumption similar to mine in their model: if the academic inventor discloses her invention in the first stage of the game, and the Technology Transfer Office finds an acquirer, then the game ends and there are no more periods of research activities. The game has indeed potentially a further stage, to which the parties end up if the academic scientist performs extra-research *before* disclosing. In my model, just as in theirs, the unit of analysis is a single project (apart from the presence of an alternative project in their model, and of the choice to stay idle, and earn zero utility, in mine), and once the project is completed, no other projects are available. We can imagine that the project has no additional commercial value after the first date in which it is successfully commercialized, because others can imitate it in the immediately subsequent period, or it has no additional scientific novelty content after commercialization of the final product. For example, after a drug successfully passes all clinical tests, basic research on that chemical entity has a much lower impact in the scientific community. Moreover, the academic team has also the choice not to enter commercial activities at all, and to perform instead pure basic research, with no level of applicability to the commercial venture, in both periods – see the following description and analysis of the model for further detail. In some sense, we can interpret this option as the performance of an alternative project.

the pre-commercial research chosen by the team. Therefore, in each period $t = 0, 1$ the complete choice set is $\{a_t^u, \gamma_t^u\}$. Commercialization costs are therefore highest when the pre-commercial research has the lowest applicability level ($\gamma^u = 0$), or when the team enters commercial activities in period 0, without performing any additional research. By entering commercialization in the second period after having performed 'applicable' fundamental research in the first period, the team gives up the option of a second try. However, it incurs in lower costs through the spillover of knowledge from fundamental research to commercially-related activities.

Through assumption (1.2), I introduce cumulativeness of knowledge, since previous knowledge produces spillovers on current activities and makes them less costly to perform. For example, a deeper knowledge of some basic properties facilitates the solution of more practical problems that can arise during the development phase, by guiding the search for solutions toward specific directions. Or, the performance of research increases the absorptive capacity of a team, i.e. its ability to exploit the publicly available knowledge and also to commercially profit from it (Cohen and Levinthal 1990).[14]

Costs and benefits from basic research The academic team receives a direct benefit from performing fundamental research, as through publications or peer recognition. Define

$$B^u = \text{Expected (gross) return from fundamental research activities} \tag{1.3}$$

As for the cost of performing fundamental research, let us call it C_s^u and assume:

$$\frac{\partial C_s^u}{\partial \gamma^u} > 0; \frac{\partial^2 C_s^u}{\partial^2 \gamma^u} > 0. \tag{1.4}$$

This assumption is meant to capture the additional difficulties in organizing (applicable) fundamental research. For example, if more applicable research requires a heterogeneous, multidisciplinary team to be formed, there may be additional (and increasing) coordination and communication costs that a more homogeneous, single disciplinary team might not bear.

[14] Or, the performance of more applicable basic research can increase the probability of successful completion of the project. Indeed, an alternative way to introduce cumulativeness of knowledge would be to assume an impact of the performance of research on p, the probability of completion and commercialization, rather than on the costs. Results are similar if this alternative modeling strategy is followed. The role of research as a cost-reducing investment is present in other woks, for example see Klepper (1996).

The team's choice of $\{a_t^u, \gamma_t^u\}$ can therefore be seen as a series of multitask problems: in each period the team has to choose between different activities. There is an implicit constraint in that the team cannot perform both s and c in the same period, and there are tradeoffs involved in this choice: scientific versus commercial rewards, early (but more costly) commercialization versus late (but cheaper) commercialization, and choice of the type of pre-commercial research (or balance between the consumption value and the investment value of research).

The company team

> Private firms feel no obligation to advance the frontiers of science as such. [...] they are always asking themselves how they can make the most profitable rate of return on their investment (N Rosenberg 1990, p. 169).

> In academia you probably wouldn't go to lunch with someone in a different department – says Maciewicz, a biochemist – but because the company's success depends on a group effort, you get to interact with people who have a really different skill base (Urquhart 2000).

I compare the timing of entry into commercially-relevant activities, as well as the returns and the costs of entry for the academic team, to a company research team. This comparison allows me to identify some peculiarities of academic research teams when they have the option of engaging in commercially-related activities. The problem and the payoffs for the company lab are the same as above, except for two modifications:

1. The company team cares only about the completion of the project, which is when potential economic returns occur.

2. The company team does not bear a 'recognition' cost from performing more applicable fundamental research, but only an organizational cost. There is no 'stigma', for example, for a company lab to perform highly interdisciplinary research, or to invest in tacit knowledge.

These two assumptions are formalized, respectively, as follows:

$$B^u > B^f = 0, \tag{1.5}$$

$$\frac{\partial C_s^u}{\partial \gamma^u} > \frac{\partial C_s^f}{\partial \gamma^f}, \tag{1.6}$$

where the superscript f stands for 'firm'. Inequality (1.5) is meant to capture the fact that there is a more exclusive focus on commercial success in industrial environments than in environment responding to academic rules (see also Rosenberg's quote above).[15] Inequality (1.6) is related to the additional loss for academics from performing 'applicable' fundamental research. For example, multidisciplinary research may not be consistent with how the peer review system works, since the system is highly discipline-based (therefore it would be more difficult to publish one's multidisciplinary work in prestigious journals), and multidisciplinarity is difficult to achieve because of the departmentalized organizational structure of universities. Brewer (1999) offers a typology of obstacles to interdisciplinary research. Some of these costs, e.g. the differences in methods and language across disciplines, can be said to refer to the nature itself of interdisciplinary research. Other sources of costs reported by Brewer, however, depends on the institutional rules and incentive systems of the environment in which the research is performed. These costs include the funding rules (and whether they give priority to disciplinary research), and scientists' concerns about their status and careers. Consider also the 'specificity-tacitness' interpretation of the level of applicability: academic scientists are penalized by their peers if they produce fundamental research which is too idiosyncractic or is kept tacit and not codified, say, in journal articles. Academicians find it therefore costly to move their basic research agenda out of the 'ivory tower' or the Bohr's quadrant.

The two teams do not interact, and I analyze the behavior of each team 'in isolation'. In fact I am performing comparative statics along a parameterized family of single-institution models rather than proposing a model of interactions among organizations. In Section 1.7.1, I outline some directions for future research that include several forms of interactions.

Comment On the one hand, the way I model the differences between an academic and an industrial team is very stark, for I assume that industrial scientists do not receive any direct benefit from performing fundamental research. More precisely, I am assuming that, in the industrial environment, both research and commercial activities are evaluated by a common set of criteria; in the academic environment, by contrast, research activities, when performed, are subject to 'peer evaluation', while commercial activities are subject to market-based rewards

[15] This assumption can be relaxed to $B^u > B^f$, without constraining B^f to be equal to 0.

(hence the idea of academia as having *multiple missions*). These differences, however, are to be seen as extreme versions of some largely plausible facts. On the other hand, the differences are minimal, and limited only to the response to scientific incentives. I am assuming that the academic team and the industrial team have the same commercial capabilities, given the same amount and type of research performed, and are equally rewarded when they perform commercial activities. I am therefore confining all of the sources of heterogeneity into the sphere of pre-commercial research. While extreme, this choice is consistent with the institutional literature on science I mentioned above (Merton 1973, Dasgupta and David 1994, and others). The focus of this literature is on the analysis of research activities, and not on commercialization activities. It is at the level of research that differences between academia and business may emerge. In particular, the criteria that govern the evaluation of research in academia do not depend on the commercial value. Notice that this implies that the extra 'recognition costs' for academics from investing in more applicable research (i.e. from choosing some value of $\gamma > 0$) is not due to the type of activity being more 'commercial', but from the fact that the type of research is just not following in full the rules of the scientific community. This observation clarifies also why I do not assume any stigma or extra disutility to emerge from commercialization for academics (except for the foregone private benefit from performing s instead): once commercialization is chosen, the rules of the scientific community do not apply any longer.[16] I capture these differences in a simple way, and also explore the consequences of these differences on an otherwise homogeneous set of activities, those concerning development and commercialization.

Functional forms

In order to obtain close (and easy to interpret) solutions, I consider specific functional forms for the cost functions:

[16]This characterization is also consistent with the characteristics of the modern university, especially in the US, where the quest for commercial success is more and more considered as part of the academic mission (also because it brings extra funds for further research projects). Moreover, recall that the model can also be applied to the provision of both academic and commercial incentives to *company* scientists. In this case, also, it is plausible to assume that the incentives scheme includes peer evaluation only when research, and not commercialization activities (development, production, etc.) are performed.

$$C_c^u = \begin{cases} K \text{ if } a_0^u = c \text{ or } \emptyset \\ K - \gamma^u \text{ if } a_0^u = s. \end{cases} \tag{1.7}$$

$$C_c^f = \begin{cases} K \text{ if } a_0^f = c \text{ or } \emptyset \\ K - \gamma^f \text{ if } a_0^f = s. \end{cases} \tag{1.8}$$

$$C_c^u = \frac{(\gamma^u)^2}{2\alpha} + \lambda^u \gamma^u. \tag{1.9}$$

$$C_c^f = \frac{(\gamma^f)^2}{2\alpha}. \tag{1.10}$$

Commercialization costs (see expressions (1.7) and (1.8)) have the same form for the two teams. The differences in the level of such costs emerge endogenously from the choice of γ^u by the academic team, and of γ^f by the industrial team.

Regarding the costs of research (expressions (1.9) and (1.10)), assume $\alpha \in (0, K]$, $\lambda^u \in (0, 1)$. α is a scaling parameter, and the upper bound to its value, as will be clear below, ensures that commercialization costs (plausibly) do not become negative for any amount of fundamental research performed.[17] The higher marginal cost of applicable research for the academic team (or the negative impact on recognition) depends on the parameter λ^u. In fact, one could think of $\lambda^u \gamma^u$ as a (negative) component of the direct benefit that academics receive from basic research. The direct benefit from fundamental research can be expressed as $(B^u - \lambda^u \gamma^u)$, and the cost as $\left[\frac{(\gamma^u)^2}{2\alpha}\right]$.[18]

Since the expressions above are equivalent to setting $\lambda^f = B^f = 0$, I will write λ and B in place of λ^u and B^u, hereinafter, without loss of clarity. Figures 1-1 and 1-2 summarize the choices and payoffs of the teams.

[17] I take this part of the cost function to be increasing and convex in γ^u: for example, it is increasingly difficult to organize a very heterogeneous team. Or, a too high level of specificity of the produced knowledge would reduce the ability to absorb knowledge from the external world.

[18] A possibly less arbitrary way to capture the lower cost for the company team (for a given γ) is to exclude the linear term $\lambda\gamma$ from the academic team's cost function, and assume that the parameter α takes two different values: α^u for the academic team and α^f for the company team, with $\alpha^u < \alpha^f$. This parameterization conveys qualitatively the same results and intuitions as the 'linear-quadratic' form I use here.

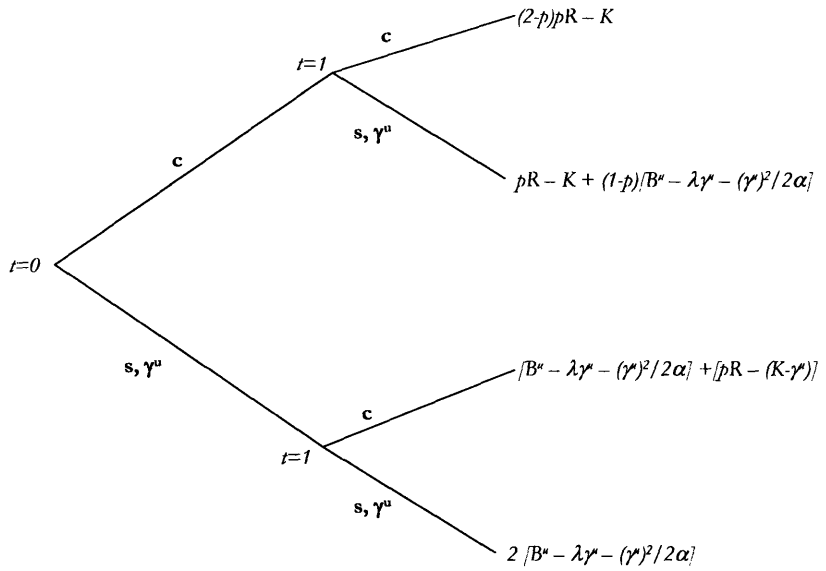

Figure 1-1: Decision tree for the academic team. The actions are reported in bold types. Ex ante payoffs are reported at the end of each branch.

1.4.2 Analysis

The model generates results that I group in two propositions. The first proposition focuses on the decision to enter commercially-oriented research. The second proposition considers the timing of commercialization. In this subsection, I state the propositions, both in informal and in formal terms, and prove them. Then, in the following subsection I offer the intuitions behind the results, as well as comments and implications.

Academic reluctance and project selection

One effect of the different institutional rules in business and academia, as modeled here, is that, when deciding whether to move from fundamental to commercial research, industrial and academic teams have different outside options and opportunity costs. As a consequence, they have different incentives to undertake a given commercial opportunity, and enter different types of projects. In particular, there is a set of projects with positive profitability that the firm would undertake, and the university team would not. The university team is more 'selective'

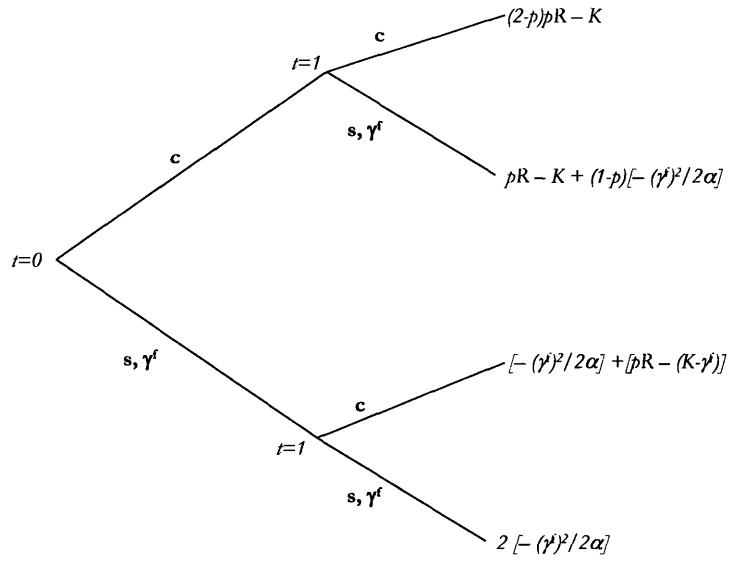

Figure 1-2: Decision tree for the company team. The actions are reported in bold types. Ex ante payoffs are reported at the end of each branch.

the higher is B, the consumption value of basic research, and more so if λ, the parameter affecting the 'recognition costs' from performing applicable fundamental research, is high.

Proposition 1.1 *The condition for the academic team to enter commercially oriented activities in period 0 or 1 is*

$$Max\left\{[p(2-p)R-K],\left[B+pR-K+\frac{\alpha}{2}(1-\lambda)^2\right]\right\}>2B, \tag{1.11}$$

and for the firm is

$$Max\left\{[p(2-p)R-K],\left[pR-K+\frac{\alpha}{2}\right]\right\}>0. \tag{1.12}$$

Condition (1.11) for the university team is more restrictive than condition (1.12).

Re-arranging the terms of expressions (1.11) and (1.12), we obtain that the company team

enters commercialization (at some period) if

$$pR > K - \frac{\alpha}{2} \quad or \tag{1.13}$$

$$pR > \frac{K}{2-p}; \tag{1.14}$$

the academic team enters commercialization if

$$pR > \frac{2B + K}{2-p} \quad or \tag{1.15}$$

$$pR > K - \frac{\alpha(1-\lambda)^2}{2} + B. \tag{1.16}$$

The ex ante revenue (or probability of commercial success) conditions for the academic team to enter commercially relevant activities are stricter than for the company team.

Proof. Provided jointly with the proof of Proposition 1.2 at pages 41-43 below. ■

Academic slowness and academic rush

The model implies not only that academic and industrial actors tend to undertake different sets of projects, but also that they can move to commercialization in different periods. The first part of the following proposition states an 'expected' result: academic teams are slower than industrial teams in moving research to commercialization. In the logic of the model, this means that the academic team undertakes commercially-relevant activities after having performed some additional fundamental research, while the company team would commercialize at period 0 with no additional fundamental research. The university team, moreover, invests in applicable fundamental research, thus reducing commercialization costs in date 1. The second part of the proposition considers a less obvious implication of the model: if performing applicable fundamental research is very costly for the academic team, and if the return from commercialization is sufficiently (but not excessively) high, then an academic team will commercialize earlier than an industrial team. The company team finds it optimal to perform some extra-research before moving to commercialization, while the university scientists do not perform any additional research. The industrial team performs pre-commercial research with a high level of applicability. This scenario is more likely to occur when λ, the parameter affecting

the recognition costs (or negative benefits) from applicable basic research is large, i.e. close to 1.

Proposition 1.2 ***a.*** *If the parameter values are such that*

$$pR > \frac{\alpha}{2(1-p)}, \tag{1.17}$$

$$pR > \frac{2B + 2K - \alpha(1-\lambda)^2}{2}, \tag{1.18}$$

and

$$0 \leq \lambda \leq 1 - \sqrt{\frac{2(1-p)pR - 2B}{\alpha}}, \tag{1.19}$$

then

$$\{(a_0^u, a_1^u), (\gamma_0^u, \gamma_1^u)\} = \{(s, c), (\alpha(1-\lambda), 0)\}, \tag{1.20}$$

and

$$\{(a_0^f, a_1^f), (\gamma_0^f, \gamma_1^f)\} = \{(c, c \text{ if fail at } t = 0), (0, 0)\}. \tag{1.21}$$

The costs of entry for the company team will be equal to K, and therefore the expected return at period 0 will be $p(2-p)R - K$. The costs of entry for the university team will be equal to $K - \alpha(1-\lambda)$, and the expected commercial return at period 1 will be $pR - K + \alpha(1-\lambda)$.

b. *If the following two conditions hold:*

$$\frac{2B + K}{2 - p} < pR < \frac{\alpha}{2(1-p)}, \tag{1.22}$$

$$1 - \sqrt{\frac{2(1-p)pR - 2B}{\alpha}} < \lambda \leq 1, \tag{1.23}$$

then

$$\{(a_0^u, a_1^u), (\gamma_0^u, \gamma_1^u)\} = \{(c, c \text{ if fail at } t = 0), (0, 0)\} \tag{1.24}$$

and

$$\{(a_0^f, a_1^f), (\gamma_0^f, \gamma_1^f)\} = \{(s, c), (\alpha, 0)\}. \tag{1.25}$$

The costs of entry for the academic team will be equal to K, and therefore the return will be

$p(2-p)R-K$. *The expected return for the company team will be, at period 1,* $pR-K+\alpha$.

Proof. I offer a combined proof for both Propositions 1.1 and 1.2. Consider the following remarks:

Remark 1.1 *The academic team invests in 'applicable' fundamental research (i.e. in* γ^u*) in period 0 only if it plans to enter commercially-relevant activities in period 1. The company team always invests in* γ^f *in period 0, if it plans to enter commercialization in period 1.*

Remark 1.2 *Neither the academic team nor the industrial team invests in* γ *in the second and last period, since there is no benefit from doing this, while there are costs. The university team does not invest in* γ^u *in period 0 either, if it plans to perform fundamental research in both periods (something that the firm will never do).*

Remark 1.3 *When the teams invest in applicable fundamental research, they choose*

$$\gamma^u = \alpha(1-\lambda) \tag{1.26}$$

$$\gamma^f = \alpha. \tag{1.27}$$

Therefore, $\gamma^u < \gamma^f$. *These values are obtained by maximizing, with respect to* γ,

$$B-\lambda\gamma-\frac{(\gamma)^2}{2\alpha}+[pR-(K-\gamma)] \;\; s.t.\; \gamma \geq 0; \tag{1.28}$$

$$-\frac{(\gamma)^2}{2\alpha}+[pR-(K-\gamma)] \;\; s.t.\; \gamma \geq 0. \tag{1.29}$$

i.e. the ex ante expected returns for the academic and the industrial team from performing fundamental science in period 0, and entering commercialization in period 1.

Remark 1.4 *If the academic or the company team enters commercialization in period 0, and they are not successful, they will both choose* $a_1^i = c$. *This choice is obvious for the firm. As for the university, the choice is between* $a_1^u = c$ *and* $\{a_1^u = s,\ \gamma^u = 0\}$ *(as for the choice of* γ^u *in period 0, see point 3 above). Now, the academic team chooses* $a_1^u = s$ *only if* $B > pR$ *(at this point the entry cost is sunk). If this is the case, then the team would have chosen* s *also in the first period, because, a fortiori,* $B > pR-K$. *Therefore, having chosen to go commercial in the first period implies that the parameter values are such that it is optimal to go commercial also in the second period.*

Remark 1.5 *No party stays idle in period 0 if it plans not to stay idle also in period 1. The company team would retard the payoffs by one period without enjoying reduction in entry costs. The academic team would also forsake the net benefit B. In fact, the academic team never stays idle, since it can always guarantee itself a benefit of $B > 0$ in each period. If $pR > K - \frac{\alpha}{2}$, the firm does not stay idle in the second period either.*

Given these observations, the decision trees for the academic and company teams reduce to what reported in Figure 1-3. Consider conditions (1.11) and (1.12) in Proposition 1.1 (page 38). If the

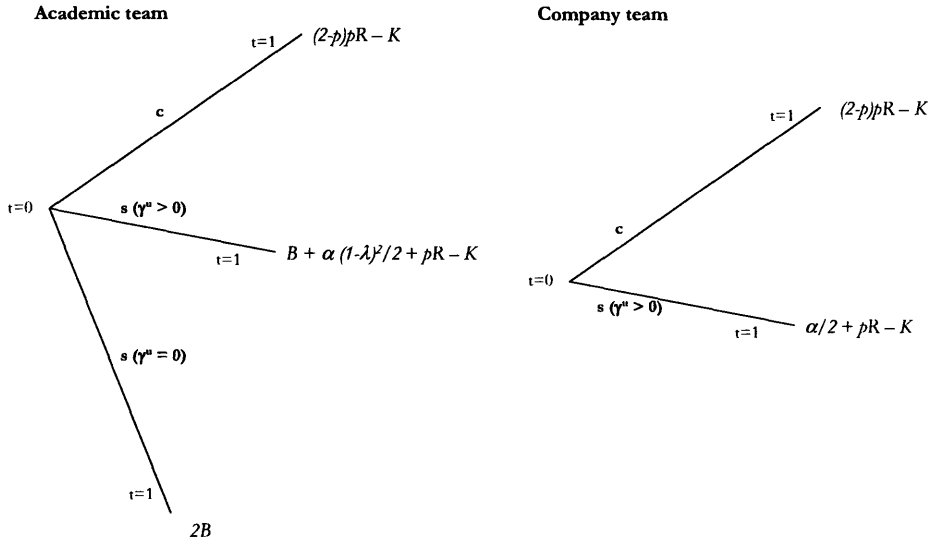

Figure 1-3: 'Relevant' decision trees for the university and the company research team.

academic team moves to commercialization, it means that either $p(2-p)R - K > 2B$ or $B + pR - K + \frac{\alpha}{2}(1-\lambda)^2 > 2B$ (or both). If $p(2-p)R - K > 2B$, then a fortiori $p(2-p)R - K > 0$, and also a company team would find it profitable to enter the project. If $B + pR - K + \frac{\alpha}{2}(1-\lambda)^2 > 2B$, then $pR - K + \frac{\alpha}{2}(1-\lambda)^2 > B > 0$. Now, since $\lambda \in (0,1)$, also $pR - K + \frac{\alpha}{2} > 0$. Any project that the academic team would enter (e.g. would move to commercialization) would also be entered by the company team, while the opposite is not necessarily true.[19]

[19] The same can be said, in terms of the probability of commercial success of a given project: if p is such that the academic team is willing to commercialize, then also the industrial team is, but the opposite is not necessarily the case.

As for Proposition 1.2-a, consider the problem of the academic team. Entering commercialization in period 1 is optimal if

$$B - \lambda\gamma^u - \frac{(\gamma^u)^2}{2\alpha} + [pR - (K - \gamma_u)] > 2B \tag{1.30}$$

and

$$B - \lambda\gamma^u - \frac{(\gamma^u)^2}{2\alpha} + [pR - (K - \gamma^u)] > pR + p(1-p)R = p(2-p)R - K. \tag{1.31}$$

Similarly, for the firm, optimal entry into commercially-oriented activities at period 1 requires

$$-\frac{(\gamma^f)^2}{2\alpha} + [pR - (K - \gamma^f)] < pR + p(1-p)R = p(2-p)R - K \tag{1.32}$$

Given the optimal determination of γ^u and γ^f from (1.26) and (1.27), we get the conditions (1.17), (1.18) and (1.19) - see page 40. By a similar procedure we obtain the conditions in Proposition 1.2-b. ■

Figures 1-4 and 1-5 represent qualitatively the cases emerging from the two propositions.[20]

1.5 Intuitions and relation to the existing literature

Let us now analyze each of the results described above. I also refer to results to the existing literature and evidence.

1.5.1 Academic reluctance (and industrial focus)

Proposition 1.1 tells us that academic research teams have strong incentives not to enter commercially-relevant activities at all. Academic scientists derive a higher benefit from perform-

[20] Figure 1-5 is drawn under the following additional assumption: $\frac{B}{p(1-p)} < \frac{K}{p} - \frac{\alpha}{2p} < \frac{B+K}{p} - \frac{\alpha}{2p} < \frac{2B+K}{p(2-p)} < \frac{\alpha}{2p(1-p)} < \frac{B+K}{p}$. This implies $K > \alpha > 2B$ (so that $\frac{B}{p(1-p)} < \frac{\alpha}{2p(1-p)}$); $K > \frac{\alpha}{2} + \frac{B}{(1-p)}$ (so that $\frac{K}{p} - \frac{\alpha}{2p} > \frac{B}{p(1-p)}$); $K < \frac{\alpha(2-p)}{2(1-p)} + \frac{Bp}{1-p}$ (so that $\frac{B+K}{p} - \frac{\alpha}{2p} < \frac{2B+K}{p(2-p)}$); $K < \frac{\alpha(2-p)}{2(1-p)} - 2B$ (so that $\frac{2B+K}{p(2-p)} < \frac{\alpha}{2p(1-p)}$); and $K > \frac{\alpha}{2(1-p)} - B$ (so that $\frac{\alpha}{2p(1-p)} < \frac{B+K}{p}$). The condition $K < \frac{\alpha(2-p)}{2(1-p)} - 2B$, if respected, also automatically verifies that $K - \frac{\alpha}{2} < \frac{K}{2-p}$, and therefore condition (1.13) is less restrictive (in terms of R) than condition (1.14) (see page 39). In other words, if $R < \frac{K}{p} - \frac{\alpha}{2p}$, then a fortiori $R < \frac{K}{p(2-p)}$ and the company team will not enter commercial research at any period. A necessary condition for the previous inequalities to hold is that $max\left\{2B, \frac{4B(1-p)}{p}\right\} < \alpha$, given that we also have to satisfy $K > \alpha$. $\frac{4B(1-p)}{p} < \alpha$ is necessary for $\frac{2B+K}{p(2-p)} < \frac{\alpha}{2p(1-p)}$ (or $K < \frac{\alpha(2-p)}{2(1-p)} - 2B$) and $K > \alpha$ to hold. Values of $K = 7B$, $\alpha = 6.5B$ and $p = .5$ satisfy the condition above. Notice that the condition excludes some scenarios, for example the case in which $\{(a_0^u, a_1^u), (\gamma_0^u, \gamma_1^u)\}$=$\{(s,s),(0,0)\}$. and $\{(a_0^f, a_1^f), (\gamma_0^f, \gamma_1^f)\}$=$\{(c, c \text{ if fail at } t=0),(0,0)\}$.

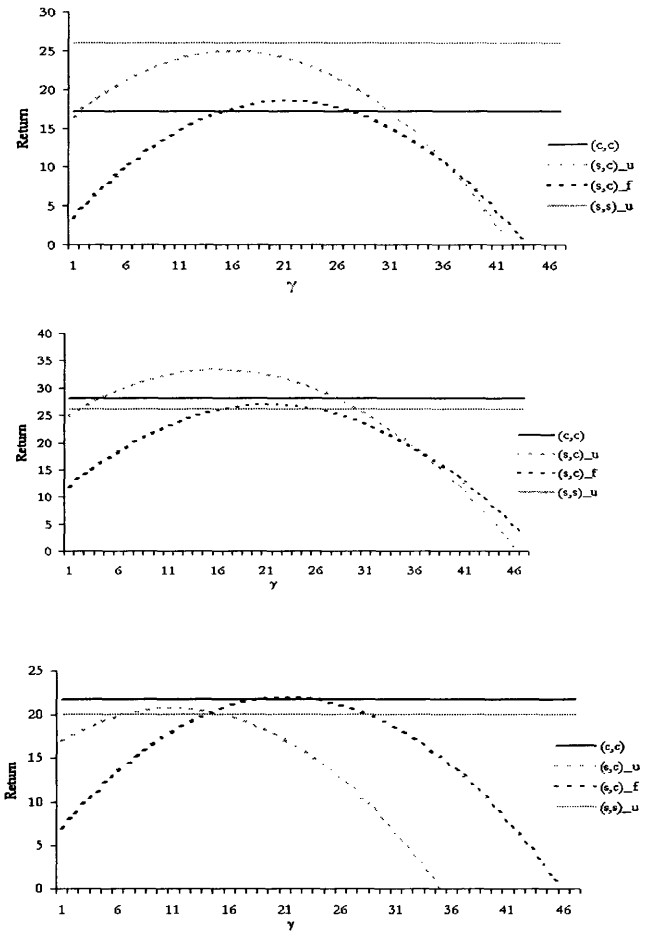

Figure 1-4: Qualitative representation of the different cases described in Propositions 1.1 and 1.2, in the (γ, [expected] return) space. The continuous black line (c,c) gives the expected payoff from trying commercialization in both periods. The dotted gray curve (s,c)_u represents the expected return for the academic team from choosing s in period 0 and c in period 1. The dotted black curve (s,c)_f represents the expected return for the industrial team from choosing s in period and c in period 1. The continuous gray line (s,s)_u gives the return for the academic team from choosing s in both periods. All of the functions are drawn for different levels of γ. The options described by these curves are the only rational ones the teams will choose. Moreover, the academic team chooses $\gamma = 0$ if it plans not to enter commercialization at any period (the (s,s) line is drawn considering this remark). The top diagram shows a case where the academic team never commercializes, while the company team does. The industrial team enters at date 1, since there are levels of γ such that it is preferable to wait before trying commercialization, and invest in cost-reducing research. The middle diagram is related to Proposition 1.2-a. The company team chooses c from period 0, while the academic team invests in applicable research and then tries commercialization. The bottom diagram represents the opposite situation, as in Proposition 1.2-b. The academic team 'rushes' to commercialization, while the company team invests in research before moving to commercially related activities.

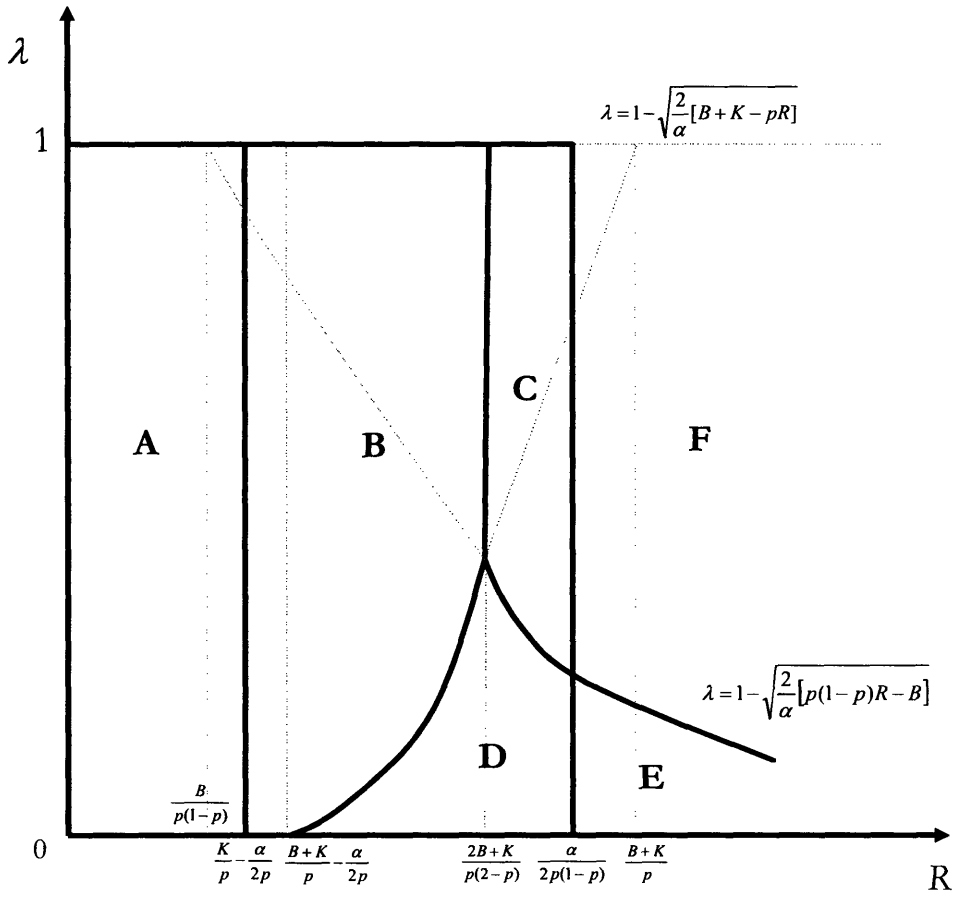

Figure 1-5: Qualitative representation of the cases in Propositions 1.1 and 1.2, in the (R, λ) space (see footnote 20 at page 43 for some extra-assumptions made in drawing the figure). In region A neither the company team nor the university team enters commercialization in any period, as the returns would be negative. Region B represents the parameter space in which the academic team does not enter commercial activities, and undertakes fundamental research (with $\gamma^u = 0$) in both periods 0 and 1. This region is obtained from expressions (1.15) and (1.16) in Proposition 1 above (see page 39), expression (1.18) expression (1.19). In regions D and E, the academic team performs applicable basic research in period 0, and enters commercialization in $t = 1$. This is obtained from inequalities (1.18) and (1.19) at page 40. In region D also the firm perform research in $t = 0$ before moving to commercialization, while in region E the firm has incentives to enter commercialization in period 0 with no additional research. In regions C and F the academic team enters commercialization in period 0 without performing any additional basic research. In region C the academic team enters commercialization earlier than the industrial team would – see inequalities (1.22) and (1.23) in Proposition 1.2-b.

ing fundamental research without direct economic value, since there is also a 'consumption-like' dimension in performing fundamental research. This creates a conflict between the pursuit of economic and scientifically-relevant activities, and will delay or exclude the movement toward more applied, commercially-oriented research. Therefore, academic entrepreneurs would rationally forsake commercial opportunities with positive economic and social value. Moreover, academic teams will generally opt for a lower level of applicability of the content of fundamental research, because of the extra cost they derive from it as compared to 'pure' basic research.[21] In figure 1-5 at page 45, region A corresponds to a case in which the firm does not find it profitable to enter at any period, nor does the academic team move to commercialization. In region B, however, the firm has incentives to undertake commercially-relevant activities, but the academic team does not (see also the top diagram in figure 1-4 at page 44).

The historical cases mentioned above showed dynamics very similar to the 'reluctance' result. Consider, as an illustration, the invention of the transistor in the late 1940s. A company research team at Bell Labs, and an academic team at Purdue, were performing very similar research on solid state physics. It can be argued, from the existing accounts, that both groups had the knowledge and the abilities to reach the invention. For example, Bardeen, Brattain and Shockley, who led the project at Bell Labs, shared the Nobel prize in 1956, and Karl Lark-Horovitz, who led solid state research at Purdue, was an authority in solid-state physics in the 1940s. Moreover, the academic scientists at Purdue were also aware of the economic and social impacts of their research, and of the possibility to profit from it (universities could file for patents in the 1940s, and in fact Purdue had already obtained some patents before entering semiconductor research). However, the academic team focused on single-disciplinary research paths with high 'pure' scientific value, but no immediate applicability. Research at Bell Labs, while having undoubtedly high scientific content, was multidisciplinary, and there was more

[21] The case of Varian Associates in the late 1940s, as described by Lenoir (1997), offers again some insights. The development of Nuclear Magnetic Resonance (NMR) instrumentation required the performance of research that was a 'disciplinary hybrid between engineering and physics' (p. 247). However, the Stanford scientists interested in NMR found it hard to conduct interdisciplinary research in their university. Somewhat paradoxically, they felt less constrained in a company environment. Interestingly, such strict disciplinary organization of research at Stanford is confirmed by Jong (2006) in a study of the biochemistry departments in the San Francisco Bay Area in the 1970s and 1980s. Also, Hall et al. (2000) find that in collaborative projects with universities, firms experience difficulties in assimilating fundamental knowledge useful for the completion of the project. This can be due to the fact that university researchers have incentive to generate less applicable knowledge.

intense communication between scientists with different backgrounds. Research at Bell Labs was also secretive, and could be diffused only several months after patent applications. There also were clear priorities in the direction of the research, and top R&D management had to approve any research program (see for example Braun and Macdonald 1978, and Bray 1997). This gave the sense of a common, practical goal to be achieved (see for example Shockley 1956, Nelson 1962, Braun and Macdonald 1978, Hoddeson 1980, Bray (1982, 1997)).[22] Contrary to an alleged uniqueness and diversity of the research at Bell Labs if compared to other industrial settings, and its alleged similarity to a university environment as claimed by many observers, a careful reading of the available accounts, and the comparison to what was simultaneously (and independently) happening in a 'real' academic laboratory, reveal that the organization and the rules of Bell Labs were not so different from what one would expect from profit-seeking, economically-focused agents, and were different from an academic setting. It is this 'normality', I claim, rather than any kind of diversity and uniqueness, that explains the greater success of Bell Labs, and the anticipation of the discovery of the transistor by as much as a decade (according to Riordan and Hoddeson 1997). Similar considerations apply to the case of the synthesis of human insulin, and of the differences in the objectives and organization of research at Genentech[23] and in the university laboratories engaged in insulin research, at Harvard and at UC - San Francisco (see Hall 1987, Stern 1995, McKelvey 1996).

The reluctance result is also consistent with the difficulties of and resistances against university-led entrepreneurial ventures as described by Kenney (1986), Argyres and Liebeskind (1998), and Lerner (2004). In most of the cases described by these authors, a major reason for the poor performance of the ventures can be reconducted to the prevalence of other objectives and missions over the focus on economic returns.

1.5.2 Project selection

Proposition 1.1 also reveals that a selection mechanism is in place: academic researchers tend to enter a different set of projects than those entered by non-academic teams. Teams responding to

[22] I am very grateful to Professor Ralph Bray, who was a doctoral student in the Lark-Horovitz's group at Purdue in the late 1940s, for agreeing to be interviewed.

[23] Some would consider Genentech as a form of academic entrepreneurship. For my purposes, Genentech represents a 'pure' firm as opposed to the university-based teams that were working on very similar research. See Hall (1987) and Stern (1995) for interpretations consistent with mine.

academic rules in the performance of research choose among projects with higher expected revenues, or equivalently higher probability of commercial success. Therefore, commercial projects entered by academics are less likely to fail, on average. Suppose, for example, that the distribution of projects' profitability (or probability of success) is skewed, with many 'marginal' projects and a few very profitable projects. Because of the higher opportunity cost to move to commercialization, the academic team is unlikely to enter the marginal projects, and is more likely to enter only the very profitable ones. As long as also the marginal projects offer a non-negative expected return, the industrial team will have incentive to move the research to the market at some point. Therefore, on average the returns for an academic team may be higher. By contrast, conditional on both teams moving to commercialization at some period for a given project, the economic profits of the academic team (net of the private benefit B) are never higher than those of the industrial team. On the one hand, the academic team picks among a better set of projects. On the other hand, it performs no better than an industrial team would, had it brought that same project to commercialization. Any empirical finding that shows either a positive or negative impact on commercial return of the involvement of academics into business activities needs therefore to appropriately control, in the definition of the statistical models and techniques, of these two potentially relevant dynamics.

While somewhat intuitive, this result has never been considered before.[24] It offers an alternative (or additional) explanation for 'success stories' of the involvement of academics into commercially-related activities in such studies as Zucker and Darby (1995), Cockburn and Henderson (1998), Torero et al. (2001), Nerkar and Shane (2003), Shane (2004), Stephan et al. (2004), Kumaramangalam (2005), Rothaermel and Thursby (2005), Toole and Czarnitzki (2005), and Agrawal (2006).[25] The positive impact of the direct involvement of academics into commercially-relevant research may be driven by the fact that academics *choose* to participate only in those commercial projects which make it worthwhile for them to forego valuable acad-

[24] A partial exception is Witt and Zellner (2005).

[25] Toole and Czarnitzki (2005) acknowledge this potential endogeneity problem in their empirical analysis. Kumaramangalam (2005) studies the impact of collaboration with academic scientists on the quality of biotech articles. He accounts for the fact that the sample of articles he considers may not be a random sample. However, he does not consider that also the subsample of biotech papers with an academician among the authors may be a self-selected sample.

emic activities, and not necessarily by the superiority of their knowledge and capabilities.[26,27] Just as the success of a business venture may depend on the direct involvement of academicians, so the choice of academicians to join a company depends on the (expected) profitability of the venture, as compared to other sources of benefit for the scientists. Comparing the outcomes of commercial ventures involving academics with those not involving academics may therefore not be appropriate, since these ventures are likely to be very different from the outset. Moreover, the model clarifies that in order for these comparisons to make sense, we need to consider counterfactuals: what would have happened to a particular commercial venture, had an academic team been involved in it? The model also shows that the involvement of academic reduces the pure economic profit since the university team invests less in applicable research. But exactly for this reason the academic team may decide not to bring these 'economically marginal' projects out of the lab, and may instead keep doing basic research without concerns for commercial applications, thus obtaining higher scientific benefits.[28]

1.5.3 Academic slowness

The second set of results, in Proposition 1.2, focusses on the timing of entry into commercially-oriented research. I first obtain (part *a* of the proposition) an expected result: the institutional and organizational features of universities make academic researchers slower than company

[26] While Lowe and Ziedonis (2006) find that spinoffs from the University of California (UC) are more successful than non-university generated spinoffs, Shane (2002) finds contrasting results for MIT spinoffs. The result discussed in this section could contribute to explain this difference. UC has shown to have a more 'conservative' approach to the involvement of academicians in commercial activities than MIT (see UC presidential Retreat 1997). This can be translated in my model as a high opportunity cost for scientists to move to commercial activities, and therefore to a higher selectivity in the undertaken activities. MIT professors may instead be attracted also by less profitable ventures.

[27] Capability and selection can coexist. Very skilled scientists may have a stronger impact on the profitability of a commercial venture both because they pick more profitable ventures, and because they have higher knowledge that can be applied to the venture. Moreover, if we look at status and academic position rather than ability, it can be argued that scientists with *higher* status would be more less selective in undertaking commercial activities, since they do not need to perform additional research to achieve peer recognition.

[28] The selection effect would be stronger for more skilled scientists: the private benefit they give up (e.g. in terms of the expected number and quality of publications they would achieve, if they keep on a pure basic research path) is indeed higher. Some of the previously mentioned empirical studies focus on highly skilled academic scientists. Calderini et al. (2004) find that the professors with highest quality publications are less likely to be listed among the inventors of a patent assigned to a firm. My selection result offers an explanation for this finding. Calderini et al. add that a further selection may occur: firms may not find academic prestige as a good proxy for the ability to perform 'applicable' research. This view is consistent with the presence of several types of basic research and of different incentives for academic and industrial teams to perform each type.

scientists in undertaking research with commercial potential. The argument is similar to that said above regarding the reluctance case. However, in this case the academic team has incentives to undertake commercial activities 'not too late'. In figure 1-5 at page 45, this case corresponds to regions D and E (in region D, both teams would wait until period 1 before entering). The survey of Franklin et al. (2001) shows that one of the major concerns of Technology Transfer officers in universities, about the direct involvement of academic inventors in commercially valuable projects, is that academics tend to focus on the scientific and technical aspects of a project, thus neglecting or delaying commercially-related activities. Rothaermel and Thursby (2005), while finding that incubator firms with an active involvement of academicians have lower rates of failure, also find that these firms take longer to be 'promoted', i.e. to exit from the incubator and become independent companies. These findings are consistent with my result. In comparison with the reluctance case, notice that not only does the academic team enter commercialization activities at some point, but it also undertakes a different type of basic research. There are incentives to 'sacrifice' some private benefits from fundamental science and perform more applicable research, with greater investment value. However, the level of applicability of basic science will not be as high as what a firm would choose (see below). The academic team, therefore, will in general be less commercially profitable than the industrial team for a given project (assuming the teams enter the same set of project, which is not necessarily the case as from the selection result – see above).

1.5.4 Academic rush

Part b of Proposition 1.2 defines the parameter space where a less intuitive scenario emerges, one in which a university research team is more eager to bring its research to the market than a company would be. The model shows that in certain circumstances academic scientists gain less than company scientists from performing additional fundamental research before moving to commercial research, if the applicable content of fundamental research is very low. Recall that the level of applicability of basic research is endogenously determined, and the more applicable the research, the higher the cost reduction. If the academic reward from the research project (the parameter B in the model) is not very high, and if the loss in recognition from performing applicable fundamental research is substantial (λ is high), then it turns out that the academic

team is more eager to move to commercialization. In figure 1-4 at page 44, this case is shown in the bottom diagram. In figure 1-5 at page 45, this case corresponds to region C.

Compared to the slowness case, now the consumption incentive and the investment incentive collide. By performing fundamental research before entering commercialization, the team receives a small consumption value from the research; moreover, since the recognition cost is high, the investment in applicability will be small (recall that the level of γ^u, the degree of applicability of pre-commercial science or cost reduction, is negatively correlated to λ, the parameter affecting the recognition costs from applicable basic research – see Proposition 1.2 at page 40). Moreover, performing additional pre-commercial research delays the achievement of (uncertain) economic returns. Therefore, the academic team would prefer to move to commercially-oriented activities right at the outset, giving up the private benefit from basic research.

The absence of consumption motives and recognition issues for a firm eliminates this contrast, and makes the investment in additional research, with no immediate economic value, still optimal. An exclusive orientation to economic profit leads a company to appreciate fully the investment value of fundamental research, while the simultaneous presence of multiple motives inhibits the investment in research by the academic team. The exclusive orientation toward economic profits from the project also leads the industrial team to choose a highly applicable type of fundamental research, more applicable than the type chosen by the academic team when it performs some fundamental research before moving to commercialization. This more applicable pre-commercial research, while of great economic potential (in terms of investment value) and potentially also scientifically novel, does not completely respond, however, to the rewarding rules of the scientific community.

Two issues can be raised regarding this result. First, isn't the academic team behaving like a 'pure firm' since it is not performing any additional research? Recall that I characterize the academic and the industrial teams as responding to different incentives when they perform research activities, e.g. activities with some level of scientific novelty. The reward system in the scientific community is concerned with this kind of activities. Development and commercialization activities are activities for which there are no 'academic' rewards, e.g. rewards in the form of recognition, publications, promotions and the like. This does not mean that universities (or individual scientists) do not care about commercialization, since they can get monetary returns

out of it. Commercialization activities, *per se*, do not imply that universities are not behaving as universities, since the differences between the academic and the industrial environment, in my setting, are confined to the research phase. As pointed out above (see in particular the comment at page 34), the peculiarity of the academic environment is the pursuit of *multiple missions*, with different activities, research and commercialization, being rewarded by peer recognition and market-based mechanisms, respectively. In the industrial setting, any activity is subject only to market-based rules. This implies that behavioral differences between the two teams, if any, will be in the amount and type of research. This will have an impact possibly on the timing of commercialization, but not in the way commercialization is performed. Recall, finally, that we look at the performance of *additional* research for a single project. Therefore, it may well be that some 'academic' research has already been performed, and that scientists are performing research for other projects. By commercializing early, an academic team gives itself one more shot to be successful on the market, but also gives up any potential 'private' benefit from the performance of additional research.

A second issue can be stated as follows: isn't the academic team, by rushing to commercialization, getting a lower payoff than the industrial team (see the bottom diagram in figure 1-4 at page 44)? Indeed, one could argue that the academic team might instead prefer to 'behave like a firm' and not care about the rules of the scientific community. This would guarantee the team a higher payoff by choosing to do some pre-commercial research in the first period, and therefore we would not observe academic rushing. However, this is precisely the case in which we are treating the academic team as just a company team. What we are interested in is instead the analysis of the behavior and performance of a team when it responds to the rules and incentives of the scientific community. This is what characterizes the team (and the entrepreneurial activity it engages in) as *academic.* If we, in fact, do not observe academic entrepreneurship in a certain area, according to the model this may be due not to the fact that an academic team would be (possibly inefficiently) too slow, but it would be (possibly inefficiently) too *eager* to commercialize (see below).

This rushing result is novel. While, at this stage, this results should be mostly seen as describing a theoretical possibility, it also matches some empirical evidence on the behavior of academic organizations when they move to commercialization, such as Jensen and Thursby

(2001) and Lowe (2002). Jensen and Thursby (2001) and Jensen et al. (2003) propose a different argument for the survey results of Jensen and Thursby (2001), and focus on the principal-agent relationship between scientists and the Technology Transfer Office of the University. Lowe (2002) motivates his findings with an argument based on contractual incompleteness and information asymmetries. My focus is less on contractual and informational issues, and more on the differences among institutional environments and their effect on the production of knowledge and on the performance of commercially-relevant research. The issues I point to are complementary to the ones these authors focus on. Kogut and Gittelman (2003), in an analysis of the biotech industry, find that there is a tension between the production of highly rewarded science and commercially viable research, with company scientists 'polarizing' toward the production of one type of activity or the other. The authors hints at the presence of different institutional logics – the scientific one and the commercial one - in order to explain the observed behaviors and outcomes. My study can be seen as an attempt to formalize the idea of the presence of multiple missions and commitments in the performance of research, and to explore the implications of this. Finally, the result that firms have incentives to do fundamental research is also consistent with the evidence of outstanding research performed in industrial labs through history. Companies have low 'static' incentives to perform basic research, say in a one-period world; however they can have strong incentives to perform fundamental research in a multi-period, dynamic setting.

1.6 Managerial and public policy insights

In this Section I infer a series of implications of my findings that can be of interest for company managers and university administrators. Even if I do not perform explicit social welfare evaluations, my results also provide useful insights for public policy makers.

The reluctance result formalizes the previously described arguments and evidence which cast doubts on the viability of academic entrepreneurship on a large scale and as a solution to problems of lack of innovativeness. Involving academics and academic organizations implies the involvement of additional, peculiar missions and incentive systems, which may take priority over the completion and commercialization of commercially viable projects. An academic team might

therefore not undertake a research project with positive (although small) profits and therefore of positive social value. An excessive reliance on academics for bridging the gap between science and business may lead to missed opportunities: some projects are never commercialized, or the commercialization is highly delayed. On the other hand, the presence of a 'positive-utility' alternative to the commercial path represents a sort of disciplining device for an academic team, which will undertake only commercial opportunities of high quality.

From both a policy and managerial perspective, the selection result (see Proposition 1.1 as well as Section 1.5.2 above) implies that any causal inference and normative implication from empirical tests of the impact of academic entrepreneurs on the viability and success of a commercial activity (and in bringing fundamental research to market successfully) should be taken with caution because of this possible selection mechanism, unless the endogeneity problem is appropriately corrected for. More precisely, empirical tests should try to tease apart the effect of the different abilities of academic scientists, of the selection into different projects, and of the potentially different incentives to invest in a given type of research, for a given project. Existing explanations of the impact of academicians into business tend to 'collapse' these three different mechanisms into a pure ability argument. The reluctance and selection results, taken together, tell us that we might observe both 'success stories' of academic entrepreneurs, and 'missed opportunities'. From a managerial standpoint, moreover, these results imply that attracting talented academic scientists (as employee or as independent collaborators) may be very costly, given the additional opportunity costs that would need to be covered.

As for the 'slowness' result derived in Proposition 1.2-a and further commented in Section 1.5.3, most of the previously cited literature that has documented commercialization delays by academics has intepreted these delays as a downside of academic entrepreneurship. In my framework, however, a delay implies that the academic team has incentives to produce a higher amount of fundamental research. If, at a given point in time and for a given amount of knowledge in the system, the performance of some additional basic research has a higher social value than the costs from the delay of commercialization, then a university team will have the 'right' incentives to perform this additional research, while a company team cannot commit to strike a compromise between the performance of additional research and the performance of commercially-oriented activities. Similarly, if a company expects to benefit from the

performance of additional research in a given project in the form, say, of spillovers of knowledge into other current or future activities, the company might benefit from tying the financial rewards of its scientists to their standing in the scientific community. In fact, publications and invitations to conferences may represent verifiable performance measures for the amount of research performed. Recall also that the scholars who see a greater involvement of academics and academic organizations into commercially-related work claim that there would be a better balance between the performance of scientifically novel and commercially valuable activities (see Section 1.2.1). In the environment I describe, a case of balance is one in which a given team perform both scientific research, and commercially-related activities. The slowness case is one in which academic incentives are necessary for the balance to be achieved. However, this might come at the cost of a delay in commercialization. These two consequences of the presence of both academic and commercial incentives would need to be weighed against each other, in any specific case.

Finally, the 'rush' result can be seen as a warning for the organization of research activities by companies as well as for policy interventions. From a managerial standpoint, there are cases in which, if a firm wants to commit to a higher effort in research, partnering with organizations responding to the incentives of the scientific community, or providing 'academic' incentives to its own scientists (e.g. by tying monetary bonuses or promotions to the reputation of the scientists in their community of peers) are not the right ways to go: researchers who respond to academic incentives, as defined above, may be even more eager than their industrial partners to bring their research to the market, potentially at high costs given the state of knowledge. Scientific and commercial incentives, if juxtaposed in their 'pure' form, may collide instead of reinforcing each other.

From a university policy perspective, if the aim of promoting academic entrepreneurship is to increase both the scientific and the commercial value of research, then in some cases academicians are not the appropriate agents of such policy. A university team in some cases has no incentives to perform additional explorations before commercialization, while a company team would. Having *academic* researchers involved in commercial research implies that these researchers will be exposed to heterogeneous sets of incentives, and will have multiple missions. It is important to analyze whether and how these missions will reinforce each other, or whether

they will collide. A clear (though simple) characterization of the academic environment, and on how academic scientists are rewarded by their peers, helps detecting these conflicts. For example, exposing scientists to strong economic incentives, without modifying the reward structure and the organization of research in academia, may not be sufficient and could actually generate the 'wrong' results. Consider, as an example, a profitable economic opportunity emerging from a project in a very young and still not well defined area of research. Since the area is new, the benefit from peer recognition may be low. Or, the new area requires an organization of research which is not rewarded in the scientific community, e.g. a high level of multidisciplinarity or tacitness. Further scientific explorations could be valuable for society, if they, say, are expected to branch into related results before the original research is 'privatized' through commercial applications.[29]

Reforms of reward criteria for academic scientists, the promotion of multidisciplinary research, and incentives for keeping knowledge more tacit and idiosyncratic would be important, for example, to avoid too early commercialization, and reach a balance between science and commercialization. David (2005) proposes to create 'bridge institutions' with rules different from both the industrial and the academic environments. Bozeman (2002) shows that in University Science and Technology Centers (often funded by both public and private entities), scientists are rewarded according to partially different rules than those prevailing in pure academic laboratories. For example peer review is not the only metric, and multidisciplinary work is promoted. The development of these hybrid organizations, partially autonomous even if not totally separated from the academic environment, might represent a viable strategy for the promotion of science-based entrepreneurship. The (partial) separation from pure university settings might allow universities not to be burdened with further tasks, in addition to those they are already called to perform. The benefits of these organizational and institutional changes, however, need to be weighed against a few potential costs. First, it may be difficult for an academic organization to sustain different rules and incentive systems within its boundaries. How to reward, for example, a scientist who works in a S&T Center, and at the same time runs a laboratory in an academic department? Second, these changes would generate an institutional

[29]This consideration is similar to Heller and Eisenberg's (1998) discussion of the 'Tragedy of Anticommons' from the introduction of Intellectual Property Rights (and therefore stronger economic incentives) in academic research, and has been considered also by Aghion et al. (2005) in what the authors call 'early privatization'.

transformation of universities in organizations very similar to business companies. Given that we already have business companies, the question is what would be the incremental benefit of modifying universities to make them similar to already existing organizations.

1.7 Extensions and directions for future research

1.7.1 Model extensions

A first, natural extension of the analysis would be to consider the academic and the company team as interacting among each other, rather than operating individually and separately. The interaction would take place, for example, in the form of knowledge spillovers among the parties. In particular, the level of tacitness of the fundamental research chosen by a research group determines to what extent another group is able to exploit the knowledge produced externally. The presence of knowledge spillovers would modify the incentive of an academic team to enter commercially-oriented research. Given the structure of the model, we could expect asymmetric effects of the presence of spillovers on an academic and an industrial team. For the industrial team, on the one hand, knowledge spillovers would generate a typical free-riding response, with a reduction of the fundamental research performed internally. The academic team, on the other hand, has stronger incentives to perform fundamental research, and, in addition, knowledge spillovers from the firm would further reduce the costs of commercially-oriented activities, thus making them more appealing than the performance of 'ivory tower' fundamental research (i.e. research with no applicability and pure consumption value). Some openness of research and free flow of knowledge would therefore stimulate academic entrepreneurship.

The academic and the company team can be influenced in their entry and timing decisions also by another form of interaction, namely competition for priority in the discovery of the commercializable results. This possibility is not an abstract one, since this type of competition actually occurs in science based sectors. For example, in the previously mentioned case of the synthesis of human insulin, there was some degree of competition between Genentech and the two academic teams (at Harvard and at the UC San Francisco) engaged in insulin research (see Hall 1987). Such competition was even more evident in the research on the human genome mapping (see Davies 2001), with Celera Genomics, a private firm, on the one hand and a public

consortium (including the NIH and Whitehead Institute in the US, and the Wellcome Foundation in the UK) on the other. Several other stories of industry-university competition the bio-pharmaceutical and bio-agricultural sectors are described in Werth (1995) and in Evans (2004). Again, given the basic structure of the model developed in this paper, we might expect asymmetric effects of the presence of competition. Both the university and the industrial team will have incentive to preempt the rival and anticipate entry into commercialization activities. However, since the academic team has the positive utility option to keep performing basic research with no commercial applications, the reduction in the expected returns from commercialization (because of competition and, let us assume, the presence of a single prize) would make the 'ivory tower' option more appealing. This incentive would contrast the tendency to anticipate entry. Interestingly, while in the human insulin case this competition did not seem to have changed the behavior of the parties, with the academic teams still preferring a longer, scientifically more relevant and commercially less applicable path of research, in the human genome case the entry of Celera into the 'race' caused the public consortium to change their path of research and to opt for shorter, less scientifically-relevant methods.

Both types of interactions between industry and academia in the performance of commercially-relevant research projects (through knowledge flows and through direct competition) seem also to characterize emergent sectors like Nanotechnology. In future work, I plan to extend my analysis in the directions I just described, and I hope to be able to capture the foundations of the different behaviors observed in actual cases.

1.7.2 Testing the model

An even more important extension would be to move the analysis from theoretical to empirical investigation, by testing the results of the model. A first direction of empirical analysis would extend the references to the cases of 'parallel' research by industrial and academic laboratories mentioned before, toward more detailed and informed historical case studies. In addition, one could think of detailed, case-based comparisons of other contexts, such as company-based and university-based business incubators (think of Xerox's PARC, for example, as opposed to university-based incubators, possibly in that same area, e.g. at Stanford). These case studies would be interesting because we could see how university-based and company-based labs

behave when faced with similar research projects, with economic potential. This comparison helps identifying the specific role (if any) of academic scientists in the commercialization of research. It would be interesting to explore whether and how the organization of research differs in these settings, and whether different amounts (and different types) of fundamental research are performed before a project is moved to the development and commercialization phases. Case studies, more generally, will be of particular relevance since my study is based on comparisons between academic and industrial research, and it is difficult to gather a large number of observations on such pairs. Moreover, while very simple, the model parameterizes issues that are difficult to measure for a large sample and without detailed knowledge of specific cases. Detailed case studies, finally, also offer insights for further elaborations to make the model closer to reality, such as the inclusion of several forms of interactions as mentioned before.

A second direction of empirical research would be an econometric assessment of the existence of the selection effect regarding the involvement of academics in commercial ventures, as described above. In absence of any consideration about the multiple institutional affiliations of academic entrepreneurs, one would expect, as several studies find, that the involvement of academic scientists in commercially-oriented research *causes* this research to be more profitable. However, my theoretical analysis shows that academic scientists may tend to enter commercial projects with higher expected returns than industrial scientists, since the alternative option, i.e. performing fundamental research, is more valuable for academic scientists than for company researchers. In order to assess this selection effect empirically, a first step is to define more narrowly the type of academic involvement into business we are interested in, so as to collect consistent and comparable data. One case to focus on would be the participation of individual academicians in joint projects with commercial entities, while keeping their academic position, similar to such studies as Zucker and Darby (1995), Cockburn and Henderson (1998) and Calderini et al. (2004). Another case would be the study of the impact of the presence of an academic professor in the founding team of a firm, similarly to Nerkar and Shane (2003) and Lowe and Ziedonis (2006). As a starting point, one might re-run some of the regressions performed in these papers with the appropriate endogeneity and self-selection corrections, such as Heckman 2-stage and instrumental variable procedures. A plausible instrumental variable for the selection equation is represented by changes in a university's guidelines regarding con-

flict of interests and of commitment for professors. These guidelines vary across universities, and many universities have modified their guidelines over time. From the point of view of the *single* scientist, this change is exogenous, and would influence the propensity to participate in commercially-oriented research regardless of the expected return or the cost from a particular venture. Another instrumental variable is given by sudden changes (e.g. cuts) in the funding coming from a university to some specific research groups. The analysis of the determinants of a scientist's choice of whether to join a commercial venture is of interest in itself in order to test the presence of tradeoffs to be solved, given the multiple institutional affiliations and the different rules in the different institutional environments. In addition to econometric tests, more fine-grained, case based evidence from interviews and qualitative research, e.g. along the lines of Murray (2004), would help detecting the presence of self-selection and reverse causation issues. For example, it would be interesting to collect information about the determinants of the choice of an academic scientists to join (in various forms) a commercial venture. If academicians are driven also by an evaluation of the expected economic returns from the venture, then the concerns about endogeneity, highlighted in my model, would find some foundations. More generally, evidence showing the existence of a self-selection effect would confirm the importance of considering the multiple affiliations of academic entrepreneurs, and of considering the role of incentives in addition to the role of the skills and knowledge of academic scientists.

Third, we could define empirical analyses to study the other major result of the model, the one regarding slowness and rushing by academic and industrial research team. The model identifies some key parameters that drive firms and universities to choose different transition times for a given project, given the assumptions on the different missions and governance modes. 'Ideal' data to be collected would concern a large number of industrial and academic research laboratories, and would give information about the timing of transition to development and commercialization phases. Similarly, data on business incubators offer a good empirical setting. We could assess, for example, whether and when university-led incubator firms tend to move to commercialization slower than commercial firms do, or whether and when they move faster, thus counteracting the common wisdom about the slowness and reluctance of academics toward applied work regardless of the environmental, institutional and organizational features. It would also be interesting to see if higher profitability coincides with slow completion. The recent study

of Rothaermel and Thursby (2005) on the performance of incubator firms with and without connections to academicians is a reference setting. The authors, as mentioned above, find that incubator firms who actively involve academicians take longer to exit the incubator. The authors attribute this result to the fact that scientists get involved in early phase projects. However, the study does not seem to control for the phase of the project. Such control would be important in order to disentangle the impact of the phase of the project from the behavior of the academic scientists: we could observe whether academic scientists tend to be slower, keeping the stage of the project constant. Hall et al. (2000) had previously found a similar result regarding projects performed jointly by companies and universities: the commercialization seems to be delayed, as compared to projects developed with no collaborations from universities. The authors, again, conjecture that this can be due to the different phases of projects involving universities, and also in this case it would be interesting to control for the phase in order to isolate the impact (if any) of the different institutional environment on the time to commercialization. Also, one could collect information about research agreements between companies and universities, and analyze which phases of a given project are done in the university and which phases are done by the firm directly. The common wisdom would predict that early phases, or those with a high content of 'basicness', will be performed by the university scientists. However, an implication of my model is that, in certain circumstances, it is the firm to have better incentives to perform certain types of basic research, while the university may prefer to perform different types or to move too early to commercialization. Therefore, in some situations we would assist to less 'conventional' divisions of labor. Major challenges for these analyses would be to find appropriate proxies for some of the parameters of the model, such as the private benefit from basic research for academic scientists, the degree of uncertainty, and the different types of basic research; and to gather information about hard-to-observe events, like to movement of a project from fundamental research to more applied and commercially-relevant investigations. Variations across sectors and scientific disciplines, variations in the maturity of disciplines, as well as structural and organizational differences between different universities in a given countries, or between academic organizations in different countries, could be explored, as a first cut, as the factors that would drive the decisions on the amount of fundamental research to perform and consequently on the timing of entry into commercialization.

A fourth avenue for empirical tests of the model concerns the analysis of the 'life cycle' of academic and non-academic entrepreneurs. For example, junior professors may be more responding to the rules of the scientific community because, in order to obtain recognition and tenure, they have to abide by the rules of the community. Senior faculty, by contrast, may be more willing to undertake types of research with no immediate academic recognition, since they have already a reputation among peers, and/or may be more eager to 'cash in'. We might therefore expect academics to undertake commercial enterprises later in their life cycle than non-academics. Audretsch found preliminary evidence for this to be the case.

1.8 Summary and conclusion

What are the peculiarities of academic entrepreneurship? How are the behavior and performance of academic entrepreneurs different from that of other entrepreneurs? Can the direct involvement of academic researchers into the commercialization of research resolve some difficulties of the research commercialization process? Despite the vast attention toward these questions in the scholarly and policy debate over the past 30 years, still very little is known about whether academic entrepreneurship is different from private-firm entrepreneurship. Clarifying this issue is of key importance in order to identify the specific role of universities in the commercialization of research.

In this essay, I have analyzed the choice of academic scientists to undertake commercially-relevant activities. I built an economic model of the decision to enter and the timing of entry into commercially-oriented activities by an academic research team, and of the returns and costs associated with these activities. In order to identify the peculiarities of academic entrepreneurship, I compared the behavior of the academic team with that of an industrial research team faced with the same choice set. In the model, academic and non-academic teams differ in the objectives they pursue and in the organizational rules they follow. Knowledge is assumed to be cumulative. The cost-reducing impact of fundamental research depends on the type of research a team chooses to perform, and each type is more or less applicable to commercially-oriented research. The choice of the type of fundamental research, in turn, depends on the rules and incentives which agents in different institutional environment respond to. The model therefore

includes considerations on the nature of knowledge, allows for the presence of several types of scientifically-relevant research, and accounts for the institutional differences between the actors and organizations performing research. The inclusion of these differences allows the identification of some peculiarities of academic entrepreneurs, as opposed to other entrepreneurs.

The model offers a variety of results that contribute to explaining the diversity in the existing evidence (historical, case-based, and large sample) on the role and success of academic entrepreneurship. I derived that there are situations in which academic organizations have incentives to enter profitably commercially-relevant activities, after having performed fundamental research that reduces the costs of transition to commercialization, while business companies are not able to 'wait' for costs to reduce. In other situations the role of academic organizations and scientists in bringing research to market is more controversial. For example, academics find it too costly to 'abandon' (even if partially) the research activities that generate peer recognition in the scientific community. They may also find the type of fundamental research that is relevant for commercial application, e.g. multidisciplinary research or research with a high content of tacit knowledge, not consistent with the rewarding criteria in the community of peers. Academic scientists would therefore choose to invest little in this kind of research. This choice can generate two opposite outcomes: either academic research teams give up commercialization altogether, or they move very fast to commercialization, at potentially high transition costs and with too low production of fundamental knowledge. The timing of entry, indeed, determines also the costs, and therefore the commercial profitability of the research effort: the later the entry, the lower the costs of transition from fundamental to commercial research. A tradeoff between timing and cost effectiveness is therefore present, and different organizations solve it differently. Moreover, academic researchers will tend to forsake commercial projects with positive but small commercial value, and will pursue the purely scientific alternative. By contrast, company teams would be willing to undertake also these 'marginal' projects with economic and potentially social value. Therefore, a self-selection mechanism is present, and the observed success of academic entrepreneurs may therefore derive from the fact that, on average, university researchers move to commercialization only if the prospects are very good.

The findings have managerial as well as policy implications. As for managerial implications, this study underlines the tensions a firm encounters when providing academic incentives to

its scientists, or trying to collaborate with individuals and organizations belonging to different institutional environments. For example, the involvement of academic scientists may excessively delay the research process (as several practitioners I have interviewed actually lamented), or, on the contrary, there are conditions under which academics are expected to push for early commercialization.

In terms of university and public policy insights, my analysis addresses several issues related to the role of academic organizations in facilitating the translation of basic research into commercial applications, and in balancing research and entrepreneurial effort. In addition to appropriately considering both the returns and the costs from commercially-oriented research, the model studies how the entry and timing decisions affect both costs and return, and, in turn, how the entry and timing decisions depend on the cumulative nature of knowledge and on the institutional differences between organizations. I determine the cases in which the entry and timing decisions of different organizations differ, and this informs us about the ability of a given organization to balance research and commercialization. For example, in the two extreme cases of no (or very late) entry and immediate entry of academic teams, there may be no positive impact of relying on academic organizations for the commercialization of the research they produce: profit seeking firms would better fulfill the role of bridging research to market, and have strong incentives to perform their own fundamental research.

Finally, any organizational, strategic or policy implications from empirical analyses that show a positive impact of the involvement of academics have to be taken with caution, unless those empirical analyses properly correct for the endogeneity of the scientists' choice of whether to participate in the collaboration, and for their incentives to invest in some types of research activities.

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Chapter 2

Different Missions and Commitment Power: an Institutional View of Industry-University Relations

2.1 Introduction

> We should work together only when we don't do violence to each other's values and roles. [...] There really are some projects that are probably inappropriate to do at the university. (Clifford Detz, Manager, Strategic and Collaborative Research Chevron Research and Technology Co. Richmond, CA. University of California President's Retreat, 1997)

Why do firms choose different organizational arrangements in order to perform their research activities? Why do they perform some research in-house and outsource other projects? In particular, why would a profit-seeking company finance research projects in academic organizations?

Despite the documented trend toward in-house R&D downsizing, especially of long-term, general-purpose research (Fusfeld 1994, Oldyzko 1995, Rosenbloom and Spencer 1996), there is vast evidence that firms still invest in scientifically-valuable research, and that they perform the bulk of it within their boundaries (NSF 2002). However, firms in research-intensive industries are also increasingly outsourcing research projects. In particular, these firms tend to collaborate

with universities in the performance of more general-purpose research (Fusfeld 1994, Mowery and Teece 1996, NSF 2002, Santoro and Chakrabarty 2002, Geiger 2004, Motohashi 2004). The last thirty years have seen a substantial increase in formal relations between companies and universities. Between the early 1980s and the late 1990s, for example, the percentage of university research funded by industry has increased from 3.5% to about 8% (NSF 2002).[1] The increase is even more compelling if considered in absolute terms. Around 1.4% of all industry-funded R&D is currently performed by academic organizations. This share has almost doubled in the last two decades. In fact, since the late 1970s several managers, academic scholars and policy makers have seen the development of stronger and more formal ties between firms and universities as a key asset for preserving America's industrial competitiveness and innovativeness. At a time when academic research was thought to be both too distant from industry needs and difficult to transfer and apply, industry-university formal relations started being seen as a way to better produce, transmit, and diffuse knowledge. In order to facilitate these relations, policy makers intervened with several provisions, such as the 1986 Federal Technology Transfer Act. In more recent years, several Western European countries have begun to adopt similar legislative provisions (Geuna et al. 2003).

Industry-university relations in the performance of research activities take several forms. They include research contracts on single projects, agreements for the funding for several projects, and the creation of university-based research centers funded by one or more firms. Also, some companies let their scientists spend some time in academic institutions or in research foundations, where they interact with their peers for the development of research of potential interest for the company. Industry-university relations also appear to be more frequent in those sectors in which basic research is said to be closer to commercial applications, and in disciplines that are in the early phases of their evolution (Hall et al. 2000, Geiger 2004). These areas include the life sciences, especially since the emergence of biotechnology, as well as some branches of engineering and information technology and, more recently, nanoscience.

Some of these formal industry-university relations involve a substantial commitment of time and financial resources by the parties. For example, in 1998 the agri-pharmaceutical

[1] Florida et al. (1994) argue that, if we consider that the government sometimes provides part of the funds for industry-sponsored projects, then industry currently participates in a higher share of academic projects (about one fifth, in dollar terms).

company Novartis signed a twenty-five million dollar, five-year, non-targeted research deal with the Department of Microbial and Plant Biology at UC Berkeley for the development of several projects (Press and Washburn 2000, Lawler 2003). The chemical company Monsanto entered a twenty-year relationship with the Washington University in St. Louis in the early 1980s. The financial resources spent by the company were between two million and five million dollars each year. The biotech company Amgen and MIT agreed in 1994 on a multi-year research collaboration, with a financial commitment by Amgen of about thirty-five million dollars over nine years (Lawler 2003). MIT formed also an alliance with DuPont, in 2000, for research in biotechnology and biomaterials. The alliance has been recently renewed, and the areas of research have been enlarged to include nanotechnology and alternative energy. The total investment by DuPont in the alliance is about sixty million dollars. In 1980, MIT also signed a eight million dollar, ten-year research agreement with Exxon, for research on combustion engineering (Kenney 1986).[2]

Several studies in the Economics of Innovation, Strategic Management, and Organization Theory literatures have offered rationales for why profit-seeking firms may find it profitable to invest in fundamental research activities (see for example Rosenberg 1990, Cohen and Levinthal 1990), notwithstanding the costs related to uncertainty and the public nature of knowledge. Other studies have explored several motives for why a firm may want to outsource some research effort to and collaborate with academic organizations. These studies focus on such key dimensions as the difficulty of knowledge transfer from academia to industry in the absence of some direct links, and the difference in the incentive systems between business and academia.

In this essay, I contribute to this stream of studies by focusing on one key feature that makes universities different from business firms: the peculiar mission to which they are committed. In addition, I account for the contractual differences, in particular related to the allocation of decision power, that are implied by the choice of different organizational structures for the performance of research. While my approach does not offer a general theory of the organization of research activities and of industry-university relations, it is robust to some of the logical and conceptual problems of other existing approaches. Moreover, the assumptions of my analysis

[2]Several other examples of research relations between large chemical and pharmaceutical companies and universities are described in Kenney (1986).

and the conclusions I obtain are consistent with some pieces of empirical evidence and with some stylized facts that are less obvious to explain through other existing arguments.

My main argument proceeds as follows. First, while firms institutionally aim to obtain economic profits, the objectives of academic organizations include the production and expeditious diffusion of scientifically-valuable knowledge. The norms of academia and, more generally, of the scientific community guarantee that scientists are to a large extent shielded from strict considerations about economic value in the choice of their topics of research and in the direction of their research (Merton 1973, Ben-David 1977, Mokyr 1990, David (1998, 2004), Argyres and Liebeskind 1998). Together with openness, this greater freedom of inquiry is a key characteristic of the academic environment. Second, outsourcing a project implies some delegation of decision power to an independent party, plausibly to a greater extent than when a project is developed under a unified hierarchical structure, as in-house. Due to the different institutional missions and to the delegation of power, outsourcing a project to an academic partner may allow a firm to make a commitment not to terminate a scientifically-valuable project before completion. This commitment is potentially valuable for the firm, in an environment where the economic value of an invention is uncertain, the scientific and economic values of a project are not perfectly aligned, and scientific workers are responsive to the incentives defined by their community of peers. A scientist may be more motivated to supply productive effort for a project if she is more confident that the project will not change direction or will not be terminated before completion for reasons not related to the scientific value of the research. Such enhanced motivation is valuable for the firm if it also increases the probability of a positive economic return from a given project, therefore counterbalancing the uncertainty surrounding the economic attractiveness of the potential invention. By performing a project in-house, on the other hand, a firm gains higher discretion through its higher formal authority: it would, for example, be easier for the firm to terminate or modify a project toward more profitable directions.

One empirical prediction of my findings is that firms will be more willing to delegate control over the conduct of research, when the research has a broader applicability. A research project that is applicable to several areas is less economically uncertain. Another prediction concerns the duration of a research project. A longer research program is arguably subject to higher uncertainty: better opportunities can emerge on which the sponsoring party and the researchers

may not agree. Thus a firm, all else being constant, might want to retain higher control over the research agenda. Preliminary evidence from a sample of research contracts between biotech companies and academic organizations shows that, when the research project is applicable to a higher number of diseases, companies delegate more decision power, while companies retain more power for longer projects. Evidence from case studies and other large sample analyses are also consistent with these findings.

Formal industry-university relations, according to my logic, will be particularly profitable when the parties recognize and respect each other's goals. From a policy standpoint, my framework could offer an economic rationale for 'middle ground' positions about the desirability of stronger formal ties between companies and academic organizations. These positions state that universities should get closer, in the definition of their research agenda, to issues of actual, concrete relevance. However, they also stress that academic organizations should stick to their original missions and should not transform into business organizations (Beckers 1984, Rosenberg and Nelson 1994, Howitt 2003, Nelson 2004). Therefore, institutional diversity should be preserved.

In Section 2.2, I present and comment on a set of existing theories that explain why universities may represent a suitable partner to perform certain projects on behalf of firms. In Section 2.3, I propose my contribution toward an explanation of the choice of different organizational structures in the performance of research activities. In Section 2.4, I build an economic model based on my novel argument, and explore its insights and predictions. Sections 2.5 and 2.6 are dedicated to the discussion of my results. In Section 2.5 I present some evidence on the allocation of decision power in biotech research collaborations between companies and academic organizations; I also refer to some stylized facts about the organization of research activities by firms, as well as about the patterns of industry financing of academic research over time. In Section 2.6, I discuss the implications of my claims and findings for managers and for public policy. In Section 2.7, I position my work within two streams of economic research: the institutional analysis of Science, and some recent developments in the Economics of Contracts and Organizations. I also briefly discuss some studies related to mine. Section 2.8 summarizes and concludes.

2.2 Why do firms collaborate with universities?

2.2.1 Insights from the existing literature

Several works in Economics of Innovation, Strategic Management, and Organization Theory have paid increasing attention to the growing interactions between business companies and academic organizations in the performance of research activities. These studies have questioned some of the traditional concerns about the profitability of contractual relations and collaborations, especially with universities. Scherer (1964) and Mansfield et al. (1977), for example, claimed that the bulk of research activities, including basic research, were performed in-house because firms could better protect their intellectual assets. However, the emergence of areas of research such as biotechnology, where intellectual property can be protected more effectively, as well as a series of legislative interventions (such as the 1980 Bayh-Dole Act) that have facilitated academic patenting and licensing, have substantially reduced the costs of collaborating with academic organizations. Typically firms receive exclusive licensing rights, and contracts are quite accurate (though, of course, incomplete) on issues regarding intellectual property and related financial rights. In fact anecdotal evidence, surveys, case studies, and some large-sample statistical findings show that firms (especially large ones) tend to collaborate with universities in more fundamental, general-purpose research (Fusfeld 1994, Mowery and Teece 1996, NSF 2002, Santoro and Chakrabarty 2002, Howitt 2003, Geiger 2004, Motohashi 2004). Companies seem therefore to outsource those types of research that could generate higher appropriability concerns. Veugelers and Cassiman (2005), furthermore, do not find evidence that appropriability problems limit collaborations with universities.

A series of recent works have also questioned the long agreed-upon argument that firms need to develop an in-house fundamental research force in order to enhance their absorptive capacities (Cohen and Levinthal 1990). Some studies have shown that companies develop absorptive capacity also through external channels, including collaborations with academic scientists (Cockburn and Henderson 1998, Lim 2000, Markiewitz 2004). A major argument brought in favor of the presence of an internal research force for the development of absorptive capacity has been that the transmission of information requires time, because the relevant knowledge may be tacit or firm-specific. This argument may rule out the viability of short-term

contacts with external agents, but it does not exclude the effectiveness of long-term deals. Such long-term deals are not infrequent (see, for example, the cases mentioned above). In fact, there is an increasing agreement that collaborations with universities may represent a key channel for the building of absorptive capacity by a firm. Contacts with academic scientists, it is argued, allow companies both to stay updated with the evolution of research areas of their interest and to monitor the most talented researchers. More generally, companies and universities present complementary capabilities. As scientific knowledge is rarely ready to use 'off the shelf', and is not a pure public good, business companies can benefit from direct and formal ties with other firms and academic organizations (Gibbons et al. 1994, Adams et al. 2000, Goldfarb et al. 2002, Goel and Rich 2002). Firms may also contract some research projects out to universities in order to overcome capacity constraints, or in order to share risks.

Other authors have stressed that academic organizations offer 'better' incentives to their scientists (Dasgupta and David 1994, Beath et al. 2003). Because scientists are members of a community with its own mission, rules, and incentive systems devised to stimulate scientific inquiry, academic scientists may be more motivated to produce high-quality science, and this increased motivation can also raise the probability of obtaining a positive economic return from a given project.

2.2.2 Limits and unanswered questions

The arguments described above hint at some key dimensions regarding the contribution that academic organizations can provide to industry through direct collaborations. In particular, these studies point both to the difficulty of knowledge transfer from academia to industry in absence of some direct link, and to the difference between the incentive systems prevailing in industry and in academia. However, these arguments present some logical and conceptual limits for the analysis of the different institutional arrangements that firms choose for the performance of research. Moreover, some empirical evidence is somewhat in contrast with these arguments.

Regarding absorptive capacity and complementarity, the arguments as elaborated so far do not explain why complementarities and knowledge absorption could not be developed through the direct employment of scientists by firms. In principle, there can be different formal ways in which a firm can acquire knowledge, ranging from employment relations to deals with in-

dependent contractors. In fact, in research-intensive companies, scientists produce results that may not be distinguishable, in type and quality, from those obtained in an academic laboratory. The existing approaches do not tell us why we observe firms organizing their research activities through *different* organizational and institutional arrangements Why are some projects conducted in-house, while other projects are contracted out or developed in collaboration with other organizations, in particular universities?[3] Why do firms tend to involve academic organizations for more early-phase, general-purpose projects, and in nascent areas of research? In other words, the relationship between organizational (and authority) structure, absorptive capacity and knowledge complementarities has not been fully explored to date.

As for the presence of capacity constraints, this argument may hold for small companies. However, large firms arguably have the human and financial resources to develop many of the projects which, rather, they outsource to other organizations. Moreover, this argument tells us neither why companies choose to collaborate with *academic* organizations, nor what is peculiar about the contribution that these organizations can offer. Regarding risk sharing, Veugelers and Cassiman (2005) find that firms tend to outsource research to universities in areas where risk is less of an issue.

Finally, several empirical studies show that innovative companies allow their scientists to participate in the activities of the scientific community, and to gain reputation among their peers for their scientific record (e.g. through publication and participation to conferences). These practices have been in place for decades and have characterized innovative companies in such industries as semiconductors and pharmaceuticals (Shockley 1956, Nelson 1962, Rosenberg 1990, Henderson and Cockburn 1994, Cockburn et al. 1999, Howitt 2003, Stern 2004). Moreover, arguably scientists respond to a multiplicity of incentives, not necessarily deriving from their

[3] Obviously, a further option for a company is to contract out a research project to another profit-seeking firm. In this paper, I am concerned with the reasons that would motivate a company to collaborate with an academic organization. The argument I propose considers the role of both the different authority structure, and of the different missions of the parties. These two features characterize, in my analysis, the relation with universities. As will be clear from my following considerations (both from the qualitative arguments and from the formal model), in my analysis outsourcing a project to another firm is equivalent to developing it in-house, because the partner company would be committed to the same ultimate objective as the financing firm: the maximization of economic value. Interestingly, the empirical study provided by Fontana et al.'s (2004) shows mixed results concerning the relation between the degree of collaboration with other firms and the degree of collaborations with universities, among European companies. These mixed results seem to imply that collaborations with other firms and with universities respond to different logics.

affiliation to the scientific community. These incentives include career concerns, job satisfaction, and public recognition. A claim of the superiority of academia in performing some types of research, founded exclusively on the incentive systems, seems neither warranted nor satisfactory.

We are therefore left with our initial questions not fully answered. We need explanations for why we see innovative firms both performing research in-house, possibly with the provision of 'academic' incentives for their scientists, and also outsourcing some projects to academic research teams. In particular, we need to explain what makes universities superior to firms in performing some projects.

2.3 Universities as commitment devices

> The traditions of the scientific community are extremely strong where freedom to pursue research is concerned. To be told just what line of research to follow - to have it made clear that the goal of the research is company profit, not increased knowledge or benefit to mankind - to realize all too plainly that a few individual supervisors, not a wide jury of scientific peers, are to evaluate the work - strikes hard at the traditions of science (R. Nelson, 1962, p. 573).

2.3.1 Institutional and contractual differences

I focus my attention on two key issues: the peculiar mission to which universities are committed, and the different authority structures of projects either developed in-house or outsourced.

Academic organizations aim to produce and diffuse scientifically-valuable knowledge, regardless of its economic return. In exchange for adherence to open-science principles concerning the diffusion of scientifically-valuable knowledge, universities grant freedom of inquiry to their affiliates. Dasgupta and David (1994) and David (1998, 2004) offer detailed (albeit informal) economic analyses of the efficiency of the norms of the scientific community for the achievement of its goal, i.e. the production and diffusion of scientifically-valuable knowledge. The Scientific Community is interpreted as an institution with its own objectives, rules and incentive systems. These works have mainly focused on openness as the key peculiarity of the academic environment and more generally of the scientific community. However, studies in the Sociol-

ogy of Science and Economic History, on which the previously mentioned works build, have stressed also another key institutional characteristic of the community of science: freedom of inquiry, more precisely freedom from influences not related to the scientific value of research activities. Robert Merton (see for example Merton 1973) sees universities as repositories and institutional guardians of the CUDOS norms: communalism, universalism, disinterestedness, and organized skepticism.[4] Disinterestedness, moreover, generates greater freedom of inquiry, making serendipitous findings more likely to occur. Ben-David (1977) stresses how freedom of inquiry, intended again mainly as disinterestedness, is at the very foundation of the modern research university. Mokyr (1990) argues that freedom of research was a key element in order to generate variety of findings, and in turn such variety can contribute to explain the development of the Western World. David (1998, 2004) sees modern universities as an evolution of the Renaissance patronage system, under which scientists were guaranteed protections from the influences of the church and of the states by noble patrons. The progress of science therefore derives from the coevolution of knowledge and of institutional arrangements. Carmichael's (1988) model shows that the tenure system, with the commitment attached to lifetime employment, may ex ante alleviate some moral hazard problems (see also Aghion et al. 2005). Argyres and Liebeskind (1998) argue that, in addition to 'self-regulation', academia is bound by an implicit contract with society to pursue its peculiar mission. Evans (2004) stresses the difference between the hierarchical decision structure in company R&D labs, which leads several projects to be abandoned if they do not promise economic returns (see also examples in Charles 2001), and the lower probability that a project will be interrupted in academia, because of economic disinterestedness (see also Cooke 2001). Masten (2005) provides evidence that the academic institutions with an organization most different from that of firms, e.g. distant from a hierarchical line of command, are those within which the promotion of leading edge research is a priority. Masten sees this more democratic structure as a device that makes the commitment to both diversity of approaches and faculty specialization credible.

A firm may therefore be able to commit to the provision of high-powered *incentive systems*, potentially consistent with those of the scientific community, for its researchers, as the previously

[4] See Ziman (1994) for a partially different treatment, and for a comparison with the organization of industrial research. See also Gibbons et al. (1994) and Leydesdorff and Etzkowitz (1997) for different views.

mentioned studies have documented. However, a firm cannot, by its own nature, commit to the institutional *objectives* of the scientific community. In other words, the quest for knowledge may conflict with the quest for economic profits.

A second key difference between developing a project in-house and outsourcing it (or collaborating on it) with an independent partner is that, in the latter case, the firm will typically surrender some authority over the project. The firm may not have the unilateral right to terminate the project 'without cause', or this right can be granted but only with restrictions, and any change of direction has to be agreed upon among the independent partners. For example, if the economic prospects from a given project turn out to be unsatisfactory for the firm during the performance of the research, it would be difficult for the firm to terminate the project, or to modify its direction, if the authority over the research is shared and there is disagreement. Moreover, at best the firm may be able to terminate the funding of the project: if the independent partner has other sources of financing, the focal firm cannot prevent the project from being continued. By bringing a project in-house, a firm gains higher discretion through higher formal authority. It would be easier for the firm to terminate or modify the project, toward more economically promising directions.

2.3.2 Some evidence

In Chapter 3, I analyze research contracts between biotech companies and universities (or other non-profit research entities). Two main characteristics of these contracts are worth considering. First, there is variation in the allocation of decision power over the conduct of the research. For example, while in some cases companies retain the exclusive right to terminate the research 'without cause' (equivalent to what a firm would be able to do, were the project performed in-house), in other contracts the firm does not have this right. Second, strong control rights are granted to the firm only in a minority of contracts. In those cases where the unilateral termination right is granted, moreover, the firm still has several restrictions. For example, the firm can exercise the termination right only after some amount of time has passed since the beginning of the contractual relationship. Also, the firm will need to pay the partner on a pro-rated basis, and for all of the non-cancelable commitments made by the academic researchers. Finally, it is very common that the equipment bought by the academic researchers with the company's

funds to perform the sponsored research will stay within the university if the firm terminates the agreement, thus making it more difficult for the company to recover the investment (or part of it) and employing it in any other opportunity that can emerge. This might make it easier for the academic scientists to continue doing research on a given area. Regarding the power of the firm to change the direction of the project, this typically requires the mutual consent of the parties. Kenney (1986) summarizes the contractual provisions of several agreements between pharmaceutical and chemical companies and universities. The control power was shared among the parties, and academic partners had non-negligible decision power. For example, in the Exxon-MIT deal mentioned above, 20% of funds had to be allocated according to the sole decision of MIT faculty members. In the 200 biotechnology research contracts analyzed by Lerner and Merges (1998), termination rights are granted to the funding party in a minority of instances, and authority is formally distributed among the parties. Hall et al. (2000) find that research projects involving universities as partners (together with companies) are less likely to be aborted prematurely. Guedj (2004) finds that firms terminate in-house projects more frequently than outsourced projects. Finally, also companies known for their 'science-friendly' environment do not seem to be able to commit to a complete adherence to academic rules when research is performed in-house by scientist-employees. Consider the following quote on Genentech, a highly science-oriented bio-pharmaceutical company:

> 'It's the scientist's job to fight for her project, but as an organization we have to be pragmatic. Letting go is hard but we can't let them hang on a failed drug'. Mr. Levinson [Genentech's CEO] can be brutal in killing projects he thinks are going nowhere (Griffiths 2005).

2.3.3 Different missions and commitment power

If scientific workers (regardless of their institutional affiliation) care about bringing a scientifically-relevant project to completion so as to receive peer recognition for their findings, and if the scientific value is not strictly correlated with economic value, then a firm may find it profitable to 'tie its hand' and delegate some decision power to an organization which, by its own institutional nature, is committed to the pursuit of scientific value. A scientist may be more motivated to supply productive effort for a project, if she is more confident that the project will

not change direction or will not be terminated before completion. Such enhanced motivation is valuable for the firm as long as it also increases the probability of a positive economic return from a given project. *Delegation of decision power to an academic organization may serve as a commitment technology for the firm.* The higher discretion and flexibility from performing the project within the boundaries of the firm may come at the cost of a softened behavioral response by the scientists.

Following my logic, we would expect companies to involve academic partners for research projects in which the impact of scientists' effort is relatively more important than the ability to modify promptly the direction of research in order to adapt to the economic conditions. We would also expect companies to prefer a hierarchical relation, when it is more important to keep discretion and flexibility and the scientist's effort is less important for the economic success of the project.

The approach I propose offers two conceptual contributions. I first attempt to explore in more depth the fundamental differences between the various organizations performing research activities. This exercise helps to understand which characteristics of an organization (or of an institutional environment) cannot be replicated by another, and therefore what can really be the comparative advantage of each institutional environment. In addition, this exercise would help to clarify both why (and how) an organization may benefit from collaborating with a different organization, and when, on the other hand, the characteristics of the potential partner may be deleterious for the achievement of certain results. This approach also contributes to a clarification of what role universities can play for industrial innovativeness and economic competitiveness. There obviously are other fundamental differences between profit-seeking firms and academic organizations. These further peculiarities are worth exploring, for they can contribute to an explanation of the willingness of firms to collaborate with universities.[5] However, they are not necessarily in opposition to the argument of this paper. Rather, they are complementary.

Second, with my analysis I contribute to the institutional analysis of academic research, as conceptualized in the early Sociology of Science and later rediscovered by the New Economics of Science (in addition to the already cited works of Dasgupta and David, see also Stephan 1996).

[5] A peculiarity of academic organizations several authors have stressed is that they combine research and teaching activities, thus providing also prospective trained personnel in addition to direct research services.

Following this institutional view, I characterize the different organizations performing research by the institutional mission they are committed to, and by the different rules and incentive systems they follow. I emphasize research freedom, rather than openness and communalism, as the foundational principle of academic research. I push forward this institutional analysis by exploring the interaction between the commitment to different objectives and the different authority structures implied by the different organizational choices for the performance of research activities.

I now build a simple economic model of the R&D organization of a firm, in which I clarify my argument, relate its general statements to the specific case of industry-university relations, and deepen the exploration of its conceptual as well as empirical implications.

2.4 A model

2.4.1 Environment

A firm has to start a research project, which is potentially profitable and it is also expected to advance scientific knowledge. The realization of economic profits out of the project is uncertain, and depends linearly on the amount of effort $e \in [0, 1]$ a scientist supplies. Moreover, there is some chance that alternative projects, equally or more profitable, can emerge as feasible in a later date. The firm can work on only one project at a time.

The scientist's effort Think of e as a function of the intellectual effort or time spent by the scientist to improve her knowledge of the subject of the research, and to define the best way to conduct the project.[6] The effort or specific investment of the scientist has a cost of

$$C(e;\gamma) = \frac{e^2}{2\gamma}, \tag{2.1}$$

[6] I am implicitly assuming that scientists working for companies and for universities have the same capabilities. This of course, is a simplification. However, several studies show that, especially in research-intensive industries, company scientists often are of a very high level and status, to the point that some company researchers have received the higher scientific honors, including the Nobel Prize (Nelson 1962, Stephan 1996, Howitt 2003). Furthermore, my argument holds even if we consider the activity of the *same* scientist (or research team) employed under different authority structures. For example, a company may send some of its scientists to spend some periods working with an academic team.

where $\gamma > 0$ is a scaling parameter. The investment is not contractible: it is too complex to write in a contract what kind of activities the scientist is supposed to perform. We could alternatively take tight monitoring as being very costly, so that the effort is not even observable.

Economic return The project yields a return of $R > 0$ at completion, i.e. when the research is completed and the product is commercialized. Therefore, the expected economic return of the project is eR. Such costs as salaries, materials and equipment are normalized to zero.

Alternative opportunities With probability $\pi \in (0, 1)$, and after the scientist has made her effort investment, new profitable opportunities can emerge. More precisely, assume that a new opportunity, with a return equal to $\rho > R$, can emerge. The new opportunity emerges before the economic (and scientific, see below) values of the research are realized.[7]

Scientific value Just like economic profitability, the *scientific* value of a project is realized only if the project is completed. The probability that, at completion, the original project has scientific value is e. The alternative project, if it emerges, is supposed not to have any scientific value, at least from the point of view of the scientist as specified below. We can imagine that the specific investment of the scientist is not applicable to the new project and therefore would not generate scientific value for it.[8]

The parameter π can be interpreted as a measure of the sensitivity of the project's profitability to a series of exogenous forces with economic relevance, and as a measure of the alignment between the realization of economic and scientific value, and therefore, as we will see, of the interests of the firm and of the scientist. With π close to zero, there is a high alignment between the realization of the highest economic and scientific value. A similar case of high alignment is

[7]This characterization is equivalent to assuming that, at the moment the original project is undertaken, the alternative opportunity already exists but has a return of $\rho_L = 0$. In a future date, there is some probability that the return will increase to ρ. Assuming $\rho_L = 0$ and $\rho > R$ is actually more restrictive than necessary to obtain the results described below. However, relaxing these assumptions would introduce some complications (e.g. multiple equilibria and equilibrium refinements) which would not add much insight to the results and the interpretation of the model.

[8]Again, the assumption of no scientific value at all from the alternative project is more restrictive than necessary. The model would produce qualitatively similar results as long as the scientific value of the alternative project (or, as we will see, the utility that the scientist attaches to it) is lower than the original project.

when R is close to ρ. For example, broader, more general-purpose projects can be characterized by a lower π: the results of the research can be applied to a wider array of problems and potential markets, and therefore there will be fewer better alternatives. A higher alignment between economic and scientific value may better represent research areas in early stages of their evolution, when it is relatively more likely to obtain scientific credit for 'any' discovery. Also the parameter ρ (the return of the alternative project) plays a role in determining the discrepancy between scientific and economic value, since it affects the commercial attractiveness of alternative ways to use the invested capital, which will not bring scientific value.

Examples Consider genetic research, such as agricultural research on genetically modified plants and food, research on stem cells and cloning, or research on methods of assisted human reproduction. Legislative provisions may be introduced that incentivize (e.g. through subsidies) alternatives to the previous methods – e.g. incentives to traditional agriculture, major government purchase, incentives for research on adult stem cells rather than from ad-hoc generated embryos, or provisions that facilitate child adoption over assisted reproduction (these examples are chosen because actual political debates and political interventions on these issues have occurred lately in several countries). These provisions would make alternative economic opportunities more appealing (e.g. less costly to pursue) than the original ones a firm might have undertaken. However, the scientific relevance of the original projects is not necessarily affected, and might be higher than the scientific attractiveness of these cheaper alternatives. A second example is a case in which, while a firm is working on a project, a substitute (and superior) product, using a different scientific base, is completed by another firm (though I do not model competition here). The economic value of the competing and successful product may be very high, and the firm can obtain a license to commercialize it. Moreover, the economic value of the original project might in fact reduce, following the introduction of the other product. Moving to the production of the competing product is unlikely to be scientifically-relevant because there is no novel research involved (the novel research in the different scientific base has been done by other actors), or because the investment of the scientist was specific to a given area and not easily redeployable in another area. A third example can be given by a strategic change in a firm, say because the firm is taken over by another company or there is a change in the top

management (which is predictable, with some probability π, ex ante). The original project may not be consistent with the new management orientation, e.g. the top executives want to focus on marketing rather than on research, and put higher value on marketing oriented activities. Therefore the firm may want to undertake a different direction, with potentially low scientific content (see Lawler 2003 for the case of Amgen, for instance). In pharmaceutical research, finally, clinical trials of a promising and scientifically novel drug may reveal that the drug is not effective, or toxic for a particular disease, but at the same time other paths can emerge from the trial, possibly commercially appealing. However, from a purely scientific standpoint, the original path of research could still be more novel and valuable than the alternative one – after all, negative results, and investigations of the reasons of such failures, could be a great advancement in science (see the quote in Section 2.4.4 at page 90 below). These issues seems to have characterized, at least in part, the activity of the biotech company Entremed on angiostatin and endostatin (see Saltus 2000, *The Gazette* 2003). The company's research, originally aimed at treating a vast array of tumors, turned out to be more useful to treat some eye disease than to treat cancer. This new line of research however was of lower scientific impact.

2.4.2 Organizational structure and authority

Organization The firm chooses whether to perform the research project in-house, i.e. under a unified hierarchical structure, or to outsource it. In particular, the firm can outsource the research to a team employed by an academic organization, which acts as an independent contractor. Call the decision of the organizational structure $\omega = \{in\text{-}house, outsource\}$. Since the research is expected to yield scientifically-valuable outcomes, the university would find the activity consistent with its aims and incentive systems, and will agree to perform the research proposed by the firm.

Authority If the project is developed in-house, the firm has the power to change the direction of the research, or to terminate it, at any moment. That the ultimate, formal decision power stays with the boss is at the very nature of the definition of the firm and of the employment relation, and this assumption has a long tradition in the Economics literature. In particular, the boss cannot commit not to overrule any proposal of the agent (Simon 1951, Holmstrom

and Tirole 1991, Aghion and Tirole 1997, Baker et al. 1999). If the project is outsourced to a university, the parties are now in an independent contractor relation, based on a formal contract. This contract implies some division of decision power. Specifically I assume that the firm, now, cannot unilaterally terminate the original project 'without cause', neither can it decide whether to undertake (if available) the alternative project. While this assumption is extreme, it captures the essence of the contractual differences between the two possible organizational and contractual structures. Extensions and more nuanced characterizations are certainly possible, and would make the model closer to reality.[9] However, I take it as reasonable that, for a firm, it is more difficult and more costly to change the direction of a project, or to shut it down, when the project is carried out by an independent contractor.

Define the project choice as a binary variable: $d \in \{0,1\} = \{\textit{stay on old project, switch}\}$.[10] The firm controls d when the project in done in-house. The decision d is non-contractible: once a party is given the right to choose d, it is not possible to establish formally how this right will be used in any possible circumstance (see Baker et al. 2004, Gibbons 2005). The discretion over d is lost when the project is outsourced.

2.4.3 Timing of the game

The game has five stages.

1. The firm chooses $\omega \in \{\textit{in-house, outsource}\}$.
2. The scientist chooses the effort level e.
3. The value of the alternative opportunity is revealed.
4. If the project is carried in-house, the firm chooses $d \in \{0,1\} = \{\textit{stay on old project, switch}\}$.
5. The project is completed and the payoffs of the parties are realized.

2.4.4 Payoffs

> A scientist might delight in a research failure [...] because [it] eliminates a range of theories

[9] For example, there may be different degree of delegation of power by a sponsor firm, as documented in the contracts I mentioned above (see page 83) and I will analyze in more detail in the next Section.

[10] Notice that, since the outcome of the alternative project does not depend on the scientist's effort, we can interpret the switching decision as a termination decision: the relation with the scientist is terminated, and the alternative path is undertaken by the firm.

and leads to new pathways. But from an appropriator's point of view, that does not look very attractive (Sharma and Norton 2004)[11].

The firm

In either organizational structure, the firm is entitled to residual financial rights. If economic profits are generated from the project, they accrue to the firm[12]. The firm's ex ante profit function, if the project is carried in-house, is:

$$\Pi^{in} = (1-\pi)[(1-d)eR + d0] + \pi[d\rho + (1-d)eR] \tag{2.2}$$

If the project is outsourced, it will never be terminated before completion, nor will its direction be changed once the state of the world is realized. Neither the firm nor the university has unilateral right to terminate, and the university has no interest in changing the original project. This is because, as we will see in a moment, the university (and the scientist) care about the realization of *scientific* value, which is higher in the original project. The firm's profit function therefore is

$$\Pi^{out} = eR \tag{2.3}$$

The scientist

Because she is affiliated to the scientific community (regardless of whether she works inside the firm or for another organization), the scientist cares about the scientific value of the project. If the original project gets successfully to completion (recall that the alternative project, if available, has no scientific value), the scientist receives a benefit equal to B. This amount is received in addition to a fixed monetary wage, paid up-front.[13] It can include private benefits,

[11] Private communications with biologists revealed that this may indeed be a major source of conflict when academic scientists analyze the effectiveness of a potential drug on behalf of pharmaceutical companies.

[12] In general, even when a project is contracted out, the funding part retains some rights to the economic results of the project. For example, typically firms obtain an option to license, or a right to first refusal to any patentable invention. The license is normally exclusive.

[13] If both salaries and non-monetary benefits are the same regardless of the organizational affiliation, this characterization may correspond to a case in which scientists can freely move across different employers.

such as recognition among peers in the scientific community, job satisfaction, public legitimacy, as well as future job opportunities (or career concerns); these benefits are therefore either difficult to translate in monetary terms, or at least they are not directly paid by the firm. I take such benefits as private and non-contractible. Anecdotal and qualitative evidence shows that these components of utility are important for the scientific profession and for motivating researchers, both in companies and in academia (Nelson 1962, Rosenberg 1990, Stephan 1996). The assumption of the private and non-contractible nature of some benefits is similar to that in other recent works in the Economics of Organizations, such as Hart and Holmstrom (2002), and in Political Economy (Hatgins and Padró i Miquel 2006). Gautier and Wauthy (2004) consider private benefits in their theoretical analysis of the behavior of university professors. In Appendix B below (pages 179 onward), I extend the model to include the response of scientists to monetary incentives proposed by the sponsor.

Since the alternative project has no scientific value, it gives a benefit of zero to the scientist. The scientist's ex ante payoff functions can be expressed as follows:

$$U^{in} = (1-\pi)(1-d)eB + \pi(1-d)eB - \frac{e^2}{2\gamma} = (1-d)eB - \frac{e^2}{2\gamma}; \tag{2.4}$$

$$U^{out} = (1-\pi)eB + \pi eB - \frac{e^2}{2\gamma} = eB - \frac{e^2}{2\gamma}. \tag{2.5}$$

U^{in} indicates the scientist's utility if the project is performed in-house and the scientist is an employee of the firm, and U^{out} indicates the utility if the project is outsourced and the scientist is an employee of the university. The institutional mission of the university allows the scientist to pursue such objective without interferences. Therefore I am taking the relation between scientists and their universities as one of perfect alignment of interests, clearly simplifying the reality but without loss of insight, in relation to the issues I deal with in this paper (for detailed analyses of the relation between academic scientists and administrators, in particular Technology Transfer Offices, see Jensen and Thursby 2001 and Jensen et al. 2003). As an implication of this characterization, the scientist and the university will not agree to terminate the project and switch to the alternative one, if there would be the opportunity to do so.

2.4.5 Analysis

Let us now solve the game by backward induction, starting from the firm's project choice.

The firm's project choice

Recall that the project's decision d is not contractible, therefore the firm cannot commit to a given project. Recall also that the decision is controlled by the firm unilaterally only when the project is developed in-house. In this case, since the expected economic value of the new opportunity, ρ, is greater than the expected value of the original opportunity, switching to the new opportunity if it emerges is a dominant strategy for the firm. The decision to switch project may be socially inefficient ex post. If the parties could renegotiate, then ex post efficiency would be reached. I assume that such renegotiation is not possible. In particular, the scientist cannot bribe the firm to continue the project, for example because she is cash-constrained; in turn, if the scientist cares only about private benefits (e.g. not related to the monetary value of the project), the firm cannot induce renegotiation either by proposing monetary payment in place of non-controllable scientific rewards.[14]

The scientist's effort

Project developed outside The firm does not have the authority to unilaterally opt for the alternative path. Therefore, there is no action at stage 4, whatever the realization of the state. The scientist's optimal choice of investment e^{out} is such that:

$$e^{out} \in \left\{ \arg\max_{e} \left[Be - C(e;\gamma) \right] \right\}. \tag{2.6}$$

Substituting the cost function as in (2.1), and solving for the (necessary and sufficient) first order conditions, we obtain

$$e^{out} = \gamma B. \tag{2.7}$$

[14] This assumption is clearly restrictive and would need to be relaxed in a less stylized model. This assumption however, while extreme, can represent a case in which an academic researcher is not allowed to undertake a research project, unless there is some potentially novel scientific content in it, since this would imply not respecting the primary mission of the university. Moreover, if the firm does not have unilateral termination rights, the academic scientist will not willingly terminate the project as long as there is scientific content in it.

The choice of effort increases with the expected private benefit from the project.

Project developed in-house The firm, now, has the option to change project. For the scientist, this implies:

$$e^{in} = \gamma B(1 - \pi). \tag{2.8}$$

When the project is done in-house, the scientist has to consider the emergence of the new economic opportunity because it determines whether the original project will be brought to completion or not, and this affects the likelihood to get rewards. Note that, if the firm shuts the original project down, the ex-post benefit of the scientist is zero. *The absence of commitment by the principal to complete the project regardless of the state of the world weakens the scientist's incentives.*[15]

The firm's organizational choice

The firm will develop the project in-house if

$$(1 - \pi)e^{in}R + \pi\rho > e^{out}R, \tag{2.9}$$

and will outsource if

$$e^{out}R > (1 - \pi)e^{in}R + \pi\rho \tag{2.10}$$

Solution

We obtain the following

Proposition 2.1 *Consider the choice of the organizational form, for different values of* π. *Assume* $B\gamma R < \rho < 2B\gamma R$. *Then,* $\exists\ \overline{\pi} \in (0, 1)$ *s.t. the project is performed in-house if* $\pi \geq \overline{\pi}$, *and the project is outsourced to a university otherwise. More precisely,*

$$\overline{\pi} = 2 - \frac{\rho}{B\gamma R} \tag{2.11}$$

[15] The absence of commitment may also affect the participation decision of a scientist. For example, a researcher may prefer not to join a firm at all, if she expects that some of the scientifically valuable projects she is supposed to undertake are going to be terminated before completion with some positive probability.

Also, we obtain:

$$\frac{\partial \overline{\pi}}{\partial B} > 0; \quad \frac{\partial \overline{\pi}}{\partial R} > 0; \quad \frac{\partial \overline{\pi}}{\partial \rho} < 0. \tag{2.12}$$

Proof. Consider the following difference:

$$\Delta\Pi = \frac{(\Pi^{in} - \Pi^{out})}{\gamma R} = B\pi^2 - \left[2B - \frac{\rho}{\gamma R}\right]\pi + (B - B). \tag{2.13}$$

Now, $\Delta\Pi \geq 0$ (i.e. the project is done in-house) if $\pi \in [0, \overline{\pi}]$, where

$$\overline{\pi} = 2 - \frac{\rho}{B\gamma R}. \tag{2.14}$$

The comparative statics in (2.12) follow straightforwardly. ■

Figure 2-1 below reports some examples, for different values of the parameters.

2.4.6 Comparison with the first best

I compare the previous results to a case in which a social planner decides whether to have the project developed within the firm, or outsourced by the firm to the university. The social planner therefore has the same choice set $\omega = \{$*in-house, outsource*$\}$ that the firm has. The major difference is that, now, the social planner accounts not only for the expected economic value of the project, but also considers the scientific value of it not related to the economic value. Suppose that the social non-economic benefit if the project is completed is given by $S \geq B$. The rest of the game is as before.[16] The social planner will choose $\omega =$ *in-house* if

$$(1 - \pi)e^{in}(R + S) + \pi\rho > e^{out}(R + S), \tag{2.15}$$

and will outsource if

$$e^{out}(R + S) > (1 - \pi)e^{in}(R + S) + \pi\rho. \tag{2.16}$$

[16] In some sense, we are looking for a constrained first best, since the only decision made by the social planner is an ex ante decision – the social planner cannot re-allocate the ownership of the decision right after the state of the world is realized.

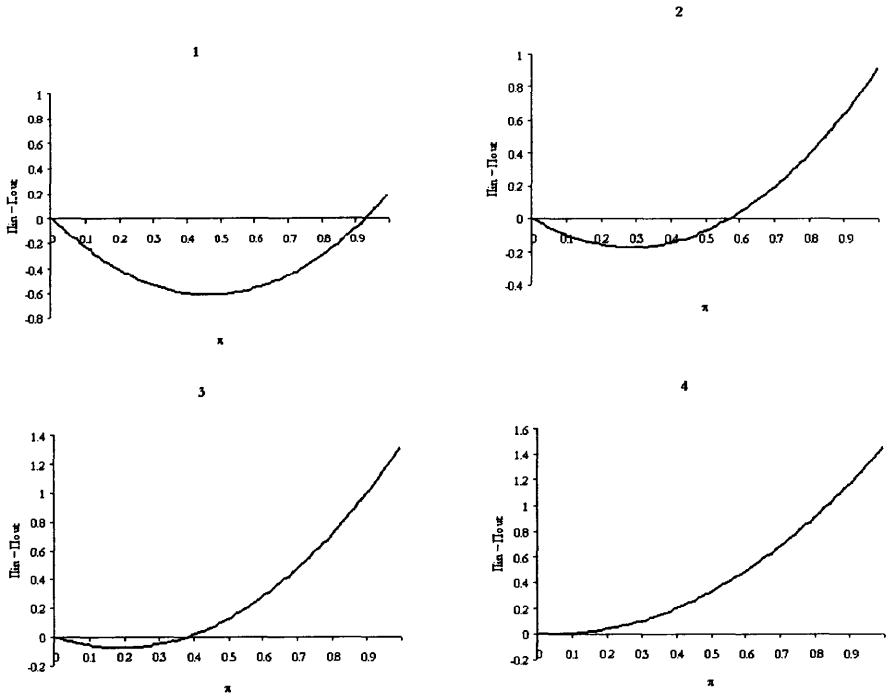

Figure 2-1: Four examples from Proposition 2.1 (page 94). The curves represent the difference $\Pi^{in} - \Pi^{out}$ for different values of π. When the curve is above the zero line, then the firm prefers to perform the project in-house. $R = 3$ in all cases. In case 1, $\gamma = .8$, $\rho = 3.1$, $B = 1.2$. In case 2, $\gamma = .8$, $\rho = 3.1$, $B = .9$. In case 3, $\gamma = .8$, $\rho = 3.5$, $B = .9$. In case 4, $\gamma = .6$, $\rho = 3.1$, $B = .9$.

Compare expressions (2.9) and (2.10) on page 94 with the expressions (2.15) and (2.16) just above. The private decision by the firm may not coincide with the social planner's decision. This would be the case especially when there is a substantial component of scientific benefit not captured by the economic benefit, i.e. when S is big. With a high value of S, ceteris paribus, the social planner values high effort more than the firm does (recall also that ρ does not depend on the level of effort). More generally, since $e^{out}S > (1 - \pi)e^{in}S$, the firm will have an extra-incentive to perform research in-house as compared to what the social planner would choose. For smaller S, the market outcome (e.g. the private choice of the organizational structure by the firm) is more likely to coincide with the socially optimal outcome (the choices will coincide for a larger interval of values of π). For a given S, the discrepancy increases with

ρ, and decreases with R.[17]

2.4.7 Description of the results and key insights

The characteristics of the project, in particular the breadth of the applicability of the potential results (and therefore the level of uncertainty concerning the economic returns from scientifically-relevant research) determine whether the firm develops the project in-house or outsources it to a university, given the values of the current and the alternative project, and the costs and benefits of performing scientifically novel research for scientists. Stronger control rights become particularly valuable for the firm for 'narrow' projects, e.g. those more likely to be overcome by economically more profitable opportunities. Also, the closer the economic return from the scientifically-relevant project to the return from the alternative project, the more likely the project will be outsourced.

The key, novel insight from my analysis can be summarized as follows. A profit-seeking firm may not be able to obtain from its scientists the same behavioral response that a university would obtain, even if the company's incentive scheme is equally (or possibly more) powerful. If scientific value does not perfectly coincide with economic value, the economic return is uncertain, and the firm has the ultimate decision over the performance of the research work, then the firm cannot unconditionally commit to the quest for scientific value. This may negatively affect the incentives of the scientific workers. If, as the model (rather realistically) postulates, the effort of the scientists also affects the economic return of a project, then the firm may be hurt by its own discretionary power. If the firm deals with scientists employed by a university, and the university is an independent contractor, then the firm may commit to the creation of scientific value by formally delegating some decision power to the university. The university is, by its mission, devoted to the production of new, scientifically-valuable knowledge, and will credibly let its scientists continue a project, even if there is little economic value in it. The firm, moreover, has a bias toward 'excessive' integration, as compared to the social optimum, because it does not

[17] Define $\Delta SW = (1-\pi)e^{in}(R+S)+\pi\rho-e^{out}(R+S)$. Now, $\Delta SW = 0$ for $\pi_1 = 0$ and for $\pi_2 = 2-\frac{\rho}{B\gamma(R+S)}$. If $S = 0$, then $\pi_2 = \bar{\pi}$ It is also easy to show that $\frac{\partial \pi_2}{\partial S} > 0$, therefore $\pi_2 > \bar{\pi}$ for any $S > 0$. Also, it follows immediately that $\frac{\partial \pi_2}{\partial \rho} < 0$, $\frac{\partial \pi_2}{\partial R} > 0$, and $\frac{\partial \pi_2}{\partial B} > 0$. Finally, $\pi_2 - \bar{\pi} = \frac{\rho S}{B\gamma(R+S)}$. This difference is increasing in S and in ρ, and decreasing in B and R.

internalize the full social value of completing the scientifically-valuable research.

The model also offers some predictions about what kind of projects are more likely to be performed through industry-university collaborations, and what degree of authority firms are more likely to retain. The model also and defines a framework to discuss and assess some managerial implications as well as policy positions about the desirability of stronger ties between industry and academia in the performance of research activities. I now turn to some considerations on these issues.

2.5 Empirical patterns

In this section I focus on some empirical predictions that emerge from the discussion and the model above. I then assess the consistency of my claims with different pieces of evidence: examples of research collaborations between companies and academic organizations, patterns from large-sample studies, and trends in company funding of academic research over the past three decades in a few disciplines and industries.

2.5.1 Empirical predictions

An empirical prediction of my findings is that firms will be more willing to delegate control over the conduct of research, when the research has a broader applicability. A research project which is applicable to several areas is less economically uncertain. Another prediction concerns the duration of a research project. A longer research program is arguably subject to higher uncertainty, for example better opportunities can emerge on which the sponsoring party and the researchers may not agree. Therefore, a firm, all else constant, might want to retain higher control over the research agenda. My perspective also implies that firms prefer to fund general-purpose research in academia and research in nascent areas of inquiry. For these projects, the benefits of stronger incentives coming from credible commitments may be higher than the reduced ability to direct the direction of the project: scientifically-valuable projects are more broadly applicable.

2.5.2 Cases and examples

Consider the previously mentioned deal between Novartis and Berkeley (page 74). The parties formed a committee with the power to allocate funds to the research projects the academic researchers proposed. Of the five seats of the committee, Novartis was granted only two, i.e. it had a minority position in terms of decision rights. This choice can be interpreted as a signal that the company would not impose entirely its logic over the decisions of which projects to promote. Since the type of research which was object of the original agreement was of broad application, scientifically-relevant, and economically very promising, it can be argued that the company cared less about being able to promptly stop a project, than about providing the strongest possible incentives to the scientists.[18] However, the growing opposition to genetically modified foods, backed also by some legislative provisions, arguably reduced the breadth of application of the research funded by Novartis at Berkeley (an increase in π, in the model), and/or the expected value from the original research projects might have reduced (equivalently, the requests for further control, or labeling of genetically modified products might have implied a delay in the accrual of economic returns). In the logic of my model, these factors would increase the incentive to perform projects under a stricter authority, and would make the deal with an independent academic partner less sustainable. The deal, in fact, was not renewed in 2003 (Lawler 2003, IFAS 2004).[19] Beside the Novartis-Berkeley experience, the research relations between Amgen and MIT were drastically downsized after some major changes in Amgen's leadership re-oriented the firm away from a major focus on R&D, towards increasing attention to marketing (Lawler 2003). These changes can be expressed, again, as a *decrease* in the alignment between scientific and economic value, given the new focus of the firm in generating value through marketing more than through research. By contrast, MIT and DuPont have recently renewed their 2000 alliance for five more years (and additional $25M), as mentioned above. Interestingly, the agreement has been extended to cover other research

[18] This does not exclude other motivations that might have driven the choice to develop such collaboration. A major reason, for example, might have been the possibility to better screen potentially valuable researchers to hire. There is contrasting evidence about the relevance of this motivation (see Lee 2000, for example). In any case, this additional explanation is not in contrast with the one I focus on in my analysis.

[19] There are also other reasons brought to explain the decision not to renew the agreement, including an increasing public distrust toward the University. See IFAS 2004. On the other hand, Novartis did not stop signing similar deals with other universities. See Krasner (2004) on a diabetes research deal between Novartis, MIT, Harvard, and the Broad Institute.

areas, like nanotechnology, which are thought to have a vast range of applications (see Brown 2005) and are in very early stages. According to my analysis, these are the areas we would be more likely to see as the subjects of collaborations between companies and academic research teams, since scientific progress is more likely to be closer to economic value. Notice that, again, it is possible to see several forms of delegation of power from DuPont to MIT. For example, each research proposal is initially screened by the MIT Internal Advisory Committee, and then reviewed jointly by this committee and the DuPont Advisory Board. Moreover, decisions are then taken by the Steering Committee, composed by MIT faculty members and DuPont personnel, and the unanimous consensus rule applies. Finally, neither party can unilaterally terminate the agreement without cause.[20] Therefore, also this case brings plausibility to my assumptions on the one hand, and support to my conclusions on the other hand.

2.5.3 Evidence from a companion project

In a companion project, described in Chapter 3 below,[21] I have collected and analyzed research contracts between biotechnology companies and universities, hospitals and other non-profit, 'open-science' research organizations. Part of the analysis in that paper is concerned with determining whether the allocation of control rights was systematically correlated with characteristics of the research project and of the parties. Here I use the data from this companion project to test whether the strength of control of the sponsoring company over the research is related to the breadth of applicability of the research described in a contract, and to the expected duration of the research project. As noticed above, the qualitative discussion and the model, while expressed 'make versus buy' terms, can also be intepreted in terms of the degree of authority a firm exerts, within the set of relations with other organizations the firm undertakes. Also, recall that a main empirical prediction of the model is that projects with a boarder applicability should be associated with lower formal ability of sponsoring firm to affect the direction of research, and a second prediction is that longer projects should be associated with stronger control by the company. I propose here some simple analyses of whether my

[20] I am very grateful to Dr. Bruce Smart at DuPont for agreeing to have a conversation with me on the features of the Alliance. See also the Alliance's web site: web.mit.edu/dma/www.

[21] The reader is referred to Chapter 3 (pages 125 onward) for details about the data collecting and coding process.

contract data show patterns consistent with these predictions. Rather than a formal test of the theory, however, the following analyses should be intepreted only as descriptive and suggestive of whether my theoretical claims have some empirical content. To be sure, further empirical work and statistical specifications are required in order to produce more compelling and well-defined tests.

I measure the breadth of applicability in terms of the number of diseases (or disease areas) the research is reported to deal with, as described in the front page of each contract, elaborated by the company Recombinant Capital, which holds the database from which the contracts are downloaded. A higher number of diseases is a proxy for breadth of applicability of the research.[22] A similar measurement choice has been made by Kocabiyik-Hansen (2004). I code duration of the project with a dummy variable taking value 1 if the project is expected to run for more than two years, and zero otherwise.[23] I use two measures of control power by the firm. The first measure is a dichotomous variable for whether the firm has unilateral termination rights without cause. In my model, terminating the research can be considered equivalent to terminating the relationship with a given research team and move to another activity. The second measure is the sum of four major control rights given to the sponsoring company: termination without cause, change to the research program, extension of the duration of the research, and duties of the research partner to periodically submit research proposals and budget, subject to the approval of the company (as opposed to the definition of a full program and budget at the signing of the contract).

Figure 2-2 reports a table of results from regressing these different proxies for firm authority on measurers of the breadth and duration of research (controlling for a vast range of other variables, along the lines of the analyses in Chapter 3).[24] Duration is strongly positively correlated

[22] For each research alliance reported in the database, Recombinant Capital produces a front page, in which the name such information as the names of the parties, the date of signing, the technologies involved, the phase of the research, and the disease areas of interest are reported. Examples of disease areas are Infection - AIDS, Infection - Antibiotics, Central Nervous System, Wound Care, Transplantation. While the database distinguishes as many as 66 disease areas, clearly the categories are quite coarse and not of equal breadth. My classification can surely be improved; however, data constraints allow only as much at this stage.

[23] This duration excludes extensions agreed upon after the contract is signed. Different cutoff, e.g. at 1-year duration instead of 2, conveys similar results.

[24] The econometric method is OLS in all cases (with robust standard errors; clustering standard errors at the level of the research organization does not change the results). Probit and logit analysis (ordered where applicable) convey similar results. Fixed effects panel method (with the cross-sectional unit being, for example, the research partner) would allow controlling for unobserved heterogeneity among research organizations. However, this would

with firm's authority. While there is not always enough power to produce high statistical significance, due to the relatively small size of the sample, the estimated coefficient on the variables representing breadth or scope of the research are consistently and sizably negative. Notice in particular the large and highly significant estimate related to the indicator for more than two disease areas been considered in the research. On the one hand, we should use some caution in the interpretation of this result since there are only ten such cases in the data. On the other hand, in all of these ten cases, the number of major control rights allocated to the company is always zero, against an overall average of about 0.5. While these findings are preliminary, and we cannot imply any clear causal direction, they still are suggestive of the impact of the breadth of applicability and duration of the research, and are consistent with the theoretical predictions of the model.[25]

2.5.4 Related empirical studies

My framework is also consistent with some of the findings of Mansfield and Lee (1996), one of the few large sample empirical studies on industry funding of academic research. Mansfield and Lee find that large, prestigious universities tend to receive (in percentage terms) less funding from firms than less prestigious universities. This can be due to the fact that these universities have other sources of funding. However, the authors also conjecture that firms may find it more costly to fund these universities, because the contractual conditions they will impose are more restrictive for a firm. On the other hand, firms appear to value the higher abilities of scientists in more prestigious universities for projects that are less narrow and specific, and of more fundamental and broad nature. In the logic of my model, broader projects are indeed those in which a firm would be willing to sacrifice some authority in order to enhance the effort of the

require further restricting the sample to those cases in which at least two contracts for a given organization are available. The sample size would reduce substantially, therefore reducing the power and precision of the tests, I therefore opted for not performing fixed effects analyses.

[25] One case I have excluded from both my theoretical and empirical analyses is when both parties are granted termination rights without cause. This case occurs in the contracts I have analyzed. Theoretically, it can be shown that a case with two-sided termination rights is very similar to the 'make' option for the firm, i.e. to the option of performing the research in-house or more generally to have strong authority over it. Indeed, I have performed additional regressions where the dependent variables is a dummy for whether either only the firm, or both parties have termination rights. Results are not reported here but are available from the author. The estimated coefficient on the breadth-of-application variable is very similar, in magnitudes and significance level, to the case in which unilateral termination rights is the dependent variable. This, again, is consistent with the theoretical predictions.

	Dep Var: Firm has unilateral termination right without cause			Dep Var: Sum of major control rights*			Dep Var: Dummy =1 if sum of major control rights>0		
	1	2	3	4	5	6	7	8	9
Regressors**									
	Estimated coefficients***								
Research projects longer than 2 years	**.19** (.07)	**.20** (.08)	**.15** (.07)	**.34** (.12)	**.33** (.12)	**.30** (.11)	**.24** (.08)	**.24** (.09)	**.22** (.08)
Num of diseases	**-.16** (.05)			**-.17** (.08)			**-.13** (.06)		
Dummy=1 if num of diseases>1		**-.21** (.07)			-.16 (.12)			-.11 (.09)	
Dummy=1 if num of diseases>2			**-.18** (.08)			**-.44** (.12)			**-.36** (.08)
Method	OLS****	OLS****	OLS****	OLS****	OLS****	OLS****	OLS****	OLS****	OLS****
R_square	.15	.15	.11	.11	.10	.10	.10	.09	.10
F-stat	**2.09**	**2.05**	**1.91**	1.25	1.07	**2.11**	1.31	1.01	**2.62**
Obs	171	171	171	171	171	171	171	171	171

*Sum of the following dichotomous variables: Firm has unilateral termination right without cause; Firm has the unilateral right to extend the duration of the project; Firm has unilateral right to modify the direction of the research; Academic partner is required to periodically submit budget and research proposals, subject to the approval of the company sponsor

** Estimates in bold types are significant at the 10% level or more. Standard errors in parentheses.

*** With robust standard errors

****Regressiors include: constant; phase of the research (early discovery phase vs research in 'lead molecule' or clinical trials phase); a dummy for whether the research partner is a university (as opposed to hospitals, foundations, etc.); a dummy for whether the research partner is a private university; a dummy for whether the research partner is within a hospital; a dummy for whether the research partner is among the 50 organizations receiving the highest dollar amount of NIH grants (in the year before the contract was signed); a dummy for whether the PI is among the top 25% (in the sample) in terms of cumulative impact factor until the year before signing the contract; dummies for the geographical distance among the partners; a dummy for whether both partners are US-based; a dummy for whether the deal was done after 1990; a dummy for whether the company has been founded at least 2 years before the contract is signed; dummies for previous collaborations (by the research partners with other companies, by the company, and by the parties with each other)

Figure 2-2: Regression results. The unit of analysis is the research contract. Contract data from Recombinant Capital, company's financial records, Medline. See Chapter 3 below for details on data sources and variable construction

scientists, which in turn is likely to be higher in broader and more fundamental projects, since peer recognition can be higher. The difficulties for firms to interact with prestigious research universities is implicit also in the findings of Masten (2005), who shows that research-oriented universities have an internal authority structure which is more distant to the one of companies. Finally, Veugelers and Cassiman (2005) find that collaborations between companies and universities are more frequent when risk is not an important obstacle to innovation. Moreover, the authors find that firms in science-based sectors like chemicals and pharmaceuticals are more likely to have research relations with academic organizations. In my framework, this means that R, the returns from investing in scientifically advanced projects, is high, and it is less likely that better opportunities will emerge.

2.5.5 Dynamics

We can also speculate on how my analysis can contribute to explaining the recent increase in formal relations between industry and academia. The 1970s, for example, have witnessed a change of paradigm in the life sciences, with the emergence of molecular biology and biotechnology. Arguably, in its early stages a discipline tends to be characterized by broader, more general-purpose questions. In the case of biotech, moreover, basic science is generally said to be closer to economic profitability than in other fields. General-purposedness, richness of novel scientific results to be achieved, and the expectation of positive returns from basic research, in my model, predict that a higher share of projects will be outsourced to academic organizations.[26] It is actually the case that the bulk of industry participation in academic research is in the life sciences. Lately, a similar pattern seems to be occurring in emerging fields such as Nanoscience.[27] In science-based sectors, moreover, some scholars have noticed a process from

[26] Recall that both the different missions and the different authority structure, and not just generic references to different capabilities, are necessary for my results to hold. Otherwise we would not have an explanation for why firms do not hire those capabilities through employment contracts.

[27] My explanation for the increase in industry funding of academic research since the late 1970s is by no means alternative to other arguments developed in the literature. Several authors have pointed to legislative changes, such as the 1980 Bayh-Dole act and the 1986 Cooperative R&D Agreements Act, as key determinants of the increase in industry participation. These changes have reduced the costs of interacting with academic organizations. However, an argument funded only on these legislative changes does not completely consider that firms, in principle, always have the alternative to perform research in-house (or, for that matter, to contract the research out to another firm). Notice, finally, that the increase of industry funding is occurring in research areas in which there has not been a decline in federal funding (Bok 2003). Increased participation of industry should not be seen, therefore, only in terms of substitution of public funding. Additional explanations are in order.

collaborations with academic organizations in the very early stages of these industries, followed by an increase in the building of in-house research capacity (see for example Dalpé 2003 for the biotechnology sector in general, and Hall 1987 for Genentech in particular). In more mature stages of an industry, more competitors can be present, and also alternative paths of research with lower scientific content might become available. Therefore a firm might prefer to exert stronger control over research and to keep more flexibility. In earlier stages, instead, the scientific content and intellectual human capital might be more determinant for economic success, and not other directions for economic success may be of relevant value. In this scenario, it becomes more important to elicit the highest possible intellectual involvement of scientists.

2.6 Managerial and public policy insights

2.6.1 Organizational issues

Guaranteeing greater autonomy to workers over their activities is a powerful device for increasing workers' incentives to supply productive effort. However, if the interests and priorities of a worker are well aligned with those of the firm, the degree of autonomy left to the worker becomes irrelevant: faced with a set of options on how to perform a given task, the worker and the company would make the same decision. Some level of disagreement, at least in certain instances, is necessary in order to make a worker's freedom of action beneficial also for a firm. If a worker is guaranteed that, in some circumstances, her priorities will prevail over those of the firm, she might be more willing to invest in a given relationship from the outset. To the extent that this increased effort also increases the expected return for a firm, then it would be in the firm's interest to leave greater autonomy to the worker. This, however, comes at a price: if some events occur such that a worker's best option is not the best option for the company as a whole, the company might not be able to intervene and modify the choice. If these discrepancies are likely to occur, then a company might prefer to retain higher control, even if this entail lower effort and involvement by the workers.

Even when it is in a firm's interest to delegate greater control to workers, such delegation may not be credible from the workers' viewpoint. In an employment relation, for example, the ultimate decision power resides in the employer, who can only informally promise that a

worker's proposal will be implemented regardless of the interest of the company (see also the evidence described in Section 2.3.2 above). The company might need to opt for organizational forms that make its commitment more credible. Hiring workers as independent contractors, or as employee of organizations whose interests are aligned with those of the workers, may be effective devices.

The performance of research activities is a major example of the previously described dynamics to occur. Scientific workers, as members of the boarder scientific community, may care about the rewards they obtain from this community (publication, peer recognition, scientific awards). These rewards are obtained when a given research activity produces scientific value, regardless of its economic potential. If scientists are more confident that the quest for scientific value will be a priority in their assignments, then they will exert greater and possibly also economically more productive effort. As discussed above, however, it may be hard for a company to commit to the quest for scientific value, if it does not coincide with the maximization of economic returns and if scientists are hired as employers. It turns out, however, that there are organizations that employ scientists, such as universities, whose main mission is aligned with that of the overall scientific community. Companies may obtain greater effort from scientists by contracting for the services of scientists employed by universities.

My analysis, therefore, shows not only the potential benefits for a firm to exert lower control over their scientific workers. It also identifies a mechanism through which this greater autonomy can be achieved: outsourcing research activities to academic organizations.

In fact, there is a vast range of 'intermediate' instruments through which a firm can empower researchers. Several companies have set up research labs in locations distant from where the other firm operations were located. These labs are often close to some major universities (consider, for example, the IBM's Watson Lab at Columbia University and Siemens' and NEC's Labs at Princeton; see Buderi 2000). In addition to facilitating knowledge acquisition from universities, a major reason for these location choices was that, being more distant from the companies' headquarters, scientists would have felt less 'controlled' and more shielded from current market needs. Therefore, they would have had higher incentives. Also, a firm can decide to employ its own scientists in an independent, non-profit research foundation created and funded by the company itself. Consider, for example, the joint creation of the biotech

company Human Genome Science (HGS), and the Institute for Genome Research (TIGR), a research foundation, by the investor Wallace Steinberg in 1993. TIGR was granted freedom of research without interference from the investors HGS (Davies 2001). Novartis, similarly, has created a series of independent foundations, through which it 'supports scientific research projects, particularly high-risk projects in areas of new technologies, that are compatible with the long-term interests of Novartis[...]'.(Novartis 2004). Another way to empower scientists that some companies have used is to create a separate division for Research, in order to make it less dependent on the current desires of other divisions. These mechanisms show that firms care about being able to send the right signal to their researchers about their attitude toward the performance of research activities. These devices do not rule out the potential value of outsourcing research activities to an organization with different objectives, in order to increase a firm's commitment to the completion of a scientifically-relevant (and potentially commercially viable) project. Given the increase of industry participation into academic research, moreover, this specific organizational choice is worth studying in its own sake, and deserves attention from company managers.

Remember that the theoretical model described above requires some degree of divergence between economic and scientific value in order for the outsourcing option to be valuable. Indeed, the organizational arrangement is irrelevant for $\pi = 0$, i.e. when opportunities with high commercial value but low scientific value are expected to never emerge. However, an excessive discrepancy, or a high (economic) riskiness of a given project makes formal collaborations with universities difficult. Projects with high economic risk, or high π, are therefore predicted to be performed by universities independently, or by firms in-house, and less likely to be done in formal industry-university collaborations where universities exert control over the research.[28] These considerations form the basis of my argument for the benefits of performing research activities in-house. The argument adds to those presented by several scholars in existing studies, as described above (see Section 2.2), and allows for a cost-benefit comparison with alternative organizational forms. The key defining characteristic of an in-house research force is that a firm has unified, centralized authority over the projects, and therefore discretion over the

[28] Evans (2004) advances a similar claim when he states that collaborations between companies and universities will involve less risky projects, and my model gives an economic rationale for this to be the case.

conduct of research activities. In cases where there is a high expected difference between the economic effects of the choice a scientist would make and the decision a managers would make, discretion is of great importance, at the cost of diluting the incentives of the researchers. Private conversations and interviews I conducted with practitioners in research-intensive companies revealed that they strongly care about being able to promptly modify the direction of research in a given project, and this is easier and faster to do if the team performing the research is directly performed by the company. Conversations with university-based researchers revealed that they generally believe that they would not have the same freedom to pursue scientifically-relevant projects if employed by a profit-seeking company. Business companies, it is the common perception, shut down projects frequently, as soon as the expectation of economic returns decreases, regardless of other considerations (see also Charles 2001 and Evans 2004).

2.6.2 Public policy considerations

A growing body of literature is warning against the increase in the relations between business companies and academic organizations. It is feared that these relations, and more generally a greater involvement of universities into 'business-like' activities (e.g. patenting and licensing), can change or corrupt the rules and the mission of academia, and they could be detrimental in the long term because less fundamental, scientifically-relevant research would be conducted (Dasgupta and David 1994, Henderson et al. 1998, Mowery 1998, Powell and Owen-Smith 1998, Krimsky 1999, Florida 1999). Other studies, however, claim that industry-university collaborative research can be beneficial to both parties. Moreover, some empirical evidence shows that academic scientists involved in commercial activities do not significantly change their research behavior (Stephan et al. 2002, Gelijns and Their 2002, Agrawal and Henderson 2002, Goldfarb et al. 2003, Markiewitz and DiMinin 2004, Azoulay et al. 2004, Breschi et al. 2005).

I derive that, when a firm decides to contract a research project out to a university partner, it might be preferable for the firm to let the academic partner 'behave like a university', and not to interfere with its activity and the pursuit of its objectives. Universities, as performers of research, are valuable for the firm as long as they can offer something that the firm is not able to replicate. In particular, it is crucial that universities keep their commitment to a mission that

is different from the one of industrial actors. My argument is consistent with (and may offer an economic rationale to) the claims of those scholars who have taken a 'middle ground' position on the role of universities for technological and industrial progress. For example, Rosenberg and Nelson (1994) and Nelson (2004) see industry-university relations as potentially beneficial, and call for an increased attention by academic research organizations to the resolution of actual scientific and technological problems. On the other hand, these eminent scholars clarify that stronger ties do not imply that universities should become business organizations. On the contrary, universities have to stick to their original mission and rules, and institutional diversity should be preserved. In a similar vein, Howitt (2003) argues that one key role of academic organizations is to preserve the mission of creating and promptly diffusing scientifically-valuable knowledge. This is fundamental for solving some of the inefficiencies in the market for knowledge. Howitt claims that business organizations would inevitably subordinate the sheer quest for knowledge to their institutional mission, e.g. the quest for economic profits. This could be perceived as a limitation to the freedom of inquiry and reduce the incentives of company scientists, as compared to academic researchers. In a speech at the 1983 Industry-University Research Interaction Conference in Stockholm, H.L. Beckers, the Group Research Coordinator for Shell International and President of the European Industrial Research Management Association at the time, claimed that collaborations with academia would be more profitable for firms if universities do not try to mimic a business organization, and they instead stay loyal to their original mission.

I also argued that, for the same reason why outsourcing to an academic organization may be beneficial, it might also be costly because the firm has less discretion and flexibility. In research activities, this problem may in fact be compelling, and can help to explain why the majority of company research is performed in-house, while industry participation in university research, though increasing, is still low (see also the more detailed evidence brought by Mansfield and Lee (1996), discussed above). I also showed that there is a tendency of firms to perform in-house projects that would be more socially preferable to be performed by universities on behalf of firms. In particular riskier projects, intended as project with more uncertain economic return, are less likely to occur through formal collaborations between companies and universities. They are more likely to be performed in-house by companies, or to be conducted by universities

independently.

A consequence of this low participation is that the ability of companies to influence the behavior of academic scientists would be limited, as the previously mentioned empirical studies have found. Another consequence however is that, if industry participation remains at this relatively low level, public funding of academic research will still be the most important financial source, and should not be strictly contingent on economic returns. Providing financial resources not strictly tied to economic success might also be important in order to safeguard the credibility of universities' commitment to their peculiar objectives. Similarly, social control and legitimacy may play an important role: universities may be socially sanctioned (e.g. by reduced donations from alumni) if they are perceived to give up on their original missions (see Argyres and Liebeskind 1998, Bok 2003). Some authors have also argued that the governance structure of an academic organization may affect the credibility of the commitment to the institutional mission (see for example Bok 2003).

2.7 Related literature

2.7.1 Building blocks

My analysis is founded on two theoretical building blocks.

One such building block is the interpretation of Science as an institution, with peculiar objectives and rules (Merton 1973, Dasgupta and David 1994, David 1998, David et al. 1999). I have described this literature in Section 3. After the description of the model, one point that emerges more clearly, and that represents a potential contribution to this literature, is that I clarify the behavioral assumptions required to obtain results consistent with this institutional view. For example, the fact that scientists value freedom of inquiry is not an *assumption* of my analysis, but a *result*. Scientists value being shielded from purely economic consideration in the conduct of their research, as long as this protection increases their chances to fulfill the requirements for success in their community of peers. The presence of organizations with different institutional objectives, the presence of different contractual relations among them, and the assumption of misalignment between economic and scientific value cause the scientists to have different degrees of freedom in different organizational arrangements.

The second building block is represented by some recent developments in the Economics of Contracts and Organizations. Recent works have pointed out that workers can be incentivized through a vast array of mechanisms. These mechanisms include the definition of pay-for-performance schemes, but also the delegation of formal authority can be a powerful incentive device (Hart and Moore 1990, Aghion and Tirole 1997). In my framework the workers, even when employed by a firm, are also affiliated to a different institutional environment, and it might be preferable for the firm to provide incentives consistent with those of the 'competing' institutions. However, this may not be enough to receive the desired behavioral responses, if the firm is retaining the formal authority. Baker et al. (1999) show that a firm can spin off an activity to an independent agent, in order to make credible its promise not to overrule the agent's proposals. Baker et al. (2001) conclude that a firm cannot replicate market-based transactions within its boundaries, because of a different authority structure (see also Holmstrom and Tirole 1991). The delegation of power to an organization which is pursuing the same ultimate goal, I add, may not still be enough to make the scientists work harder. The increased commitment power may come from the presence of different missions.

2.7.2 Related works

Aghion et al. (2005) have independently performed a study which is most closely related to my paper. However, whereas the point of view of my analysis is that of a firm deciding how to organize its research activities, i.e. which projects to develop in-house and which projects to outsource, Aghion et al. study the decision of a social planner about which stages of a research project to allocate to a firm and to a university. They assume that firms give less freedom of inquiry to their scientists than universities, and in exchange firms offer higher salaries. In the initial phases of a project, the expected economic value is small; the social planner therefore prefers lower salaries, and allocates these early phases to a university. If the project reaches late phases and gets close to completion, then the expected value of the project increases, and tight authority over the research direction is more important than increases in wages. Therefore, the social planner will transfer the project to a firm. The key trade-off the authors identify (wage versus freedom of inquiry) is different from the one I point to. Unlike my analysis, moreover, Aghion et al. do not model the scientist's effort and its impact on the value of a

project. In the version of their model more closely comparable to mine (the version with a single scientist), in fact, the project is always more productive (more likely to be completed) when it is carried out in a firm, and the only benefit from academia is given by the lower wages. Also, Aghion et al. do not explicitly consider the reaction of firms to exogenous events that change the economic returns. The process through which the firm implements its authority is not expressed in their model, while I make it explicit through the presence of non-contractible ex post decisions. Finally, different levels of freedom of inquiry in different organizations are taken as given in Aghion at al.'s paper, while my analysis endogenizes them, by modeling the differences in the missions of universities and firms. The paper of Aghion et al. and my paper are part of a recent tradition of theoretical works that analyze research activities as performed by actors that follows different missions and possibly respond to different incentive systems (see also Jensen and Thursby 2001, Jensen et al. 2003, Beath et al. 2003).

My study also shares some insights with a few other works. Glaeser and Shleifer (2001) model the choice of an entrepreneur between a for-profit and not-for-profit legal status for her company. The authors argue that a profit-seeking entrepreneur can rationally choose a not-for-profit legal status, in order to credibly signal to potential customer her commitment the high quality of the goods and services the company supplies. In a series of influential papers, Julio Rotemberg and Garth Saloner (see Rotemberg and Saloner (1993, 1994) and Saloner and Rotemberg 2000) derive that a firm may prefer to hire a CEO with a vision, or consistently biased beliefs, or may choose a narrow strategy and forego unrelated profit opportunities, as ways to commit to some actions (see also Van den Steen 2005). Melkonyan (2002) elaborates a model in which a principal and an agent contract both on the incentive scheme, and on the allocation of decision power. He finds that the choice of authority structure affects also the shape of the incentive contract, and both the authority structure and the incentive scheme affect the agent's behavior. Dessein (2002) proposes a model in which a principal with formal control rights over an agent in general gains from delegating control to an intermediary whose preferences are intermediate between the principal's and the agent's (with reference to the topics of interest in my paper, the university, or the Technology Transfer Office, could play this role in relations between firms and academic research teams). With reference to open-source and technology sharing, Lerner and Tirole (2005) suggest that a corporation may not be able

to credibly commit to keeping all source code in the public domain. Argyres and Mui (2005) analyze commitment problems that principals face when they try to stimulate agents to express their dissent, and dissent can be informative. Principals may not be able to follow an agent's dissenting proposal, once the proposal has been made.

2.8 Summary and Conclusion

In this essay, I ask what makes academic organizations particularly suitable to conduct some types of research on behalf of business companies, and why companies delegate a lot of power over the direction of research to these organizations. I also ask why, on the other hand, firms still perform the bulk of their research activities, including fundamental research, within their boundaries. Following an institutional approach to the analysis of Science, I argue that a major feature that differentiates academic research from industrial research is the pursuit of different objectives. The ability of firms and academic organizations to pursue their missions, moreover, is influenced by the organizational structure and the distribution of authority among the parties, when they formally interact. I claim, also on the basis of some existing evidence, that firms may be able to provide high-powered *incentives* to the scientists, possibly even stronger than those provided by the scientific community. However, a firm cannot commit to the *objectives* of the scientific community, if they are not perfectly aligned with the quest for economic profits. These considerations allow me to identify a mechanism through which firms may find it profitable to outsource research projects to academic organization: universities are contractual partners to which the firm can delegate power and commit to the quest for novel, valuable scientific knowledge. This choice can enhance the scientists' incentives to provide high effort, and the higher effort can counterbalance the risk of poor economic returns from the research. In addition to a level of uncertainty regarding the economic profitability of a project common to whatever organizational structure is chosen, a further source of risk from collaborating with an independent partner is that it would be more difficult to stop or alter the conduct of a project, if economic returns turn out to be low. The cost of the outsourcing choice, indeed, is a loss of discretion. Firms may therefore prefer to keep hierarchical power over some projects, and perform them in-house.

I build a simple economic model that formalizes these arguments. The assumptions of the model are grounded in the economic theory of contracts and in the existing evidence on the characteristics of actual research contracts among independent organizations. I also consider some key characteristics of the research process. For example I assume that economic value out of a research project is driven both by the intellectual effort of scientists, and by random shocks not correlated to effort. I also distinguish between economic and scientific value, and account for the differences in institutional missions and in the allocation of power deriving from different contractual arrangements, in particular employment vs. outsourcing. The analysis, while not defining a general theory of R&D organization and of industry-university relations, sets up a framework to consider some costs and opportunities of in-house research and of collaborations with academic organizations. A key driver of the results is the degree to which a research project is subject to sources of uncertainty such as demand shifts, legislative interventions or strategic changes by companies, not immediately related to the scientific value of a research project and the intellectual work of scientists.

According to the analysis, we would expect projects less subject to such random fluctuations to be developed by a firm with the participation of an academic partner, and with a lower involvement of the firm in the definition of the direction of the research. This would be more likely to be the case for research projects whose results are expected to have a broader arrays of applications, and for projects expected to run for shorter periods of time. I offer some evidence from the analysis of biotech contracts between companies and universities or other non-profit research organizations that is consistent with these predictions: when the research project is applicable to a higher number of disease areas, the sponsoring firm is granted significantly less power to influence the performance of the research, while the firm retains stronger authority for longer projects. Also, we could argue that in very early stages of a research project, there is a vast set of valuable scientific results to be achieved, and the results are more likely to have a vast array of economic applications. Some case-based evidence, and the little available large-sample evidence, show that interactions with universities by firm tend to concern mainly projects in their early stages. My theoretical analysis is able to offer an explanation of these patterns. Moreover, by adding to the picture institutional considerations, my analysis is able to explain not only why a firm might want to finance research in universities in its behalf, but

also what kind of projects a firm may be willing to fund. In so doing, I add both empirical content and stronger logical foundations, as well as managerial implications.

My analysis also defines a framework to discuss and assess some policy positions about the desirability of stronger ties between industry and academia in the performance of research activities, the importance of public funding of academic research, and the role of social legitimation of the academic mission.

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Chapter 3

Openness and Authority in Industry-University Relations

3.1 Introduction

> Recipients should be aware that their interest in the scientific endeavor covered by a sponsored research agreement and the interest of the industrial sponsor may not be totally consonant. As a result, in general, Recipients should ensure that sponsored research agreements preserve the freedom for academic researchers to select projects, collaborate with other scientists, determine the types of sponsored research activities in which they wish to participate, and communicate their research findings at meetings, and by publication and through other means. [...] [A]n agreement which gives an industrial sponsor the ability to direct the research mission of a Recipient would be inappropriate (NIH, 1994).

This study analyzes research collaborations between biotechnology companies and universities, hospitals, and other 'open-science' research organizations. I aim to analyze such major contractual provisions as the decision rights over the definition of the research agenda granted to the firm, and the publication restrictions imposed upon the open-science partner. The influence on the research agenda and the limits to an open diffusion of the results are the issues that have attracted most interest in science policy circles (Blumenthal et al. 1986a, Blumenthal et al. 1986b, Blumenthal et al. 1996, Florida 1999, Krimsky 1999). These issues are also

considered of great importance by companies, since the 'openness' of research exerts an impact upon the appropriability of the results, and the definition of the research agenda has an obvious effect on both the strategic orientation and the likelihood of success of a firm. However, there are no large-sample statistical analyses that assess whether these concerns are really borne out in the actual contractual provisions on which the parties base their relations, nor are there large-sample studies on the relationship between contractual provisions in industry-university collaborative research agreements, and characteristics both of the research activities and of the parties. The several studies of Blumenthal and his coauthors, mentioned above, represent relevant exceptions. These works differ from mine in that they are based on surveys among scientists and companies rather than on the direct analysis of contracts.

This essay can therefore provide valuable information to policy makers about the existence and the relevance of concerns related to the freedom and openness of research. From a managerial standpoint, the analysis of the determinants of openness and authority structure can provide insights about the challenges that firms are likely to face if they undertake research relations with academic and other open-science organizations. Finally, this work can contribute to the small but increasing set of studies in the so-called 'empirical contract economics'. This field includes a series of statistical analyses of the characteristics of contracts and how they relate to other features such as the type of activities, the parties involved, and so on. These studies include Lafontaine (1992), Crocker and Reynolds (1993), Lerner and Merges (1998), Lafontaine and Shaw (1999), Bercovitz (2000), Ryall and Sampson (2002), Argyres et al. (2004), Higgins (2004), Kyle and Argyres (2004), Lerner and Malmendier (2005), Robinson and Stuart (2004, 2005), and Kocabiyik Hansen (2004). None of these studies has focused on contracts between parties belonging to different institutional environments, such as firms and open-science organizations.

Given the limited extant evidence about the characteristics of contractual relations between companies and open-science organizations, this project contributes to provide such evidence in the first place, and offers a general description of the main characteristics of these contracts. I focus on issues related both to the control of research and to its secrecy. I first offer information on the variation among these provisions, and then look for systematic correlations between these provisions and other characteristics of the research projects and of the parties (both at

the individual and organizational level). In order to explore these relations, I integrate the information in the contracts with information from several other sources.

To be sure, the data do not allow me to perform any structural analysis or to infer any strong causal implications. Aware of these limits, I believe that there is non-negligible value in offering a thorough, descriptive account of industry-university contracts. The spirit of this work is therefore very similar to that of Robinson and Stuart (2005). Like me, these authors aim to provide detailed descriptive evidence rather than to infer any strong causal implication.

The major findings of my analysis can be summarized as follows. Stronger publication restrictions are more frequent in projects concerning earlier phase research and projects with longer duration. Research teams based in hospitals have significantly lower publication delays. Longer project duration is also strongly correlated with higher authority of the sponsoring firm over the direction of research. Teams in more prestigious research organizations tend to be subject to lower control by the sponsor company. Further, younger companies agree on more liberal publication policies. Longer projects, therefore, require company managers to have a more active role in collaborative projects, and call for stronger overview of both the research agenda and the confidentiality of the research. Managers also need to pay attention to the differences that projects in different phases of development present, especially in terms of intellectual property protection. Also, the reason why firms agree on more liberal provisions when they are younger, or when they interact with prestigious researchers, may be related to the presence of additional benefits that firms may receive from these collaborations. From a policy perspective, if we think of stronger publication restrictions and higher control by sponsoring firms over the research agenda as the results of tensions among the parties in industry-university contractual relations (and possibly as the sources of further tensions), the results I obtain can help policy makers (as well as university administrators and technology transfer officers) to predict the situations where these conflicts are more likely to occur. This, in turn, can help policy makers to anticipate the extent and limits of private funding of academic research, and the extent to which private money can substitute or complement public funding.

In Section 3.2, I describe the data collection process, the sources of the data, and the coding of the information. Section 3.3 is dedicated to the analysis of the data and to the discussion of the findings. In Section 3.4 I infer some managerial and policy insights that emerge from my

analysis. I then conclude, in Section 3.5, with some considerations on future work on the topic. Section 3.6 contains tables and figures that illustrate the analyses of the previous sections.

3.2 Data and variable construction

3.2.1 Data sources and selection criteria

The primary source of data is 550 research contracts I have downloaded from rDNA, the website of Recombinant Capital (ReCap), a San Francisco based consulting company specializing in the biotechnology industry. One of the services ReCap offers is the collection of contracts between biotech companies, between biotech and large pharmaceutical companies, and contracts between companies and university and other open-science research organizations.

Previous studies have employed this database as the source of contract data. These include Lerner and Merges (1998), Higgins (2004), Lerner and Malmendier (2005), Robinson and Stuart (2004, 2005), and Baker et al. (2004). The procedures Recombinant Capital uses in collecting these contracts and in categorizing them are discussed in some of these works, such as Lerner and Merges (1998) and Lerner and Malmendier (2005). The reader is referred to these papers. I focus, here, on some peculiarities of my data collection process, and on some differences from previous works.

First, I select contracts in which one of the partners, more precisely the one performing the research, is an open-science organization. All of the existing studies which have employed biotech contracts have expressly excluded this subset of deals from their sample, with the claim that they represent a special category that needs to be analyzed separately. This is what my study plans to do.

Second, most, if not all of the existing studies, are limited to those contracts for which Recombinant Capital provides an analysis, i.e. a standardized summary of the main features and provisions.[1] In contrast, I have collected, analyzed, and coded the actual contracts. The advantage of using the ReCap analyses is that they are easier and quicker to read, since they are standardized and much shorter than the actual contracts (a typical analysis is about four pages,

[1] Some studies (Kocabiyik Hansen 2004, Robinson and Stuart 2004) limit their evidence to the front page of each deal, as provided by ReCap regardless of whether the actual contract or the analysis are available or not.

while a contract can reach thirty to forty pages). Moreover, ReCap analysts try to complement the data from the actual contracts (for example when some provisions are redacted) with information from other sources. However, the standardization of the format leaves out some potentially relevant and more detailed information, especially on such issues as restrictions on publications. In addition, only a small subset of the contracts are analyzed by ReCap. These contracts tend to be the most recent ones and also involve the greatest amounts of financial resources.[2] Limiting a study to the analyzed contracts can therefore lead to serious selection problems that can put the representativeness of the sample under question. Finally, ReCap charges twice as much money for the access to any single analysis as it does for the access to actual contracts. With the same (limited) budget, therefore, an option for a study of the actual contracts doubles the available sample.

I adopted some additional criteria in selecting my sample. The contracts collected by ReCap includes several deals, from research agreement, to licensing deals. to marketing and commercialization contracts. For each contract, ReCap elaborates a front page that reports the 'nature' of the contract. I collected all of the contracts within the University-Pharma and University-Biotech categories that included some form of research activities as broadly defined (contract research, research collaboration, development and co-development agreement, joint ventures with research purposes). I left out, for example, contracts exclusively describing licensing deals. There are about 500 such 'research-related' contracts. A large percentage of them, unfortunately, could not be used for this analysis. Within the University-Pharma and University-Biotech categories, ReCap includes also deals between companies and such Federal and State Agencies as the NIH or the USDA. I excluded these contracts because they may be inherently different from those between 'private' actors. Moreover, and more important to note, in several contracts most information on many provisions is redacted by the involved parties for confidentiality reasons, thus rendering these contract hard to code and use of the analysis. Finally, some contracts reported as 'research' deals are instead only licensing deals; I discarded these as well. The contracts I determined to be usable for my analysis are 283 (and, also among these, it was not possible to code some provisions). These contracts involve 139 academic and

[2] See Lerner and Malmendier (2005) for a discussion of these limits

other non-profit research institutions, and 159 biotech companies.

I then read the contracts and coded the major characteristics and provisions of interest. Each contract was read at least twice, in different periods, in order to ensure some consistency in my coding.[3]

3.2.2 Variable construction

I coded restrictions to publication by considering whether a contract included the possibility for a firm to request that the submission of a publication to a journal was delayed beyond the date that the research team at the open-science organization would have submitted the paper. Delays are typically requested in order to file a patent application or, more generally, to protect some confidential information. However, these delays often exceed the time necessary to file a patent application, and reflect a more general demand for secrecy by the firm. In some contracts, the company has no such rights and can at most check an article before it is actually submitted. In addition to counting the number of days of the submission delay, I also defined categorical variables by setting some cutoffs. First, I defined a categorical variable which separates contracts with no publication delay from contracts with any positive level of delay.[4]

[3] Contracts were read the second time several months after the second time. While this by no means eliminate a 'recall bias', it should reduce this concern. Several contracts were read a third time in order to solve doubts on the coding of some provisions.

[4] Contracts do not always describe the publication policy in a standardized, homogeneous way. There are, however, some recurrent verbal formulae, which reduce (though not completely eliminate) the risk of arbitrariness in coding publication delays. In general, the research partner is required to send to the company sponsor a draft of the manuscript before the planned submission date. The firm, in turn, analyzes the paper and may or may not be allowed to ask for an additional delay to submission, beyond the planned date. I take the submission date as the date in which a paper would have been submitted for publication, were the researchers not be subject to any restriction. Here are three cases that I coded as 'zero delay': [1] 'PRINCIPAL INVESTIGATOR shall have the right to present or publish the results of the research [...] and shall provide an early draft [...] for review by [Company's name] at least thirty (30) days prior to its presentation or submission for publication. At the end of such thirty (30) days, PRINCIPAL INVESTIGATOR shall have the right, in his/her discretion, to make such presentation or to submit such manuscript for publication'. [2] 'It is anticipated that the Institute may publish information regarding [...] findings made by Institute employees under this agreement. [...] Institute agrees to submit a copy of the proposed publication to the sponsor preferably at least 60 days prior to, but in no case later than simultaneously with submission for publication. [...] In no case shall publication be delayed longer than 60 days after a copy of the planned publication is furnished to the Sponsor.' (This second case allows for some more discretion, but the delay can in fact be zero, in other words the research partner is not required to delay publication after a planned date). [3] '(Company's name) will be furnished with a draft of any proposed publication [...] at least 30 (thirty) prior to submission. At the expiration of such thirty (30) day [...] period, the investigators may submit such manuscript [...] for publication.' Following are a case of 60 days,90 days and 540 days delay, respectively. [1] 'UNIVERSITY will submit any material to SPONSOR for review at least sixty (60) days prior to planned submission for publication. [...] Publication of any commercially prejudicial material shall be deferred, at the request of SPONSOR [...], however, such deferral shall in no event exceed one-hundred and

I then distinguished between delays equal or shorter than sixty days, and longer delays. This threshold is considered by the NIH as the maximum appropriate delay to which a university lab agree upon when negotiating a research collaboration with a company (see NIH 1994). Recall that, in the life sciences, articles are reviewed in about four or five weeks within submission. It is estimated that, in one of the most prestigious journals, *Science*, the time from first submission to publication is three months (see Abelson 1990). Therefore, a delay of two months comes to be perceived as a substantial one.

I have coded several provisions related to the control and monitoring power of the company over the performance of the research project. They include the exclusive right for the company to terminate the contract without cause, to change the direction of the research, and to extend the duration of the research beyond that which was contractually agreed upon; the obligation for the open-science partner to propose a research budget in order for the research to be continued, with the approval of the company partner; the presence of a dedicated project management body, or the provision of periodic meetings among the parties; and also 'monitoring' rights like the possibility for company employees to visit the premises where the research is conducted, and the obligation for the open-science partner to send periodic reports on the progress of the research. Most of these control-related provisions have been used also in previous works (see for example Lerner and Merges 1998, Lerner and Malmendier 2005, and Robinson and Stuart 2005). In order to have synthetic measures of the control rights of the company partner, I summed up some of the dichotomous control variables. I first defined a 'stricter' measure of control, composed by those provisions considered to have a stronger impact on the company's ability to affect the research agenda: exclusive termination rights; budgeting duties of the open-science partner; and a company's right to extend the research or to change its direction. I also defined a 'broader' measure of control, into which I added the presence of a project management body,

twenty (120) days from receipt by SPONSOR of the materials.' (Notice that the 120 days are calculated starting from receipt by the company, which is required to occur 60 days before planned submission for publication. Therefore, the *additional* delay is 60 days). [2] '(University's name) agrees to provide Sponsor with copies of any publication or notify Sponsor of any public presentation relating to the research 30 days before disclosure for review and comment. Sponsor may request that disclosure be delayed for an additional period not to exceed ninety (90) days total [...].' [3] '[...] the proposed publication shall be provided to the patent counsel of the sponsor. [...] patent counsel shall have a period of sixty (60) days to review the publication. [...] the research steering committee may in no event delay publication for the longer of (i) eighteen (18) months from the date of discovery of the results to be published or (ii) eighteen months from the date of filing of a U.S. patent application [...].'

or the explicit provision of periodical meetings among the parties, to the strict control measure. While meetings and management bodies do not directly express the right of the company to define the research agenda, the company can exert influence over the research by having some of its employees interact with researchers from the open-science organization on a regular basis. I then defined categorical variables to distinguish cases in which the firm had any one of these rights from cases in which the firm had none.

I also coded several other characteristics of the agreement and the research project as defined in the contracts. These included the duration of the contract, the year in which the contract was signed, the identity of the partners (including their addresses), and the dollar amount invested by the company. The front page generated by ReCap also classifies the contracts according to the phase of the research with which they were concerned: from the discovery phase (before a lead molecule is identified) to studies on the lead molecule, to clinical trials. I categorized the phase by distinguishing the discovery phase from the later phases.

Finally, I coded the previous experience of the partners in similar deals. Using all of the downloaded contracts as the 'universe', I built a variable that recorded whether the open-science partner had previous collaborations with companies, and also coded previous deals with open-science partners by a biotech company. Finally, I also tracked those companies and open-science organizations having had previous deals with each other.

3.2.3 Additional data sources

Additional information was obtained from other sources. In order to define measures of the bargaining power of the open-science partner, I collected proxies for the 'prestige' of the whole organization as well as of the Principal Investigators (PIs) for the specific project. At the organizational level, I obtained data from the National Institutes of Health (NIH) about the annual overall ranking of each organization in terms of funds received by the NIH.[5] At the

[5]In the few cases in which I was not able to find ranking information for the year of the contract, I used information about the closest available year. In general this should not introduce substantial errors. For example, Stanford University has been among the top 10 non profit institutions in terms of NIH funding through the 1980s and 1990s. The dummy variables I construct discriminates between top 50 institutions and all of the others, in a given year. It is therefore reasonable to assume that Stanford was among the top 50 also in 1975, the year in which it signed one of the contracts in my sample but for which I do not have NIH funding information. Similarly, City of Hope has rarely ranked higher than 200th in terms of NIH funding in the 1980s and 1990s, therefore I assumed it did not rank among the to 50 in 1976. Also, MGH has consistently ranked among the top

individual level, I recorded the entire publication history of all of the PIs mentioned in each contract. In addition to the publication counts, I also determined the impact factor of each PI's publications on a yearly basis. I was also able to determine more finely-grained publication and impact factor counts. For example, I limited the counts to the publication in which the PI appeared as first or last author (the first author is normally the one who did most of the work, and the last author is the PI for the project that led to that specific publication). I was also able to exclude publications, such as book reviews or letters, with no real scientific novelty content. I used the PublicationHarvester software, based on the Medline publication database and the ISI impact factor.[6]

In order to account for some company characteristics, I collected information from Annual Reports and SEC files. Some of these documents were easily available from online sources. However, earlier data (for example, those of the 1980s and early 1990s) and information on private companies were not easily available. I was able to retrieve some of this info from the HBS Baker Library Microfiche collections.

A complete list of the information I have collected and the variables I have created are reported in figures 3-1 and 3-2 on pages 151 and 152.

3.3 Data analysis

I analyze the data in three steps. In Section 3.3.1, I offer a basic description of the data. When possible, I compare the characteristics of my sample to those of samples used in previous studies. I then perform some bivariate analyses, in order to identify some correlations of the publication policies and the allocation of control with several features of the research projects and of the collaborating parties. Section 3.3.2 describes and comments on these analyses. Finally, in Section 3.3.3, I describe and comment upon the results from multivariate regression analyses. Figures and tables that illustrate the different steps of the analysis are reported in Section 3.6 at the end of this essay.

40 NIH funds receivers from 1985 to 2000. I assumed that MGH was among the top 50 in the early 1980s too.

[6] See Azoulay et al. (2006). This software allows for high precision in identifying authors and publication records. However it also imposes most of the onus to the end user for the definition of appropriate search queries. Determining the publication records for the about 300 PIs in my sample was therefore a highly laborious and time-consuming task.

3.3.1 Descriptive statistics

Figure 3-3 reports descriptive statistics for the variables that I have created from the sources of information described above. The simple collection and description of this data are contributions in and of themselves, given the paucity of quantitative information and increasing interest on the topic of industry-university research relations.

The contracts span a period from 1975 to 2003. The company partner in the contracts is typically a relatively young biotechnology company. Some companies were founded in the same year in which the contract was signed; therefore the sponsored research represents one of the first activities of these companies. Some companies are 'older', up to twenty years at the moment the contract is signed. The average age of a company is four years. Some of these companies were private at the moment the contract was signed, only to go public in later periods.

Among the open-science partners, about two thirds are universities (or, better stated, teams within universities, or organizations whose one of the primary missions is teaching), while the remaining third is composed of hospitals (possibly affiliated with academic organizations), foundations, and private research institutes. Hospitals are defined as organizations whose primary mission (possibly joint with others) includes patient care.[7]

The average research project described in a contract runs for about 2.5 years, with a range from four months to ten years. About 45% of the contracts have a duration longer than two years. The survey by Blumenthal et al. (1996) on university researchers involved in collaborations with companies in the life sciences shows a significantly lower median and average duration of these interactions.

The majority of the contracts, about 57%, concern research in the discovery phase, with the remaining 43% being composed by research in the 'Lead Molecule' phase for one half, and

[7]Some of these institutes, like Scripps in San Diego, CA also host PhD students and offer some classes. Others, like Fred Hutchinson in Seattle, WA also treat some patients. However, in both cases the predominant mission is research. At Scripps, for example, teaching is only a function of research activities, therefore this institute is not classified as a university. At Fred Hutchinson, a limited number of patients are experimentally treated with bone marrow transplant, however this is not a patient care facility, and its mission is related to research. Therefore, it is not classified as a hospital in my data. Conversely, the mission of the Dana Farber Cancer Institute, for example, if first of all to provide care to patents, while at the same time advancing knowledge through research. Therefore, Dana Farber is classified as a hospital. The majority of cases, like MGH or the Hospital for Sick Children in Toronto, do not present such ambiguities and are easy to categorize.

preclinical/clinical trials and formulation for the other half. Three contracts concern research on devices and are coded as in the post-discovery phase.[8] If compared to collaborations between companies, industrial biotech research sponsored at open-science organizations seems more unbalanced toward early phase research. Robinson and Stuart (2005), for example, find that slightly less than 40% of their 125 contracts concern the discovery phase, a significantly smaller share than that I find in my data. The higher share of early phase projects when collaborations are with academic and other non-profit research organizations is consistent with the theoretical results of Aghion et al. (2005). They show that it is optimal to have universities perform early stage research with commercial potential, rather than profit-seeking organizations.

Approximately 82% of the contracts have both partners based in the United States. The remaining contracts are split in those between an American company and a foreign open-science organization, and those in which both partners are not U.S.-based. Foreign countries include Canada, the United Kingdom, France, Belgium, and Australia. There are no contracts between an American research organization and a foreign company. The number of contracts per company spans from one to then; the number of contract per open-science organization spans from one to eleven.

The average geographical distance between the partners is high: 1,246 miles. However, the distribution is skewed, with a non negligible subset of contract being between co-located partners, and only a few between very distant partners. The median distance is 389 miles.

The average delay to submission of a paper for publication is about 60 days. This turns out to be the maximum reasonable delay the NIH recommends Universities and other non-profit research organizations to agree upon (see NIH 1994, Blumenthal et al. 1996). About 30% of the contracts have a delay longer than two months, and this delay can reach one year or more in some cases. Three out of five contracts with a publication delay of one year or more were signed by the same company, and two of these with the same academic partner. This same company, moreover, has agreed on a shorter delay in another contract of my sample. On the other hand, in about 30% of the contracts no additional delay is allowed. Some open-science

[8] Only one of these three device contracts turns out to be used in the restricted sample I describe below. The project described in this contract consist in the testing of a prototype already realized and patented, therefore it is appropriate to consider this contract as occurring in a later phase than discovery.

organizations, like the Massachusetts General Hospital (MGH), seem particularly strong in obtaining this 'openness' condition. In no case may a company partner require the suppression of a publication. This contrasts with comparable data on biotech research contracts between companies. For example, among the 200 contracts analyzed in Lerner and Merges (1998), 19% allow the sponsor firm to suppress publications of the research partner. Given the number of observations in their sample and in mine, this 19% amount is significantly different from zero at any statistical significance level.

About one quarter of the contracts give exclusive termination rights to the company sponsor, while about one third grant this right to both partners. In about ten percent of the deals, the open-science research partner is required to submit periodic budgets and research proposals, subject to the firm's approval, rather than having a (possibly multi-year) budget defined at contract time. A specific project management body is instituted in less than 10% of the contracts. Reports and inspections are more frequent, while exclusive rights for the company sponsor to extend or to modify the research content are rare. We can, again, compare this data to previous studies from the same database, but concerning deals between two companies. Robinson and Stuart (2005) find that about half of the contracts between two companies they examined grant exclusive termination rights to the sponsor, a significantly higher proportion than the one in the contracts I analyze. About 70% of the contracts include at least one of the broadly defined control rights for the firm, while in about 30% of the cases the sponsor firm is granted one of the more strictly defined rights to influence the research agenda.

Approximately half of the open-science organizations are among the top 50 worldwide recipients of NIH funding in the year before the contract is signed. The average 'cumulative impact factor' for a PI up to the year before the contract is 178.

The low average age of the companies, and the characteristics of a science-based sector, are reflected in the financial data. Most companies have limited sales at the time of signing the contract, and most of them are suffering net losses. By contrast, the Research and Development (R&D) expenses are very high.

3.3.2 Bivariate correlations and conditional distributions

In order to provide a first cut at the relationships of publication restrictions and control allocation with several other characteristics of the research projects and of the parties (both at the individual and at the organizational level), I performed a series of bivariate analyses, including pairwise correlations, mean comparisons, and contingency tables for different groupings of the data. Tables, graphs, and figures from page 154 to page 163 below provide 'visual' evidence for the results. Overall, 180 observations are used for analyses concerning publication delays, while 201 observations are used for analyses involving control rights. These are the highest numbers for which observations of all variables used in the regression analyses (see Section 3.3.3 below) are available (excluding fixed-effects regressions for which a lower number of observation is used). In order to make my comparisons across different analyses more consistent, I limited the number of observations to the numbers mentioned above, rather than using all of the available observation of each pair of variables. It turns out that the results are very similar when the full sample for each pair of variables is used.

Additional delays to publication are more frequent when the research project is in the discovery phase. It can be argued that, when the project is in an early phase, a given compound has not yet received any (or has received only limited) patent protection. Furthermore, due to the plausibly incomplete information on the potential of a given research result, defining the Intellectual Property Rights (IPRs) over this result may take some time. However, very long delays do not seem to be required, for there is no systematic relationship between publication delays beyond 60 days and the phase of the research.

Longer delays characterize longer research projects. Projects with a longer duration appear also as involving greater amount of financial resources (see figure 3-13); therefore, we might expect firms to be more sensitive to IPR protection, and possibly research partners to be more willing to agree on longer delays, given that they are being supported for greater financial amounts. More generally, longer projects imply a greater commitment by a company; thus we can expect more sensitivity to IPR protection by companies. Early phase projects, moreover, seem to require longer time for completion (see again figure 3-13); this may confound our ability to distinguish the impact of duration on publication delays from the impact of the phase of the

research.

Interestingly, universities, unlike other non-profit research organizations, seem to allow on average for longer delays. In particular, hospitals seem able to obtain the highest research openness: less than ten percent of hospital-based research teams are constrained by a publication delay longer than 60 days, against an overall frequency between one quarter and one third. This fact can in part be explained by hospital-based teams performing post-discovery research with higher frequency, and engaging in projects with shorter duration (see the correlation tables in figure 3-4 and the contingency tables in figure 3-13). However, both the difference in average publication delays and the much higher occurrence of no delay at all (see figure 3-10), hint at some additional peculiarities of hospital-based teams. Moreover, as shown in the contingency tables on page 163, there is a non-negligible number of hospital-based teams engaged in discovery/early phase research. Prominent institutions like the Massachusetts General Hospital and Sloan Kettering Cancer Center are well-known to be engaged in basic research. To a more accurate look at the single data points, in fact, this higher openness appears to be due in large part to a few organizations, such as MGH, where researchers are very reluctant to grant publication restrictions of any sort. Conversations with company managers involved in deals with several open-science partners, and with MGH researchers confirmed this fact.

American open-science organizations are significantly less likely to agree on publication delays, and especially on long delays (see the correlation tables at page 154). This may derive from some requirements of U.S. public agencies, such as the NIH, to limit the concession of delay, while such requests may be looser in other countries.

The overall 'prestige' of an open-science organization, as expressed by the ranking in NIH funding, is not correlated with publication delays, while the prestige of the Principal Investigator is weakly negatively correlated to the presence of long publication delays. Prominent scientists may be therefore able to obtain better deals in terms of their ability to promptly diffuse their findings. In turn, firms may be willing to be less secretive in exchange for the services of major scientists.

While a company's size (as expressed by the value of its assets) is not significantly correlated with publication delays, contracts with very young companies (just founded or one year old at contract signing) are characterized by shorter delays to publication. These younger companies

may have a lower bargaining power, or may still be affected by the 'academic background' of the founders, when these founders are scientists. Finally, a younger company might prefer more openness in order to achieve quick visibility and reputation. The alignment of interests between the parties would therefore be higher.

Contracts concerning early phase research command stronger control for the company partner. However this relationship seems stronger for less 'strong' rights (the relationship is significant for the broad definition of firm control–see figures 3-4 and 3-7) than for the ability to influence more explicitly the research agenda.

The strongest predictor of the level of control by a firm appears to be the duration of a research project. If research is such that a longer amount of time is predicted for completion, then a firm exerts, as witnessed in the contracts, a stricter authority over the project management and performance. This is discussed in more detail in the description of multivariate regression results in the next session; however, I state here that longer projects imply a greater commitment of time and resources by companies. Also, unforeseen contingencies are more likely to occur (ex ante) if the projects last longer, and the sponsoring party might want to keep the prerogative to terminate (and possibly re-negotiate) a deal. The duration of the project is strongly and positively correlated with all of the different measures of control, as well as with most of the single provisions that compose these synthetic measures (see figure 3-7 at page 157).

Figures 3-4 and 3-7 show that, unlike the case of publication delays, there is no clear trend in the allocation of control rights to the sponsoring company over time. An interesting exception is represented by budgeting duties for the research partner, which seem to have declined over time (see figure 3-7 at page 157, and the bottom chart in figure 3-8 at page 158). This pattern may simply be due to the few instances in which open-science partners have budgeting duties (around thirty instances overall), so that even small absolute variations have greater impact on percentages. However, the finding also calls for further investigations into those control provisions that received greater attention in the earlier days of industry-university relations in biotech, than they have in more recent years. A series of interviews with technology transfer officers as well as in-depth historical analysis would be appropriate.

Other relevant control provisions, such as unilateral termination rights without cause for the sponsoring company, do not show any time trend. However, as the table at page 157

displays, research teams based in open-science organizations that differ from universities, and notably hospital-based teams, are associated with a significantly lower frequency of unilateral termination rights by the sponsor. Together with the findings on publication delays in different open-science organizations discussed above (page 138), these results hint at some possibly substantial differences among types open-science organizations. Termination rights are also slightly more frequently associated with projects in the discovery phase. It can be argued that a company has not committed substantial resources at these early stages, and is more worried about the possibility to exit the relation promptly and before further investment.

Among the 'stricter' control provisions, the allocation of termination rights is that which is the most present in the contracts (though apparently at a lower rate than in research contracts between firms, as discussed above and as shown in the descriptive statistics at page 153). Conversations with managers of biotech companies and with officers in technology transfer and sponsored research offices of a few open-science organizations confirmed that this right is perceived as an important one, and as a possible source of conflict among the parties. Termination (possibly followed by renegotiation, I conjecture) appears therefore as the main channel through which a company exerts some control over the agenda of the projects it sponsors in academic and other open-science institutions. Other channels like periodic budget duties are less frequent. Still others, like the unilateral right to modify the direction of research, or to extend the duration of the project, are very rarely present.

As for the broader control provisions, periodic meetings are explicitly defined in about 40% of the contracts. These meetings are significantly more likely to be defined for projects in the discovery phase than for later stage projects. One may argue that, in earlier phases of a project, information is more incomplete, and both the beliefs and interests of the parties are more likely to diverge. Periodic meetings can therefore help smoothing these divergences. Interestingly, longer projects do not differ from shorter ones along the provision of periodic meetings. Companies seem to deal with the challenges related to longer projects through provisions that imply a more direct intervention over the research, than simply through meetings.[9]

[9] Interestingly, the institution of a dedicated project management body is significantly more likely for projects with longer duration. A specific management body or steering committee is arguably a more direct and influential form of control than generic meetings among the parties' representatives. Since there are very few occurrences of this provision, I do not perform any more systematic statistical analysis with it. I make the same choice for

Finally, one should note that there is a positive relationship between the prestige of a PI and the distance between the parties. This is consistent with the arguments and findings of Mansfield and Lee (1996), who argue that companies move farther away from their geographic regions in search of academic partners, only if the quality of the scientists is very high and cannot be found locally.

3.3.3 Regression analyses

While indicative of some general patterns in the data, and possibly stimulating further theoretical and empirical inquiries, the bivariate relations discussed in the previous section may hide spurious correlations due to the co-variation of other variables. In order to detect correlations between the variables of interest in a more systematic and convincing way – i.e. while keeping all other variables constant – I performed multivariate regression analyses. I first used several indicators of publication delays as dependent variables, and then some indicators of the company's control over the research. Results are reported in the last two pages of Section 3.6. Most of the analyses I performed have categorical values as left hand side variables.[10] In the regressions with control provisions as dependent variables, I used the two aggregate measures of control, more precisely on dichotomous variables having value zero if no control right is attributed to the company, and value one if at least one of the rights that composes the aggregate measures is given to the firm. This choice is meant to control for outliers and for the

the two 'stricter' control rights that appear only rarely in the data: the company's unilateral right to extend the duration of the project, and the company's unilateral right to change the content and direction of the research.

[10] In particular, I report here regression results where the publication restriction variables are a dummy for whether any post-submission delay is defined at all, a dummy for whether such delay is greater than 60 days, and a trichotomous variables for zero delays (value 0), positive delays no longer than 60 days (value 1), and delays longer than 60 days (value 2). Using these categorical variables allows us to distinguish between different types of delays, with cutoffs consistent with what the scientific community (especially in the physical and natural sciences) considers more or less 'acceptable'. Therefore, the regression results are easy to interpret. Moreover, by defining different dependent variables with different cutoff points, one can also distinguish between variables correlated with long, less acceptable delays, and those correlated with the presence of any delay at all. In regressions not reported here, I have used the number of days of publication delay as the dependent variable. I also made some corrections are made in order to account for outliers, such as the few cases of publication delays longer than 200 days – for example by using the natural logarithm of the number of delays (setting ln(0)=0, or using ln(publication delay+1) in order to deal with the presence of zeroes) or by running negative binomial models (the dependent variable is non-negative and discrete, and negative binomial techniques are less sensitive to outliers than standard Poisson regressions, because they weights for over-dispersion). Notice that also the use of categorical variables is a way to reduce outlier issues. Especially when these corrections are made, results are consistent with those reported in the tables below.

skewed distribution of the aggregate control variables toward zero.[11] Among the single specific provisions, I performed regressions only on a company's unilateral termination rights, since this appears to be the most relevant single control right.

Ordinary Least Squares (OLS) regressions (or linear probability models) with robust standard errors were employed; probit and logit regressions convey very similar results. In the tables reported below, I also show some preliminary results from fixed effect regressions, with the open-science organizations being the cross sectional unit of analysis. So doing, I control for invariant, unobservable characteristics of open-science organizations – for example, the specific 'philosophies' of Technology Transfer offices; these apply to all of the research labs in a given organization. In order to perform these panel analyses, I needed to limit my sample to the cases in which an open-science organization had signed at least two contracts. In addition, fixed effects regressions further reduce the degrees of freedom. These results need therefore to be taken with caution.[12]

Regarding the project, company, and research organization characteristics that are correlated with publication restrictions, the effect of the phase of research over the probability of not having any delay to publications 'resists' the series of additional variables I partialed out from the regression. The duration of the research project, as well, keeps a very strong, stable and robust positive effect on the various degrees of publication restrictions. In addition to what said in the description of the bivariate analyses, we can argue that a project in an early phase, as well as a project that is supposed to require a longer time to be completed, is more likely to be a more complex project. Therefore, the definition of IPRs over the research may require some extra time. Moreover, in a longer project, researchers may also be publishing partial results, and a company may be more reluctant to allow for this, which can compromise its ability to capture value out of the competed project if information leaks out before completion.

Research teams in hospitals are significantly more likely to keep their research as open as they would have without company funding. This result is consistent with the finding of

[11] Exercises with the actual number of rights as dependent variable convey very similar results.

[12] As can be seen from the regression tables, I do not report regression results where financial variables are included among the regressors. Regressions including these variables did not show any improvement and the coefficients associated to these variables are not significant. Moreover, I was not able to collect information for all of the companies. The sample since would shrink further were the financial variables added. Therefore, for the moment I leave them out, planning to explore more in depth their effect once additional data will become available.

Seashore Louis et al. (2001), who show that in the life sciences clinical faculty members are less secretive in their research than non-clinical faculty members. The negative estimated coefficient is significantly different from zero in the regression with no delay as the dependent variable, and in the regressions with the trichotomous distinction of degrees of delay. It seems, therefore, that hospital-based teams characterize themselves especially for the absence of any form of delay than for the level of the delay. Notice also that the regressions control for phase and duration, and still the estimated coefficient on 'Hospital' is significant is several cases; therefore, as argued in the previous section, the fact that hospital-based teams are more likely to undertake shorter and later phase projects does not entirely explain the higher openness that these teams show.[13] As in the bivariate exercises, private universities do not present any systematic peculiarity.

More prestigious scientists are less likely to be given stronger restrictions to publications, but this relationship disappears when fixed-effects for the research organization are added. The overall prestige of an organization is negatively associated with the probability of imposing a publication delay of any length in the fixed-effect exercise. Since fixed effects are used, this result says that, in periods in which an open-science organization is highly ranked in terms of NIH funding, researchers in this organization obtain better 'openness' conditions from company sponsors. The presence of higher NIH funds in a given period may also increase the bargaining power of the research partner, since it is more likely that alternative funds are available. The value of the estimated parameter on the variable NIH_top50 (see column 5 of the first regression table), however, is very large and leads to some doubts about its consistency. The size of the sample as well as the fact that there are only very few cases in which an open-science organization ranks within the top fifty NIH receivers in some periods, and below the top fifty in a different period, should make us cautious in interpreting this value.

Another fact that emerges from this study is that restrictions to publications of any sort have been more often introduced in more recent years than in the 1970s and 1980s (see also the graphs at page 156), though the evidence is stronger in pairwise correlations than in multivariate analyses. Several scholars have noticed an increasing acceptance across universities, over time,

[13] As mentioned in the previous section, these peculiarities of hospital-based teams may be due to a few major organizations that are present with multiple contracts in my sample, notably MGH. I performed some exercises with a dummy for MGH among the regressors, and I also excluded the ten observation where MGH team are involved. The estimated coefficient on MGH is significant and slightly weakens the significance (but does not change the sign) of the 'Hospital' variable. More generally, results are very similar in these unreported exercises.

of the fact that researchers receive money from industrial sponsors, and of the different rules that these relations require. It is therefore plausible to expect more recent deals to include some form of additional secrecy in research. Note also that the majority of the contracts have been signed in the last fifteen years (see the descriptive statistics at page 153).[14] The positive relationship between age of the company and restrictions to publication keeps its statistical significance even when the relationship with the other regressors is partialed out, therefore making sponsor's age a major predictor of the level of openness in industry-financed academic research. Plausibly, younger companies have lower bargaining power, and may compensate for a reduction in secrecy with an increase in visibility and access to scientific network, by having the research performed on their behalf promptly published. In the mean comparison table in figure 3-5, I also show that prestigious PIs have especially lower average publication delays in younger companies (due to the small sample size, I do not obtain strong statistical power, however). Younger companies may benefit more from dealing with a more respected scientist. While this require more detailed scrutiny, a preliminary and incomplete search of the companies' founders shows that, in some cases, academic scientists (and even the PI of the collaborative project under exam) are among a company's founders, and the research described in the contract is one of its first activities. This can also explain why 'newborn' firms agree on greater openness.

Consistent with the findings in the bivariate exercises, deals between American partners are less likely to include major delays to publication. The geographical distance among the parties, as well as any previous experience of academic-industry collaborations, do not show any significant co-movement with publication restrictions.

The positive impact of project duration upon the level of company control over the research is robust to different empirical model specifications, and appears as the variable most strongly related to company influence. As mentioned above, it can be argued that, since the project is longer, the company is committing more resources (not only financial) and is more dependent upon the outcome of the project; it therefore asks for a stronger ability to influence its direction. Also, the longer the project is supposed to last, the more likely that unforeseen contingencies

[14] Regressions using a time trend rather than a dichotomous variable for period convey similar if not stronger results, with a positive and significant coefficient associated to the time trend variable. Regressions with year dummies convey similar result as well, however the coefficients associated to the dummies, while showing a clear increasing trend, are not jointly significant. I suspect this may be due to the small sample size and to the small number of observations in some years.

can happen, and the company might want to be able to modify or even terminate the originally agreed-upon project more promptly (on this point, see also Chapter 2). The phase of research (even when coded according to different criteria, e.g. by grouping the discovery and lead molecule phases together) is not an adequate predictor of the sponsor's control. This is also the case for termination rights, which resulted as weakly correlated with the project being in earlier phases in the bivariate analyses described in the previous section. The positive correlation is still present, but it loses statistical significance. This result also counters the results of Lerner and Malmendier (2005), who find a positive relationship between unilateral termination rights and the research being in earlier phases.

As in the bivariate analyses, tighter control is more likely to be exerted by firms over university-based teams than over teams based in other research organizations; however, the regressions do not have enough statistical power to reach statistical significance in all cases. Teams in more prestigious organizations (and that attract more public funding) keep higher control over the research. Plausibly, a company is more willing to allow a project to take directions it does not completely approve when highly talented people are working on the research. Also, having a tie to a prestigious research organization may generate extra-benefit for a company; therefore, companies may enjoy other types of returns, even if the projects turn out to fare poorly in economic terms. See Mansfield and Lee (1996) for similar considerations. While publication restrictions appear as related to the prestige of the PI directly involved in the project, the authority over the research conduct is related (albeit weakly) to the prestige of the open-science partner overall. The data constraints and the noise in the variables chosen to proxy for prestige might explain these findings. However, the locus of bargaining may not be the same for different provisions. Prominent Principal Investigators, for example, may be particularly influential in guaranteeing that the research results are promptly diffused in the community of peers, while administrators or organizational guidelines may deal, say, with termination rights for the company sponsor. The finding that publication delays seem to have changed, on average, over time, while most of control rights have not, may be seen as consistent with this interpretation, if we believe that decisions taken at a more aggregate level in an organization are slower to change than choices delegated to single individuals or small teams. More generally, the fact that control rights have fewer and weaker correlations with other characteristics of the

contracts and of the parties than publication restrictions, may indicate a greater stability or inertia of these provisions. More detailed analyses and case studies of guidelines for sponsored research and of the bargaining processes would help to substantiate these conjectures. Just as geographical distance and previous contracting experience do not appear as strong predictor of publication restrictions, so these dimensions are not significantly correlated to the allocation of decision power among the parties.

When introduced in the regressions, fixed effects at the level of the 'open-science' partner are generally jointly significant. There appear to be institutional and organizational characteristics that affect all of the research contracts signed by teams within the organization, regardless of the specific characteristics of the research project and of the parties. It is well-known in the literature that different universities have different attitudes toward relations with industry and technology transfer, with some organizations being more favorable than others, or having moved toward the development of relations with industry earlier others, or both (Feldman and Desrochers 2004, Mowery et al. 2004). I conjecture that these differences are among the main determinants of the statistical significance of the fixed effects. However, as noted above, the small size of the fixed-effect sample leads me not to stress these results too much. Additional data and further analyses are necessary.

3.4 Managerial and policy insights

The variety of data sources that provide the information of my study allows an analysis of the relationship between some major provisions of 'industry-university' research contracts, and several characteristics of the project and of the parties. This, in turn, allows for a number of managerial and policy considerations.

From a managerial standpoint, this study offers insights about those characteristics of a research project and of an 'open-science' partner that may lead a firm either to reinforce the control over and the secrecy of the research, or to delegate more power over the research agenda and the diffusion of the results to the research partners. Projects that require a longer time commitment, for example, may require a firm to be more directly involved over the research, and also to monitor the protection of Intellectual Property Rights more closely. On the other

hand, a firm may trade off the prestige of the research partner for a reduced influence over it, possibly hoping for extra benefits from the research through additional channels, such as higher productivity and likelihood of success, higher visibility, and access to high-end scientific networks. A few existing studies have found that these channels are indeed highly considered by companies (Cohen et al. 2002, Agrawal and Henderson 2002). For example, start-ups may face a trade off between letting the research results be freely available as soon as possible, so as to enhance the firm's visibility, and protecting their (ill-defined) intellectual property. Companies also need to pay attention to the phase of the research in the definition of contractual provisions related to the protection of intellectual property. As shown above, early phase research projects may require additional forms of protection and therefore additional negotiation with the academic partners concerning some form of publication delay. A more general insight from this analysis is that companies seem to recognize (or academic organizations are able to impose) the specific status of their open-science partner, by agreeing, in the majority of cases, to relatively mild forms of control.

Regarding policy considerations, the risk of excessive secrecy and diversion of the research agenda when academic research is sponsored by industry has received a great deal of attention in recent years. In this respect, a first contribution of my study is to quantify these problems, by offering detailed data on such issues as the frequency of publications delays and their lengths, and the kind of control rights over the research industrial sponsors retain. The study also informs about the type of companies and of open-science organizations that are more likely to manage in these inter-institutional agreements. Second, my regression results point out some relevant associations with policy implications. For example, stimulating collaborations on early, basic research or on longer projects may imply that academic organizations accept stronger control and secrecy over their research. Also, pushing for the substitution of public money for private resources may have different effects for highly-respected (and highly publicly funded) institutions than for the less prestigious ones. Since the latter group is more likely to be in need of money from private sources, we should also expect to observe more restrictive contractual provisions. My finding about the more liberal provisions in contracts involving hospitals (and more generally teams based in open-science organizations different from universities) should induce policy scholars to investigate the differences between teams affiliated with

medical institutions as opposed to other public research organizations, and in particular the features of some hospitals like MGH, where freedom and openness of research are raised to their extreme level in almost of the deals that I have analyzed. In fact, a valuable complement for my large-sample study would the to conduct a series of case studies that follow the creation of specific contracts, in different organizations, from the moment the parties establish a contact, to the negotiation phase, to the conduct of the research and its outcomes. The result of this multi-method analysis may give us insights into whether there in fact exists a unique scientific community with shared rules, or different institutions in the scientific community are committed to different sets of rules and respond to different incentives. Finally, by pointing out the circumstances under which contracts include potentially more controversial provisions, my analysis contributes to an identification of the situations in which contrasts may emerge between academic and industrial partners. This, in turn, would help to define the feasibility of these research relations, and to predict the extent and directions they might take over time.

3.5 Limits and future work

The proposed analysis is limited by several data constraints, some of which are highlighted above. Such relevant information as financial data is available only for a subset of the companies; additional effort to retrieve company financials is necessary. The analysis would also benefit from a more detailed knowledge of the activities of the academic researchers involved in the projects. Were the PIs actively involved in the sponsoring companies, for example as members of the Scientific Advisory Boards, at the time that the contracts were signed? Were they in the founding team? Does this more direct involvement reflect in any contractual provision, such as the acceptance by the PI of stricter restrictions to publication? Just as more detailed information at the level of the single researchers is important, so is information at the organizational level. For example, many universities and other non-profit research institutions have changed their guidelines on conflicts of interest and commitment over time, as well as their guidelines on the type and degree of acceptable restrictions by company sponsors. These organizations, moreover, typically differ among each other along these dimensions in any given period. Acquiring this information would facilitate the isolation and appropriate quantification

of the impact made by institutional constraints on single contractual relations. With reference to the results described above, this more detailed information might assist in explaining, for example, why publication restrictions seem to be correlated with the prestige of the single investigator, while the allocation of authority over the conduct of the research appear as related to the status of the whole research organization. Also, a higher number of data points would allow splitting the sample across some relevant dimensions, e.g. the prestige or the type of research organization, or the historical period, in order to assess whether the relationships described above hold differently for some subsets of observations.

The collection of these sets of information is going to be extremely difficult, especially if the required data come from far back in the past, e.g. from the 1980s or the early 1990s. There is no guarantee, in fact, that these data are available for a sufficiently large and heterogeneous set of research organizations, scientists, and companies. For this reason, an alternative strategy would be to focus on a small number of cases, rather than on large samples, and to proceed through qualitative, archival, and historical inquiry, as well as through interviews, rather than through statistical analyses.

Further insights into research collaborations between companies and research organizations can be obtained by changing the unit of analysis, the dependent variables, and the industry. The study at the contract level could be complemented with an analysis of the characteristics and the behavior of the single Principal Investigators. Do scientists who perform industry-sponsored research differ from the 'average' researchers in any relevant manner? I am currently in the process of collecting bibliometric as well as demographic information on the PIs mentioned in the research contracts I have analyzed. I am using a plurality of sources, which I aim to complement with a set of direct interviews. I plan to define an appropriate 'control sample' of scientists, and to compare such features as age, education, and scientific productivity between the two groups. An appropriate control sample may be composed, for example, by a random selection of scientists from the same department where the PIs in my contracts were working. Also, is the type, rate, and direction of scientific activity of these PI affected by their participation in industry-sponsored research? Existing studies have tested for the complementarity vs. substitutability between scientific and commercial work using patenting activity as the proxy for commercial activity – a clean but rather imprecise measure, especially in those fields like the

life sciences where also basic research results are patented, and the sheer patenting process is delegated to the Technology Transfer Office. Actual interactions with companies, for example in the form of sponsored research, are more accurate measures, though collecting full information about these relationships appears to be difficult, as well solving obvious endogeneity issues in any statistical analysis.

As for alternative constructs of interest, my study does not allow to say anything about the outcomes (both commercial and scientific) of the research projects described in the contracts. It would of course be of great interest to track these projects beyond the moment in which the contract is signed, and possibly to relate different types of outcomes to the contractual provisions. Again, integrating large sample statistical analyses with in-depth studies of a few instances appears as a promising approach.

Finally, it surely is time to move the study of industry-university relations beyond biotechnology and the life sciences, and toward other fields of research and industries. The focus on biotech has been motivated both by the availability of data, and by the relevance that this sector has both for managers and for policy makers (and these two reasons of course depend on each other). However, industry-university relations have been present in other areas as well – for example in chemicals and semiconductors – and are also developing in such new fields as nanoscience and nanotechnology. Additional information on these sectors, and comparisons with fields where data and analyses are already available, are in order.

3.6 Figures and tables

Variable name, description and proxied constructs	Source
Pub_Delay: longest delay the company can ask to the submission of a paper to a journal, beyond the submission date defined by the PI and his/her team **Pub_Delay0**: =0 if the company cannot ask any delay to the submission of a paper to a journal, beyond the submission date defined by the PI and his/her team; = 1 otherwise. **Pub_Delay60**: defined as Pub_Delay0, but with 60 day delay as the cutoff. 60 day is the maximum 'acceptable' delay a university should allow for, according to the NIH. Notice that the average time from first submission to publication in Science is about 90, and reviews are sent to author in 4-6 weeks of submission. Therefore a 60 days delay is a substantial one in the Life Sciences. **PubDelay0_60_more**: =0 if no delay; =1 if the delay is >0 and <=60 days; =2 otherwise *These variables are meant to proxy for the degree of openness vs secrecy of the contract research.*	Contracts (Recap)
Proj_manag_body: =1 if the parties establish a dedicated committee to supervise the project; =0 otherwise **Other_Meetings**: =1 if the parties are required to regularly meet; = 0 otherwise **Either_term_rights**: =1 if either party can terminate the research 'without cause', e.g. not for specific reasons (bad performance, ...); =0 otherwise **Firm_sole_term_right**: =1 if only the company partner has the riegh of termination without cause; =0 otherwise **Uni_budget**: =1 if the 'open-science' partner is require to periodically send proposals (research and budget) in order to obtain funding for the following period; =0 o/w **Uni_report**: =1 if the open-science partner is require to send reports on the state of the research; =0 otherwise **Firm_inspection**: =1 if company people can enter the open science partner's lab and inspect the work; =0 o/w **Firm_extend**: =1 if the firm has the exclusive right to extend the duration of the research contract; =0 otherwise **Firm_modify**: =1 if the firm has the exclusive right to modify the direction and content of the research; =0 otherwise	Contracts (Recap)
Control: sum(Proj_manag_body, Other_Meetings, Firm_sole_term_right, Uni_budget, Firm_extend, Firm_modify) **Control0**: =1 if control>0; =0 otherwise. **Control_Strict**: sum(Firm_sole_term_right, Uni_budget, Firm_extend, Firm_modify) **Control_Strict0**: =1 if Control_Strict >0; =0 otherwise *Control_Strict is meant to capture the subset of decision rights which appear to have a stronger and more direct impact on the direction of research*	Contracts (Recap)
Duration: duration (in years) of the research project, excluding 'ex post' extensions **Duration1**: =1 if duration>1, 0 o/w **Duration2**: =1 if duration>2, 0 o/w **Size**: contract dollar size (in 2000 dollars) **Size50**: =1 if Size>$500,000; =0 o/w	Contracts (Recap)
EarlyPhase: =1 if research is in discovery phase; =0 if research is in later phases (lead molecule, preclinical, clinical trials, formulation) or if the research is about a device.	Contracts (Recap's front page)

Figure 3-1: Variable Construction (continues in next page)

Firm_Uni: =1 if the open-science partner is affiliated to a university; =0 o/w (partner is a hospital, a foundation, a private research center. Public agency like NIH or USDA are excluded) **Privuniv**: =1 if Firm_uni=1 and the university is private; =0 o/w **Hospital**: =1 if Firm_Uni=0 and partner is a hospital (possibly affiliated to a university); =0 otherwise	Contracts, manual checks
NIH_top50: =1 if the open-science partner is among the 50 organizations worldwide receiving the highest NIH support in the year before the contract is signed; =0 o/w (note: data are not available for the early 1980s and the 1970s, periods in which I have only a few contracts. I tried to imply the ranking from the closest available year, and I believe no case was dubious) **PI_impactFact**: cumulative impact factor of all the publication the PI (or, if more than one PI, the one with the highest value) has up to the year before the contract is signed **PI_prestige75**: =1 if PI_impactFact is in the top 25% in my sample; =0 o/w	NIH database Medline Search + PublicationHarvester Software
US_US: =1 if both partners are US-based; =0 o/w **Distance**: geographical distance between the partners, in miles (if firms has multiple sites, the one closest to the open-science partner was considered) **Distance_short**: =1 if distance<=100miles; =0 o/w **Distance_med**: =1 if 100miles< distance<=1000miles; =0 o/w **Distance_long**: =1 if distance>1000miles; =0 o/w	Contracts (Recap) Contracts (recap) + web searchfor addresses; web search. Distance calculator at http://www.geobytes.com/CityDistanceTool.htm?loadpage
Year_Sign: Year in which the contract was signed **Period**: =1 if Year_Sign>1990; =0 o/w	Contracts (Recap)
Assets: company's total assets in year before deal is signed **Revenues**: company's revenues in year before deal is signed **RD**: company's R&D expenses in year before deal is signed **Equity**: company shareholders' equity (deficit) in year before deal is signed **Cash**: company's cash and equivalents in year before deal is signed **Net_income**: company's net income and equivalents in year before deal is signed **Assets_10**: =1 if Assets>$10,000,000; =0 o/w **Year_found**: year of company's foundation **Firm_age**: year of contract signed-Year_found **Firm_age1**: =1 if Firm_age>1; =0 o/w	Compustat; company's annual report and SEC files; Kresge Microfiches (HBS Baker Library); Thomson Global Access; Web search. Financials are in 2000 dollars

Figure 3-2: Variable construction - cont'd

Variable	Obs	Mean	StDev	Median	Min	Max	Mean/Median in other studies
Pub_Delay	245	61.10	82.34	45	0	540	
Pub_Delay0	245	.70					
Pub_Delay60	245	.27					
Pub_Delay0_60_more	245	.97	.75	1	0	2	
Suppress Publication	245	0					**.19** (mean; Lerner-Merges 1998)
Firm_sole_term_right	283	.24					**.54** (mean; Robinson-Stuart 2005)
Uni_budget	283	.12					
Firm_extend	283	.06					
Firm_modify	283	.02					
Other_meetings	283	.43					
Control	283	.92	.75	1	0	4	
Control0	283	.70					
Control_Strict	283	.43	.64	0	0	3	
Control_Strict0	283	.30					
Duration	269	2.46	1.73	2	.33	10	**1** (median; Blumenthal et al. 1996)
Duration1	269	.67					
Duration2	269	.44					
Size ($million)	211	2.24	11.43	.43	0	132.0	
Size50	211	.48				7	
EarlyPhase	257	.57					**.40** (mean; Robinson-Stuart 2005)
Firm_Uni	283	.66					
Privuniv	281	.29					
Hospital	280	.21					
NIH_top50	258	.49					
PI_impactFact	259	178.05	254.24	87.79	0	1446.	
PI_prestige75	259	.25				82	
US_US	283	.82					
Distance	281	1246.63	1976.19	389	0	10530	
Distance_short	281	.37					
Distance_med	281	.26					
Distance_long	281	.37					
Year_Sign	283	1992.41	4.96	1992	1975	2003	
Period	283	.71					
Assets (million$)	234	17.80	31.7	7.61	0	292	
Revenues	238	3.01	7.35	3.51	0	88.2	
RD	229	5.29	7.45	3.08	0	55.6	
Equity	229	11.6	22.8	3.54	-17.8	163	
Cash	229	12.4	24.1	3.88	0	246	
Net_income	237	-5.19	7.87	-3.46	-77	12.8	
Assets_10	234	.46					
Year_found	276	1988	4.98	1988	1973	2000	
Firm_age	276	4.38	3.66	4	0	20	
Firm_age1	276	.79					

Figure 3-3: Descriptive statistics. See pages 151 and 152 for the construction of the variables. Means and medians from other studies reported in bold type are significantly different from those in the present study at 95% level or more.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Pub_delay																
2	Pub_Delay0	**0.48**															
3	Pub_Delay60	**0.66**	**0.39**														
4	Pub_Delay0_60_more	**0.68**	**0.84**	**0.83**													
5	EarlyPhase	0.11	**0.24**	0.00	**0.15**												
6	Duration2	**0.27**	**0.18**	**0.33**	**0.30**	**0.13**											
7	Firm_Uni	**0.20**	**0.26**	**0.25**	**0.31**	**0.15**	0.10										
8	PrivUniv	-0.08	0.12	-0.04	0.05	**0.25**	0.09	**0.46**									
9	Hospital	**-0.22**	**-0.34**	**-0.25**	**-0.36**	**-0.15**	-0.11	**-0.82**	**-0.38**								
10	NIH_top50	-0.03	0.01	-0.07	-0.04	0.11	0.01	-0.08	**0.14**	0.10							
11	Plprestige75	**-0.13**	-0.03	**-0.14**	-0.10	0.10	**0.20**	-0.11	0.05	0.09	0.05						
12	US_US	**-0.31**	**-0.15**	**-0.34**	**-0.29**	-0.01	**-0.19**	**-0.12**	**0.24**	0.11	**0.37**	-0.01					
13	Period	**0.18**	**0.22**	**0.16**	**0.23**	-0.08	0.05	**0.14**	-0.08	**-0.21**	**-0.16**	-0.05	-0.12				
14	Firm_age1	0.08	**0.25**	0.12	**0.22**	-0.01	-0.11	-0.07	**-0.12**	0.07	0.06	-0.11	-0.06	**0.15**			
15	Past_Deal_Firm	0.02	0.00	0.04	0.03	0.02	**-0.17**	-0.02	-0.02	0.02	-0.04	-0.11	0.02	**0.18**	**0.46**		
16	Past_Deal_Uni	-0.06	0.07	**-0.15**	-0.05	-0.01	-0.09	-0.04	0.00	0.09	**0.29**	0.06	**0.18**	**0.21**	**0.12**	0.07	
17	Past_Deal_Same	**0.15**	-0.04	0.02	-0.01	**0.13**	0.05	-0.05	-0.09	0.03	0.02	-0.02	0.00	0.07	0.11	**0.36**	**0.29**

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Control																	
2	Control0	**0.81**																
3	Control_stict	**0.74**	**0.45**															
4	Control_stict0	**0.68**	**0.49**	**0.91**														
5	Firm_sole_term_right	**0.54**	**0.37**	**0.73**	**0.75**													
6	EarlyPhase	**0.13**	**0.12**	0.03	0.04	0.10												
7	Duration2	**0.28**	**0.24**	**0.22**	**0.21**	**0.22**	0.12											
8	Firm_Uni	0.09	0.00	0.11	0.09	0.17	**0.13**	0.06										
9	PrivUniv	0.10	0.00	0.07	0.06	0.11	**0.22**	0.10	**0.45**									
10	Hospital	-0.07	0.00	-0.08	-0.06	-0.14	**-0.13**	-0.06	**-0.82**	**-0.36**								
11	NIH_top50	-0.06	-0.09	-0.08	-0.08	-0.07	0.09	0.00	-0.03	**0.14**	0.07							
12	Plprestige75	0.09	**0.12**	0.06	0.05	0.04	0.08	**0.19**	-0.09	0.09	0.08	0.07						
13	US_US	-0.10	-0.07	-0.04	-0.02	-0.02	-0.01	**-0.16**	-0.07	**0.24**	0.05	**0.38**	0.00					
14	Period	0.03	0.00	-0.02	-0.04	0.05	-0.11	0.06	**0.16**	-0.04	**-0.20**	**-0.12**	-0.04	-0.10				
15	Firm_age1	0.03	-0.03	0.00	-0.04	-0.02	-0.03	**-0.14**	-0.03	-0.10	0.02	0.04	-0.10	-0.07	**0.15**			
16	Past_Deal_Firm	0.02	0.00	0.07	0.06	0.11	0.01	**-0.15**	0.03	0.01	-0.01	-0.06	-0.10	0.01	**0.21**	**0.46**		
17	Past_Deal_Uni	0.00	0.01	-0.01	-0.02	0.09	-0.07	-0.11	0.00	0.05	0.05	**0.30**	0.08	**0.19**	**0.23**	**0.16**	0.07	
18	Past_Deal_Same	0.04	0.06	0.09	0.11	**0.14**	0.08	0.05	-0.03	-0.06	0.01	0.05	-0.02	0.01	0.09	0.11	**0.36**	**0.28**

Figure 3-4: Pairwise correlation coefficients (see pages 151 and 152 for the construction of the variables). N=180 in the first table, and N=201 in the second table. Coefficients in bold types represent correlations significant at the 90% level or more (p-value below 0.10). Correlation coefficients ρ between each pair of variables are calculated, as usual, as $\rho = \frac{\sum_{i=1}^{N}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\left[\sum_{i=1}^{N}(x_i-\bar{x})^2\right]\left[\sum_{i=1}^{N}(y_i-\bar{y})^2\right]}}$, where $\bar{x}$ and $\bar{y}$ are the sample means of two given variables. The p-value for statistical significance is calculated as $p = 2* \left[1 - F\left(\frac{\rho\sqrt{N-2}}{\sqrt{1-\rho^2}}\right)\right]$, where $F(\cdot)$ is the cumulative distribution function of a random variable distributed according to a Student t with N-2 degrees of freedom.

	Obs	Pub_delay	Pub_Delay0	Pub_Delay60
Discovery Phase	106	65.80	**.80**	.27
Post Discovery Phase	74	49.05	**.58**	.27
Hospital	42	**27.86**	**.43**	**.07**
Non-Hospital	138	**68.37**	**.80**	**.33**
University	124	**69.56**	**.79**	**.35**
Non-University	56	**35.36**	**.54**	**.11**
Duration<=2	103	**40.49**	**.64**	**.15**
Duration>2	77	**83.57**	**.81**	**.44**
PI top 25	51	**42.65**	.69	**.18**
PI bottom 75	129	**65.35**	.72	**.31**
PI top 25, firm's age <=1	15	28.00	.53	.07
PI bottom 75, firm's age <=1	25	59.40	.48	.24
PI top 25, firm's age >1	36	48.75	.75	.22
PI bottom 75, firm's age >1	104	66.78	.78	.33
NIH top 50	95	56.37	.72	.24
NIH below top 50	85	61.77	.71	.31
1975-1990	54	**37.22**	**.56**	**.17**
1991-2003	126	**68.21**	**.78**	**.32**
Firm's age<=1	40	47.63	**.50**	*.18*
Firm's age>1	140	62.14	**.77**	*.30*
Obs	180			

Figure 3-5: Mean comparisons for different groupings of the data (see pages 151 and 152 for a description of the variables). Numbers in bold type indicate that the differences in the means of two given sub-samples are significantly different from zero at the 90% significance level or more. Numbers in italics indicate differences significant between 85% and 90% levels. The statistic used to estimate mean differences is the usual t-test for unpaired samples, calculated as: $t = \frac{\left(\frac{1}{n_x}\sum_{i=1}^{n_x} x_i\right) - \left(\frac{1}{n_y}\sum_{y=1}^{n_y} y_j\right)}{\sqrt{\left[\frac{(n_x-1)s_x^2+(n_y-1)s_y^2}{n_x+n_y-2}\right]\left(\frac{1}{n_x}+\frac{1}{n_y}\right)}}$. The numerator is the difference between the sample means of the sub-samples x and y of a given variable. The sub-sample x has n_x observations, and the sub-sample y has n_y observations. Finally, s_k^2, $k = x, y$ is the sample variance of each sub-sample. Equal variances between groups are assumed.

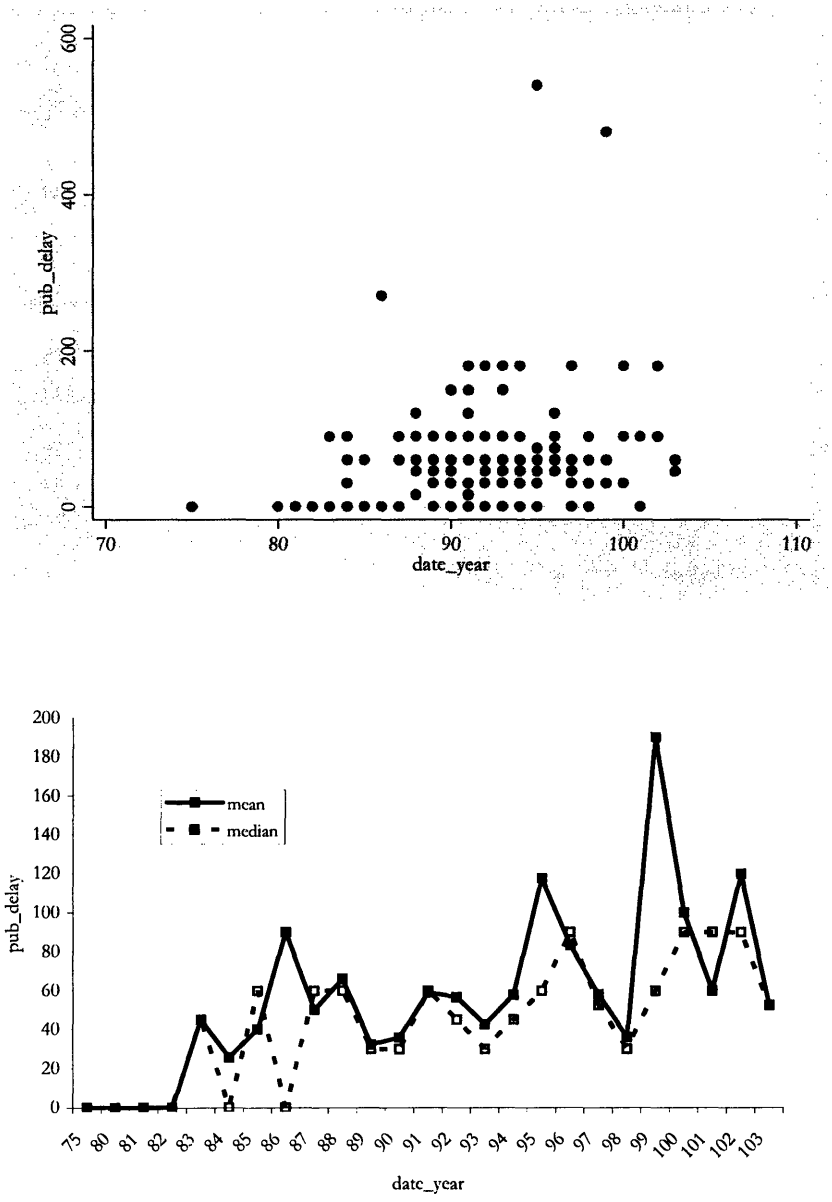

Figure 3-6: Top chart: Scatter plot of publication delays in different years. Bottom chart: average and median publication delays over time. Date_year = year-1900 (for example, 90 stands for 1990)

	Obs	Meetings	Firm_sole_term	Uni_budget	Control	Control0	Control_stict	Control_stict0
Discovery Phase	120	**.48**	*.28*	.12	**1.00**	**.74**	.47	.38
Post Discovery Phase	81	**.32**	*.19*	.14	**.80**	**.63**	.42	.33
Hospital	46	.43	**.13**	.17	.83	.70	.35	.37
Non-Hospital	155	.41	**.27**	.11	.95	.70	.48	.30
University	139	.42	**.29**	.11	.96	.70	*.50*	.39
Non-University	62	.42	**.13**	.16	.82	.69	*.34*	.29
Duration<=2	115	.40	**.16**	**.09**	**.74**	**.60**	**.32**	**.27**
Duration>2	86	.44	**.36**	**.17**	**1.16**	**.83**	**.62**	**.48**
PI top 25	53	.47	.26	.09	1.03	**.79**	.43	.40
PI bottom 75	148	.40	.23	.14	.88	**.66**	.51	.35
NIH top 50	105	.43	.21	.11	.88	.68	.40	.32
NIH below top 50	96	.41	.27	.14	.97	.74	.50	.40
1975-1990	62	.42	.21	**.21**	.89	.69	.47	.39
1991-2003	139	.42	.25	**.09**	.94	.70	.44	.35
Firm's age<=1	43	.40	.26	.05	.88	.72	.44	.40
Firm's age>1	158	.42	.23	.03	.93	.69	.45	.35
Obs	201							

Figure 3-7: Mean comparisons for different groupings of the data (see pages 151 and 152 for a description of the variables, and page 155 for a description of the mean comparison test). Statistics on single control provisions are reported only for those provisions for which the number of occurrences is not 'too small' (less than 10% of the contracts). Due to the small number of occurrences, statistics on Proj_manag_body, Firm_extend and Firm_modify are not reported. See footnote 9 at page 140 for some considerations on these contractual provisions.

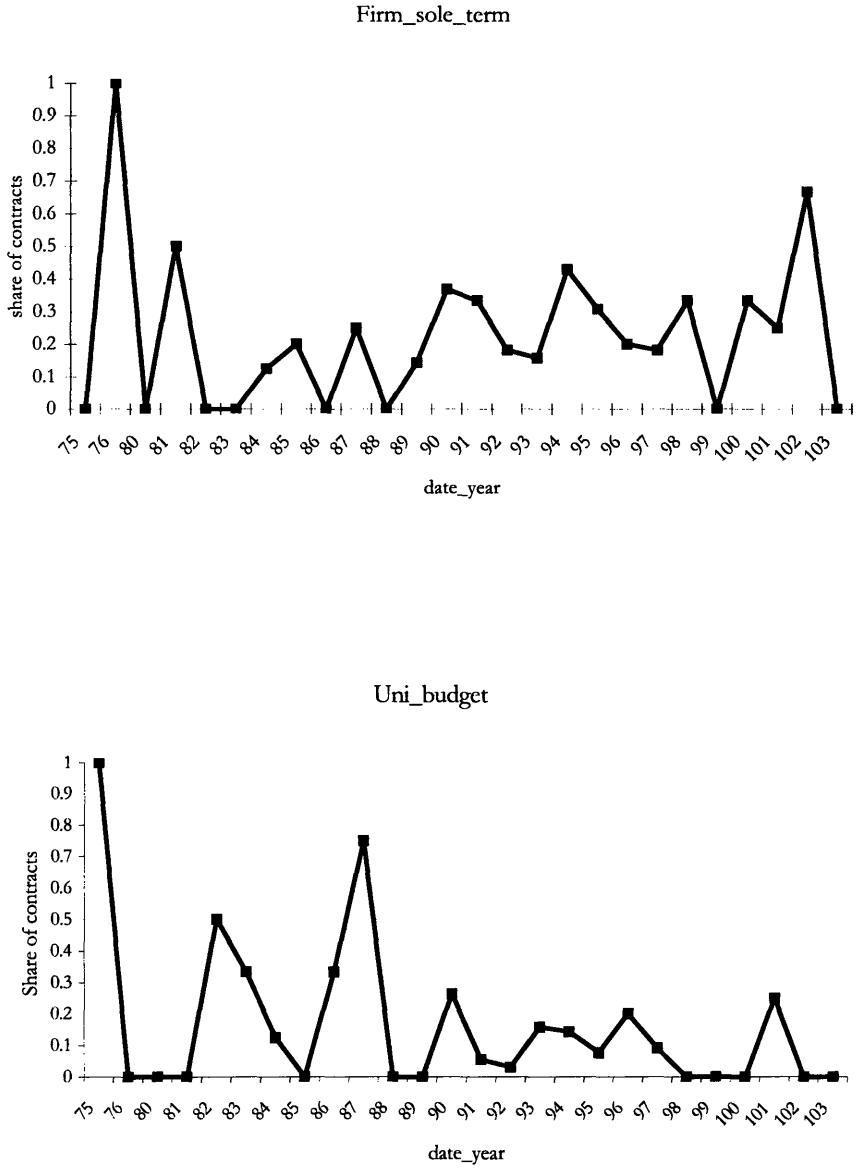

Figure 3-8: Share of contracts with unilateral termination rights without cause of the sponsor company (top chart) and with the provision for the research partner to submit periodical budget and research proposal, to be approved by the sponsor company (bottom chart), in any given year.

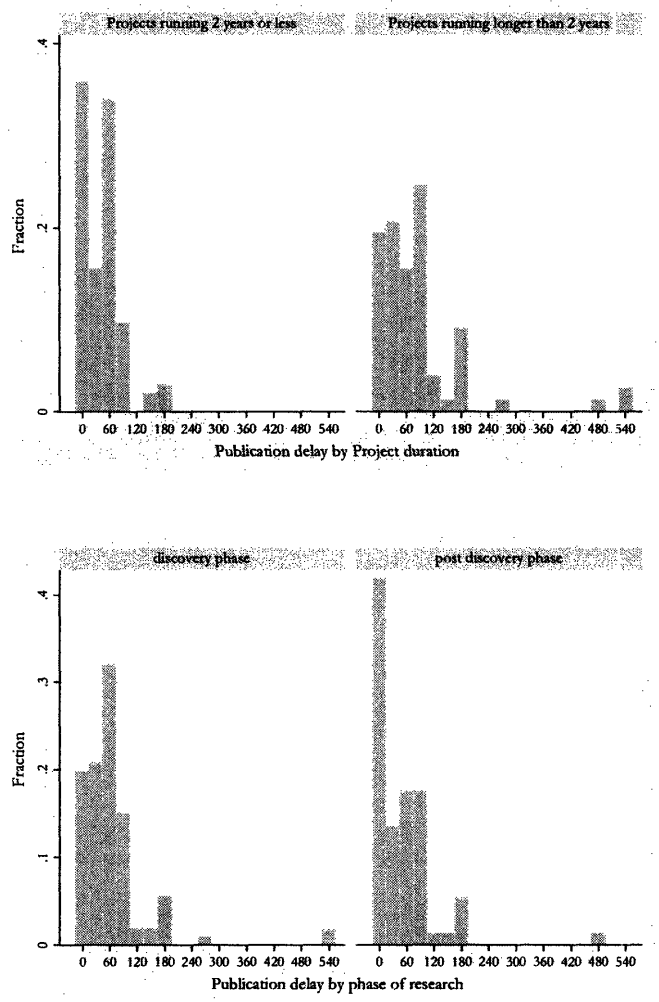

Figure 3-9: Distribution of publication delays, for different groupings of the data.

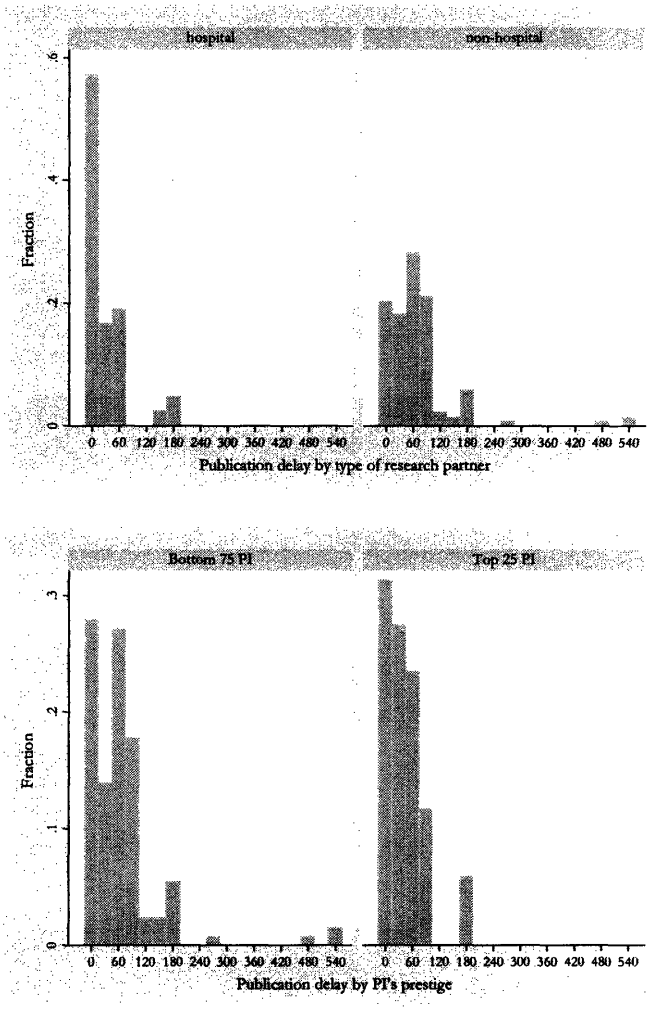

Figure 3-10: Distribution of publication delays, for different groupings of the data – cont'd.

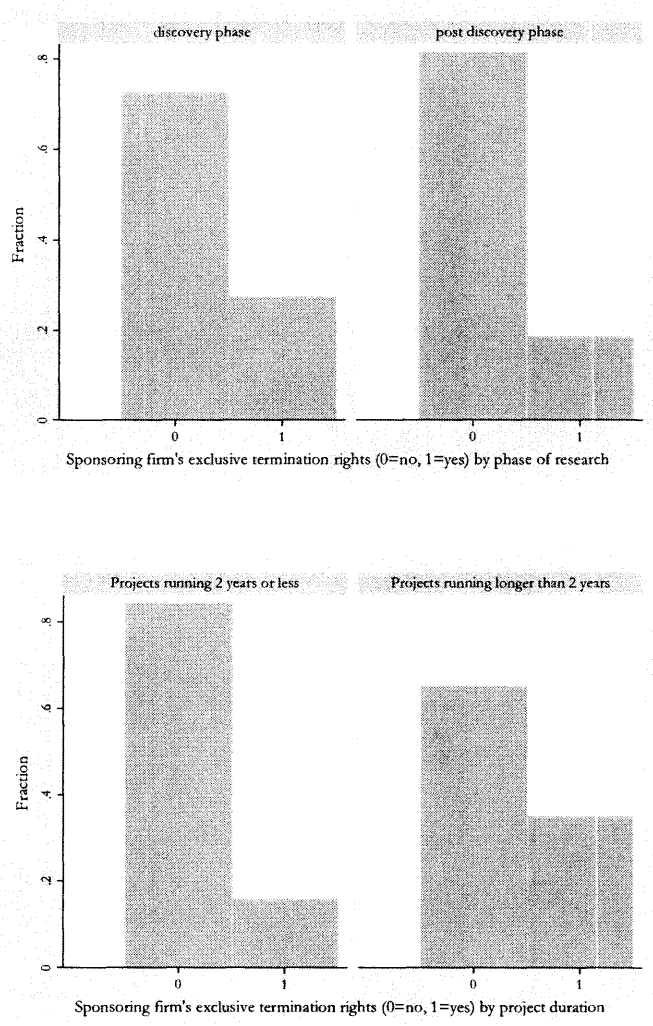

Figure 3-11: Frequency of exclusive termination rights for the sponsor company, for different groupings of the data.

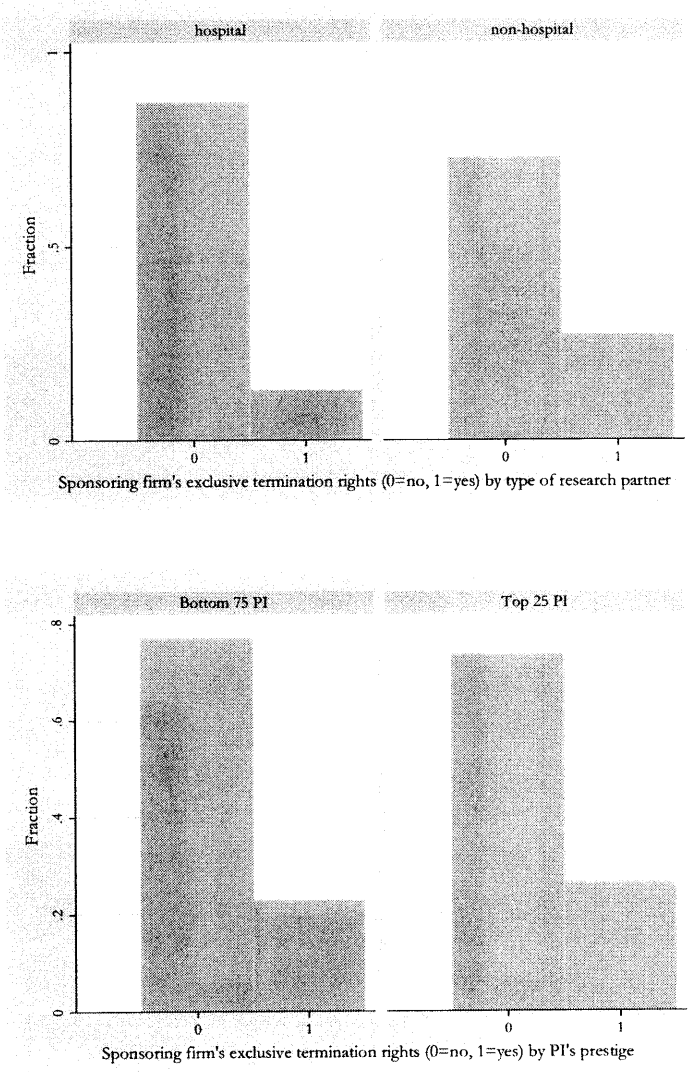

Figure 3-12: Frequency of exclusive termination rights for the sponsor company, for different groupings of the data – cont'd.

	Discovery phase	Post discovery phase	Total
Duration<=2yrs	**55**	**48**	103
%	**51.89**	**64.86**	57.22
Duration>2yrs	**51**	**26**	77
%	**48.11**	**35.14**	42.78
Total	106	74	180

	Discovery phase	Post discovery phase	Total
Hospital	**19**	**23**	42
%	**17.92**	**31.08**	23.33
Non hospital	**87**	**51**	138
%	**82.08**	**68.92**	76.67
Total	106	74	180

	Discovery phase	Post discovery phase	Total
Bottom75 PI	72	57	129
%	67.92	77.03	71.67
Top25 PI	34	17	51
%	32.08	22.97	28.33
Total	106	74	180

	Duration<=2yrs	Duration>2yrs	Total
Hospital	28	14	42
%	27.18	18.18	23.33
Non hospital	75	63	138
%	72.82	81.82	76.67
Total	103	77	180

	Duration<=2yrs	Duration>2yrs	Total
Size<=$0.5M	**61**	**11**	72
%	**73.49**	**20.75**	52.94
Size>$0.5M	**22**	**42**	64
%	**26.51**	**79.25**	47.06
Total	83	53	180

	Distance<=100m	100<Distance<=1K	Distance>1K	Total
Bottom75 PI	**55**	**38**	**36**	129
%	**77.46**	**79.17**	**59.02**	71.67
Top25 PI	**16**	**10**	**25**	51
%	**22.54**	**20.83**	**40.98**	28.33
Total	71	48	61	180

Figure 3-13: Contingency tables for different pairs of variables. Bold types are used to indicate that, for a particular pair of variables, we reject the tests of independence between them at least at the 90% statistical confidence level. Tests of independence assess whether the conditional distribution of a given variable is the same for any value of the other variable. The two most used tests are the likelihood ratio chi-square test, and the Pearson chi-square test. They are defined, respectively, as: $LR = 2\sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij} \ln\left(\frac{x_{ij}}{e_{ij}}\right)$; $P = \sum_{i=1}^{I}\sum_{j=1}^{J} \frac{\left(x_{ij}-e_{ij}\right)^2}{e_{ij}}$. I and J represent the number of rows and columns of the tables. Both tests have (I-1)(J-1) degrees of freedom and are asymptotically equivalent. The variable x_{ij} indicate the actual occurrence in a given row i and column j of a table, or the actual frequency. The variable e_{ij} represents the expected frequency for given columns and rows, i.e. the frequency that an occurrence would have, were the variables independent. The expected value is calculated as follows. If a variable is independent from another, then the probability of observing a given value of that variable should be the same, for any value of the other variable. Consider, for example, the top-left table. Among the 180 observations, the percentage frequency of (or probability of observing) duration≤ 2 is 57.22% (103 out of 180 observations). The frequency of duration> 2 is 77 out of 180, or 42.78%. Therefore we would expect that, conditional on the project being in the discovery phase, there will be 57.22% of shorter projects and 42.78% of longer projects, were the two variables independent. We would expect the same frequencies if the project is in later phases. Equivalently, we would expect about 61=106*57.22% occurrences of shorter projects, and 42 occurrences of longer projects. Conditional on the project being after the discovery phase we would expect 42 cases of shorter projects, and 32 occurrences of longer projects. These values define the values of e_{ij}. More generally, the values of e_{ij} are calculated as $e_{ij} = \frac{N_i N_i}{N}$, where N_i is total number of occurrences on the ith row, N_j is the number of occurrences on the jth column, and N is the total number of observation. Notice that $p^e_{ij} = \frac{e_{ij}}{N} = \frac{N_i N_i}{N^2} = \frac{N_i}{N}\frac{N_i}{N} = P(i) * P(j)$: the expected probability of a given cell is given by the product of the probability of a column and of a row to occur. The product of probabilities represents the probability of two events to occur, when independent. The higher the value of the two test statistics described here, the more different the observed values from the expected frequencies, the less likely we are to accept the hypothesis of independence.

Regression results

	Dep Var: Pub_Delay0					Dep Var: Pub_Delay60					Dep Var: Pub_Delay0_60_more			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Regressors														
EarlyPhase	**0.20**	**.18**	**.19**	**.20**	**.18**	-.04	-.02	-.03	-.04	**-.17**	*.17*	*.16*	*.15*	.01
	(.07)	(.07)	(.07)	(.06)	(.08)	(.06)	(.06)	(.06)	(.06)	(.08)	(.11)	(.11)	(.11)	(.12)
Duration2	**.14**	**.13**	.09	**.12**	*.13*	**.30**	**.32**	**.27**	**.28**	**.19**	**.44**	**.36**	**.39**	**.33**
	(.07)	(.06)	(.06)	(.06)	(.08)	(.07)	(.06)	(.07)	(.07)	(.08)	(.11)	(.11)	(.11)	(.12)
Firm_Uni		-.06	-.09	-.11			*.19*	.12	.15			.03	.04	
		(.10)	(.11)	(.11)			(.12)	(.12)	(.12)			(.18)	(.18)	
PrivUniv		-.05	.01	.03			**-.18**	-.07	-.07			-.06	-.04	
		(.08)	(.09)	(.08)			(.08)	(.08)	(.08)			(.14)	(.14)	
Hospital		**-.40**	**-.34**	**-.38**			-.11	-.10	-.07			**-.44**	**-.46**	
		(.12)	(.12)	(.13)			(.12)	(.12)	(.12)			(.20)	(.20)	
NIH_top50		.03	.07	.01	**-.60**		-.01	.06	.08	-.03		.13	.09	*-.63*
		(.07)	(.08)	(.07)	(.28)		(.06)	(.07)	(.07)	(.26)		(.11)	(.11)	(.42)
PIprestige75		-.05	-.07	-.05	.03		**-.16**	**-.18**	**-.15**	-.01		**-.25**	**-.21**	.02
		(.07)	(.07)	(.07)	(.08)		(.07)	(.07)	(.07)	(.08)		(.11)	(.11)	(.12)
Distance_med			.06	.04	.08			-.09	**-.12**	-.05		-.03	-.08	.04
			(.08)	(.08)	(.11)			(.07)	(.07)	(.10)		(.12)	(.12)	(.15)
Distance_long			.10	.07	.06			.00	.02	-.08		.11	.05	-.02
			(.07)	(.07)	(.08)			(.07)	(.08)	(.08)		(.12)	(.12)	(.13)
US_US			**-.16**	-.12				**-.35**	**-.31**			**-.50**	**-.43**	
			(.10)	(.10)				(.12)	(.12)			(.18)	(.19)	
Period			**.17**	*.12*	**.17**			.06	.08	-.07		**.24**	**.20**	.10
			(.08)	(.08)	(.08)			(.07)	(.07)	(.08)		(.12)	(.12)	(.13)
Firm_age1				**.33**	**.22**				**.12**	.03			**.46**	*.26*
				(.08)	(.11)				(.07)	(.1)			(.13)	(.16)
Past_Deal_Uni				.10	-.00				**-.13**	-.06			-.04	-.06
				(.08)	(.11)				(.08)	(.10)			(.13)	(.15)
Past_Deal_Firm				-.11	-.02				.02	.08			-.09	.07
				(.07)	(.10)				(.08)	(.09)			(.12)	(.14)
Past_Deal_Same				-.10	-.01				.02	.01			-.08	.00
				(.09)	(.11)				(.09)	(.10)			(.14)	(.16)
Constant	**.53**	**.71**	**.65**	**.45**	**.60**	**.16**	.15	**.44**	**.36**	*.31*	**.70**	**.99**	**.81**	**.91**
	(.06)	(.12)	(.16)	(.16)	(.23)	(.05)	(.12)	(.18)	(.19)	(.21)	(.10)	(.28)	(.29)	(.34)
Method	OLS	OLS	OLS	OLS	FE (res partner)	OLS	OLS	OLS	OLS	FE (res partner)	OLS	OLS	OLS	FE (res partner)
R_square	.08	.18	.22	.31		.11	.22	.28	.31		.10	.28	.35	
F-stat	**7.44**	**5.24**	**5.59**	**7.75**	**2.03**	**10.03**	**7.58**	**7.35**	**5.85**	1.26	**9.81**	**8.47**	**9.15**	1.26
F-stat (FE)					**2.31**					**1.85**				**2.46**
Hausman Test					**25.46**					**18.45**				14.14
Obs	180	180	180	180	125	180	180	180	180	125	180	180	180	125

OLS regressions with robust standard errors (reported in parentheses). Estimates significant at the 90% level or more are in bold types. estimates significant between 85% and 90% are in italics.

Regression results

	Dep Var: Control0					Dep Var: Control_strict0					Dep Var: Firm_sole_term_right				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Regressors															
EarlyPhase	**.09**	*.10*	*.10*	*.11*	-.01	.02	.01	.01	.00	**-.16**	.07	.05	.07	.07	.01
	(.06)	(.07)	(.07)	(.07)	(.10)	(.07)	(.07)	(.07)	(.07)	(.09)	(.06)	(.06)	(.06)	(.06)	(.08)
Duration2	**.22**	**.20**	**.21**	**.22**	*.16*	**.21**	**.20**	**.21**	**.21**	**.21**	**.18**	**.18**	**.18**	**.20**	**.18**
	(.06)	(.06)	(.07)	(.07)	(.10)	(.07)	(.07)	(.07)	(.08)	(.09)	(.06)	(.06)	(.07)	(.07)	(.08)
Firm_Uni		.03	.04	.03			.13	.15	.14			*.15*	*.16*	.14	
		(.13)	(.13)	(.13)			(.14)	(.14)	(.14)			(.11)	(.11)	(.11)	
PrivUniv		-.04	-.05	-.05			.01	-.00	.00			.02	.00	-.00	
		(.08)	(.08)	(.08)			(.09)	(.09)	(.08)			(.08)	(.08)	(.08)	
Hospital		.04	.05	.03			.08	.07	.06			.03	.05	.01	
		(.14)	(.14)	(.14)			(.15)	(.15)	(.15)			(.11)	(.11)	(.11)	
NIH_top50		*-.09*	*-.11*	**-.13**	**-.92**		-.08	-.11	-.11	**-.99**		-.07	-.09	**-.12**	**-.48**
		(.06)	(.07)	(.08)	(.36)		(.07)	(.08)	(.08)	(.33)		(.06)	(.07)	(.07)	(.30)
PIprestige75		.09	.08	.08	.10		.02	.01	.00	-.19		.01	-.00	.01	**-.16**
		(.07)	(.07)	(.07)	(.10)		(.08)	(.08)	(.08)	(.09)		(.07)	(.07)	(.07)	(.08)
Distance_med			-.01	.00	-.15			.02	.05	-.11			.05	.09	-.06
			(.08)	(.08)	(.12)			(.09)	(.09)	(.11)			(.07)	(.07)	(.10)
Distance_long			.02	.04	-.04			.05	.09	-.02			.08	*.11*	.12
			(.08)	(.08)	(.11)			(.08)	(.09)	(.10)			(.07)	(.07)	(.09)
US_US			.04	.03				.09	.07				.10	.06	
			(.11)	(.11)				(.11)	(.11)				(.10)	(.09)	
Period			-.00	-.03	-.05			-.07	-.11	-.04			.02	-.05	-.01
			(.07)	(.08)	(.10)			(.08)	(.08)	(.10)			(.07)	(.07)	(.09)
Firm_age1				-.00	-.13				-.05	**-.20**				-.07	-.10
				(.08)	(.13)				(.10)	(.12)				(.08)	(.11)
Past_Deal_Uni				.07	.02				.03	-.08				**.14**	.10
				(.08)	(.12)				(.09)	(.12)				(.07)	(.10)
Past_Deal_Firm				.02	.14				.08	.03				*.11*	.05
				(.08)	(.11)				(.09)	(.10)				(.07)	(.09)
Past_Deal_Same				.03	.13				.14	.16				.10	.10
				(.10)	(.13)				(.12)	(.12)				(.10)	(.11)
Constant	**.55**	**.55**	**.52**	**.49**	**1.28**	**.26**	.18	.15	.13	**1.35**	**.12**	**.56**	-.09	**-.13**	**.49**
	(.06)	(.13)	(.18)	(.19)	(.28)	(.06)	(.14)	(.20)	(.20)	(.27)	(.05)	(.13)	(.15)	(.15)	(.24)
Method	OLS	OLS	OLS	OLS	FE (oso)	OLS	OLS	OLS	OLS	FE (oso)	OLS	OLS	OLS	OLS	FE (oso)
R_square	.07	.09	.09	.09		.05	.06	.07	.09		.06	.08	.09	.14	
F-stat	**7.23**	**2.54**	**1.64**	1.43	1.40	**4.62**	**1.75**	1.32	1.34	**2.78**	**5.31**	**2.78**	**2.03**	**2.01**	**1.61**
F-stat (FE)					**1.60**					**2.20**					**2.07**
Hausman Test					**19.11**					**83.9**					**779**
Obs	201	201	201	201	135	201	201	201	201	135	201	201	201	201	135

OLS regressions with robust standard errors (reported in parentheses). Estimates significant at the 90% level or more are in bold types, estimates significant between 85% and 90% are in italics.

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Appendix A

An infinite-time version of the model in Chapter 1

In this appendix, I sketch an infinite (discrete) time extension of the model that nests the two-period basic framework described in Chapter 1. Some clarifications and modifications are necessary to adapt the model to the infinite period case. Consider first, as before, the academic team. In each period $t = 0, 1, 2, ...$, the team chooses $\{a_t^u, \gamma_t^u\}$, where $a_t^u \in \{s, c, \emptyset\}$ and γ_t^u, as before, is the level of applicability of fundamental research. Once the team enters commercially-relevant activities (choice of c), then there is a probability p, in each period to receive an amount R, and occurrences are independent across periods. The investment in γ_t^u is separate in each period, and the impact on the reduction of commercialization costs is additive. So for example, if in time t the team invests an amount γ^*, and it enters commercialization in period $z > t$, the cost reduction in z will be equal to γ^*. Recall that the cost of commercially-relevant research is paid only once, the first time the team tries commercialization. There is discounting across periods; the discount factor is $\delta \in (0, 1)$. We derive the following

Proposition A.1 *Define*

$$\Pi_0 = pR + \delta(1-p)pR + \delta^2(1-p)^2pR + \cdots = \frac{pR}{1-\delta(1-p)} - K. \tag{A.1}$$

$$SC^u(\tau) = \frac{1-\delta^\tau}{1-\delta}B + \frac{\alpha\lambda^2}{2}\frac{1-\delta^\tau}{1-\delta} - \tau\delta^\tau\alpha\lambda + \frac{\alpha\delta^\tau}{2}\frac{\left(\delta - \delta^{\tau+1}\right)}{(1-\delta)} + \delta^\tau\Pi_0 \tag{A.2}$$

and

$$NND^u(\tau,t)=\frac{1-\delta^{\tau-t}}{1-\delta}B+\frac{\alpha\lambda^2}{2}\frac{1-\delta^{\tau-t}}{1-\delta}+\alpha\lambda\left(t-\tau\delta^{\tau-t}\right) \tag{A.3}$$
$$+\frac{\alpha\delta^{\tau-t}}{2}\frac{\left(2\delta^{t+1}+\delta^{\tau+1-t}-2\delta^{\tau+1}-\delta\right)}{(1-\delta)}-(1-\delta^{\tau-t})\Pi_0$$
$$\forall t=1,2,...,\tau-1.$$

i. *If* $\exists\ \tau^u \in (0, \frac{\ln\lambda}{\ln\delta})$ *such that*

$$\tau^u=\arg\max_{\{\tau\}} SC^u(\tau)\ s.t.\ 0<\tau<\frac{\ln\lambda}{\ln\delta}, \tag{A.4}$$

$$SC^u(\tau^u) > Max\left\{\frac{B}{1-\delta},\Pi_0\right\}, \tag{A.5}$$

and

$$NND^u(\tau^u)>0\ \forall t=1,2,...,\tau^u-1, \tag{A.6}$$

then the academic team performs fundamental research for τ^u *periods, from period* 0 *to period* τ^u-1, *enters commercially relevant activities in period* τ^u, *i.e.* $a^u_{\tau^u}=c$, *and keeps trying until success. In each period* $t=0,1,...,\tau^u-1$, *the team invests an amount* $\gamma^u_t=\alpha(\delta^{\tau^u-t}-\lambda)$ *in 'applicable' basic research:* $\{a^u_t=s,\ \gamma^u_t=\alpha(\delta^{\tau^u-t}-\lambda)\}\,\forall t=1,2,...,\tau^u-1$; $a^u_t=c$ *at* $\forall t=\tau^u$ *and in any further period, until success.*

ii. *If* $\Pi_0 > Max\left\{\frac{B}{1-\delta},SC^u(\tau^u)\right\}$, *then the team undertakes commercially relevant in the first period* $t=0$ *and tries until success:* $a^u_t=c$ *(until success)* $\forall t=0,1,...$

iii. *If* $\frac{B}{1-\delta} > Max\left\{\Pi_0,SC^u(\tau^u)\right\}$, *then the team never undertakes commercially relevant activities:* $a^u_t=s\ \forall t=0,1,....$

Proof. I prove the proposition in three points.

Remark A.1 *The options reported in the previous proposition - performing* s *in each period with no investment in applicability, entering commercialization in the first period and trying* c *until success, and performing applicable research in the first* x *periods before entering commercialization - are the only rational ones. The reasoning is similar to the one offered for the proof of propositions 1.1 and 1.2 in Chapter 1, and is expressed in the following steps:*

a. *Once the team chooses c in some period z, there are no incentives to switch to any other activities thereafter. Conditional on having entered in a given period z and having failed to complete, there is no reason to invest in applicable research afterwards since the one-shot commercialization cost has already been paid, and further expenses in* γ_t^u *will not translate in cost reduction. Moreover, choosing c in a period z implies that the expected return from commercial research* $(pR-(K - \text{cost savings}))$ *is greater than the return from choosing pure basic research (i.e.* $\{a_z^u = s,\ \gamma_z^u = 0\}$*). Consider period* $z+1$*. Suppose that, instead of trying c again, the team makes a one-time deviation to* $\{a_{z+1}^u = s,\ \gamma_{z+1}^u = 0\}$*, and gains* B*. From period* $z+2$*, the team is back to the 'c path'. This deviation is profitable if* $B + \delta pR + \delta^2(1-p)pR + \cdots = B + \frac{\delta pR}{1-\delta(1-p)} > \frac{pR}{1-\delta(1-p)}$ *or, rearranging, if* $\frac{B}{1-\delta} > \frac{pR}{1-\delta(1-p)}$*. If this is the case, then a fortiori* $\frac{B}{1-\delta} > \frac{pR}{1-\delta(1-p)} - (K - \text{cost savings})$*, so never entering into commercialization dominates entry. This contradicts the assumption of entry into commercialization at a finite date z.*

b. *A path in which the team chooses c at some finite period, and has chosen inapplicable basic research in at least one previous period (i.e.* $\{a_t^u = s,\ \gamma_t^u = 0\}$*) is not an equilibrium path. Suppose that, in some period t, the team finds it optimal to choose* $\{a_t^u = s,\ \gamma_t^u = 0\}$*, and gets a payoff of* B*. Take the path (or plan) after t (i.e. from* $t+1$ *to entry into commercialization) as given, and as yielding an expected sum of discounted payoffs of* A_{t+1}*. Now, at t, if the team chooses* $\{a_t^u = s,\ \gamma_t^u = 0\}$*, this means that* $B + \delta A_{t+1} > A_{t+1}$*: the team is better off retarding the payoff A from the established policy by one period, and getting B in the current period. A and B are time independent: choosing* $\{a_t^u = s,\ \gamma_t^u = 0\}$ *'today' does not change the number of periods in which the team will perform applicable research from tomorrow on before moving to action c, and therefore retards entry into commercialization by one period. Hence, at each subsequent period, the team faces the choice between* $B + \delta A$ *on the one hand and A on the other hand. If* $B + \delta A_{t+1} > A_{t+1}$ *(or equivalently* $\frac{B}{1-\delta} > A_{t+1}$*), then in each period the team is better off doing inapplicable research in any subsequent stage, rather than undertaking the path that leads to commercialization at some point. This contradicts the assumption that the team would choose c at some finite time.*[1]

c. *The team chooses* $\gamma_t^u > 0$*, at a given period t, only if the team chooses* $a_z^u = c$ *at some finite*

[1] *Note that I am implicitly assuming that the path that leads to entry in a finite period includes some periods of applicable research (in fact, I just proved that all of the periods preceding entry will be spent in applicable basic research). Clearly, performing basic research with* $\gamma = 0$ *and then moving to commercialization is not optimal: if no applicable research is being performed, in each period the alternative is between getting* $pR - K$ *and getting* B*, independent of time. So if one is greater than the other, it is so in any period.*

date $z > t$. If the team never chooses c, obviously it would be better off by performing $a_t^u = s$ with $\gamma_t^u = 0$ at any period t, since $\gamma_t^u > 0$ entails a cost and the benefit is enjoyed only if the team moves to commercialization at some finite time.

Remark A.2 *Consider the choice of the investment levels $\{\gamma_t^u\}, t = 0, 1, ..., \tau^u - 1$, taking τ^u, i.e. time in which c is first chosen, as given. Consider the first period $t = 0$ (see the three steps of the previous remark). The payoff function for the academic team, at period $t = 0$, can be expressed as*[2]

$$SC^u(\tau^u) = B - \lambda^u \gamma_0^u - \frac{(\gamma_0^u)^2}{2\alpha} + \delta\left(B - \lambda^u \gamma_1^u - \frac{(\gamma_1^u)^2}{2\alpha}\right) + \cdots \tag{A.7}$$
$$+\delta^{\tau^u - 1}\left(B - \lambda^u \gamma_{\tau^u - 1}^u - \frac{(\gamma_{\tau^u - 1}^u)^2}{2\alpha}\right) + \delta^{\tau^u}\left(\Pi_0 + \sum_{t=0}^{\tau^u - 1} \gamma_t^u\right)$$

This means that, when the team has to choose the level of investment γ_0^u, it expects this investment to generate a cost reduction equal to γ_0^u in $\tau^u + 1$ periods from the present period. Therefore, while the cost $\lambda^u \gamma_0^u + \frac{(\gamma_0^u)^2}{2\alpha}$ is borne in the present period, the benefit is discounted by a factor δ^{τ^u}. When the team has to choose the level of investment γ_1^u, the cost $\lambda^u \gamma_1^u + \frac{(\gamma_1^u)^2}{2\alpha}$ is borne in the current period, while the benefit is discounted by a factor $\delta^{\tau^u - 1}$. And so on. Therefore, maximizing the present-valued intertemporal payoff in each period t with respect to γ_t^u yields a sequence $\{\gamma_t^u\} = \{\alpha(\delta^{\tau^u - t} - \lambda)\}$, $t = 0, 1, ..., \tau^u - 1$. Notice that $\gamma_t^u > 0$ if and only if $\delta^{\tau^u - t} - \lambda > 0$ or, equivalently, $t > \tau^u - \frac{\ln \lambda}{\ln \delta}$. From remarks 1-b and 1-c above, the team will perform at most $\frac{\ln \lambda}{\ln \delta}$ periods of applicable research, and, if it decides to do applicable research, it will start from $t = 0$.

Remark A.3 *Now, take the sequence $\{\gamma_t^u\} = \{\alpha(\delta^{\tau - t} - \lambda)\}$, $t = 0, 1, ..., \tau - 1$ as a function of τ, and consider the choice of the optimal τ, which we call τ^u. In point 2 of the proof, we took τ^u as given and found the optimal sequence $\{\gamma_t^u\}$ (given also remarks 1-a, 1-b, and 1-c). In this point 3, we instead consider the sequence $\{\gamma_t^u\}$ for any value of τ (the time of entry into activity c), and then find the optimal $\tau = \tau^u$. The team is choosing both $\{\gamma_t^u\}$ and τ^u, and the two choices have to be consistent.*

[2] *Assume that K is always greater than the sum of cost-reducing investments, in order to ensure that commercialization costs be non-negative, no matter how much (applicable) fundamental research is performed.*

Substituting $\{\gamma_t^u\}$ into (A.7), we obtain

$$SC^u(\tau) = \frac{1-\delta^\tau}{1-\delta}B - \alpha\lambda\sum_{t=0}^{\tau-1}\delta^t(\delta^{\tau-t}-\lambda) - \frac{\alpha}{2}\sum_{t=0}^{\tau-1}\delta^t(\delta^{\tau-t}-\lambda)^2 + \delta^\tau\left[\Pi_0 + \alpha\sum_{t=0}^{\tau-1}(\delta^{\tau-t}-\lambda)\right], \tag{A.8}$$

or equivalently

$$SC^u(\tau) = \frac{1-\delta^\tau}{1-\delta}B + \frac{\alpha\lambda^2}{2}\frac{1-\delta^\tau}{1-\delta} - \tau\delta^\tau\alpha\lambda + \frac{\alpha\delta^\tau}{2}\frac{\left(\delta-\delta^{\tau+1}\right)}{(1-\delta)} + \delta^\tau\Pi_0. \tag{A.9}$$

Consider $\tau^u = \arg\max_{\{\tau\}} SC^u(\tau)$ s.t. $0 < \tau < \frac{\ln\lambda}{\ln\delta}$. If τ^u maximizes (A.9) with respect to τ under the constraint that $0 < \tau < \frac{\ln\lambda}{\ln\delta}$, and condition (A.6) is satisfied (see page 172), then it is optimal to choose $\{a_t^u = s,\ \gamma_t^u = \alpha(\delta^{\tau^u-t}-\lambda)\}\ \forall t = 1,2,...,\tau^u-1$, and $a_t^u = c$ at $t = \tau^u$ and in any further period, until success. Condition (A.6) at page 172 ensures that, in each period before τ^u, entering commercialization (with the cost reduction accumulated up to that point) is not profitable if compared to staying on the path that implies investments in γ up to τ^u-1, and first attempt to commercialize at τ^u, given the path $\{\gamma_t^u\} = \{\alpha(\delta^{\tau-t}-\lambda)\}$, $t = 0,1,...,\tau-1$. Suppose, for example, that $\tau^u > 1$. Consider the choices available to the team at period 1, and recall we keep the sequence $\{\gamma_t^u\}$ constant. The team can choose between staying on the 'equilibrium path', i.e. investing a sequence $\{\gamma_t^u\}$ up to period τ^u-1, or entering commercialization $a_t^u = c$ in period 1. Notice that in period 1 the team has already sunk the cost of investing in γ_0^u, and expects to gain $\Pi_0+\alpha(\delta^{\tau^u}-\lambda)$ from 'deviating'. If instead the team stays on the path, the expected return is

$$\begin{aligned} ND^u(\tau^u,t)\,|_{t=1} &= \frac{1-\delta^{\tau^u-1}}{1-\delta}B - \alpha\lambda\sum_{i=0}^{\tau^u-2}\delta^i(\delta^{\tau^u-1-i}-\lambda) \\ &-\frac{\alpha}{2}\sum_{i=0}^{\tau^u-2}\delta^i(\delta^{\tau^u-1-i}-\lambda)^2 + \delta^{\tau^u-1}\left[\Pi_0 + \alpha\sum_{i=0}^{\tau^u-1}(\delta^{\tau^u-i}-\lambda)\right] \end{aligned} \tag{A.10}$$

or equivalently

$$\begin{aligned} ND^u(\tau^u,t)\,|_{t=1} &= \frac{1-\delta^{\tau^u-1}}{1-\delta}B + \frac{\alpha\lambda^2}{2}\frac{1-\delta^{\tau^u-1}}{1-\delta} - \tau\delta^{\tau^u-1}\alpha\lambda \\ &-\frac{\alpha\delta^{\tau^u-1}}{2}\frac{\delta-\delta^\tau}{1-\delta} + \left(\alpha\delta^{\tau^u-1}\right)\frac{\delta-\delta^{\tau^u+1}}{1-\delta} + \delta^{\tau^u-1}\Pi_0. \end{aligned} \tag{A.11}$$

More generally, the expected return from deviating at a given period $t < \tau^u$ is

$$D^u(\tau^u, t) = \Pi_0 + \alpha \sum_{i=0}^{t-1} (\delta^{\tau^u - i} - \lambda)$$

and the expected return from staying on the path is

$$ND^u(\tau^u, t) = \frac{1-\delta^{\tau^u - t}}{1-\delta} B - \alpha\lambda \sum_{i=0}^{\tau^u - t - 1} \delta^t (\delta^{\tau^u - t - i} - \lambda)$$
$$- \frac{\alpha}{2} \sum_{i=0}^{\tau^u - t - 1} \delta^t (\delta^{\tau^u - t - i} - \lambda)^2 + \delta^{\tau^u - t} \left[\Pi_0 + \alpha \sum_{i=0}^{\tau^u - 1} (\delta^{\tau^u - i} - \lambda) \right], \tag{A.12}$$

or equivalently

$$ND^u(\tau^u, t) = \frac{1-\delta^{\tau^u - t}}{1-\delta} B + \frac{\alpha\lambda^2}{2} \frac{1-\delta^{\tau^u - t}}{1-\delta} - \tau \delta^{\tau^u - t} \alpha\lambda$$
$$- \frac{\alpha\delta^{\tau^u - t}}{2} \frac{\delta - \delta^{\tau^u + 1 - t}}{1-\delta} + \left(\alpha\delta^{\tau^u - t}\right) \frac{\delta - \delta^{\tau^u + 1}}{1-\delta} + \delta^{\tau^u - t} \Pi_0. \tag{A.13}$$

In order for any deviation to be not profitable, we need $ND^u(\tau^u, t) - D^u(\tau^u, t) = NND^u(\tau^u, t) > 0$, $t = 1, ..., \tau^u - 1$ (see condition (A.3) at page 172).Notice that $SC^u(0) = \Pi_0$. Moreover, if $\tau^u > \frac{\ln \lambda}{\ln \delta}$, then this implies that there will be some periods of inapplicable basic research performed ($\gamma_t^u = 0$). However, from the remarks above we know that either the team performs applicable research in any period before entering commercialization, starting from $t = 0$, or the team always chooses $\gamma_t^u = 0$ and does s in any period. Therefore we can write $SC^u(\tau) = \frac{1}{1-\delta} B$ for $\tau > \frac{\ln \lambda}{\ln \delta}$.[3]

■

As for the industrial team, we proceed in the same way, and obtain the following

Proposition A.2 *Define*

$$\Pi_0 = \frac{pR}{1 - \delta(1-p)} - K. \tag{A.14}$$

$$SC^f(\tau) = \frac{\alpha\delta^\tau}{2} \frac{\left(\delta - \delta^{\tau+1}\right)}{(1-\delta)} + \delta^\tau \Pi_0 \tag{A.15}$$

[3] *The problem can also be seen as one in which the team has a dichotomous choice: either enter commercially relevant activities, or not enter. If it does not enter it performs inapplicable basic research for ever. If it does enter, the team decides how many periods it will perform applicable basic research before attempting the commercial activities.*

and

$$NND^f(\tau,t)=\frac{\alpha\delta^{\tau-t}}{2}\frac{\left(2\delta^{t+1}+\delta^{\tau+1-t}-2\delta^{\tau+1}-\delta\right)}{(1-\delta)}-(1-\delta^{\tau-t})\Pi_0 \qquad \text{(A.16)}$$
$$\forall t=1,2,...,\tau-1.$$

i. *If* $\exists\,\tau^f$ *such that*

$$\tau^f=\arg\max_{\{\tau\}} SC^f(\tau)$$

$$SC^f(\tau^f)>\Pi_0,$$

and

$$NND^f(\tau^f)>0\ \forall t=1,2,...,\tau^u-1, \qquad \text{(A.17)}$$

then the company team performs fundamental research for τ^f *periods, from period* 0 *to period* τ^f-1*, enters commercially relevant activities in period* τ^u*, i.e.* $a^u_{\tau^f}=c$*, and keeps trying until success. In each period* $t=0,1,...,\tau^f-1$*, the team invest an amount* $\gamma^f_t=\alpha\delta^{\tau^u-t}$ *in 'applicable' basic research.*

ii. *If* $\Pi_0>SC^f(\tau^f)$*, then the team undertakes commercially relevant in the first period* $t=0$ *and tries until success.*

Proof. Follows from the proof of Proposition 3, once we recall that $B^f=\lambda^f=0$. ■

We see how the results derived and discussed in the paper can all be derived also from this more general formulation. The reluctance and selection results, which state that the parameter space for which the academic team enters commercialization at some finite time is a subset of the parameter space for which the company team enters, can be seen as follows. If $\Pi_0>\frac{1}{1-\delta}B$, then a fortiori $\Pi_0>0$, so for sure the company team does find it profitable to enter commercialization, at least a $t=0$. Suppose now that $\Pi_0<0$ and

$$SC^u(\tau)=\frac{1-\delta^\tau}{1-\delta}B+\frac{\alpha\lambda^2}{2}\frac{1-\delta^\tau}{1-\delta}-\tau\delta^\tau\alpha\lambda+\frac{\alpha\delta^\tau}{2}\frac{\left(\delta-\delta^{\tau+1}\right)}{(1-\delta)}+\delta^\tau\Pi_0>\frac{1}{1-\delta}B \qquad \text{(A.18)}$$

or equivalently

$$\frac{\alpha\lambda^2}{2}\frac{1-\delta^\tau}{1-\delta}-\tau\delta^\tau\alpha\lambda+\frac{\alpha\delta^\tau}{2}\frac{\left(\delta-\delta^{\tau+1}\right)}{(1-\delta)}+\delta^\tau\Pi_0>\frac{\delta^\tau}{1-\delta}B(>0) \text{ at some } \tau\in(0,\frac{\ln\lambda}{\ln\delta}). \qquad \text{(A.19)}$$

This implies that the academic team will enter commercialization at some point. If assumption (A.19) is true, then the company team could always choose an investment level and entry time so as to achieve a positive return, and therefore will enter. The opposite case (with the academic team commercializing at some finite period and the industrial team never commercializing), in contrast, will not occur.[4]

The upper bound to the applicable research periods for the academic team introduces a 'bias' for the academic team not to spend too much time in applicable research, making the two 'extreme' options, i.e. entering commercialization at date 0 or staying on 'ivory tower research' for ever, more appealing. The upper bound to τ^u is negatively related to λ, the recognition cost: the closer λ is to 1, the smaller $\frac{\ln\lambda}{\ln\delta}$.

[4]For example, for $p=\delta=.5$, $R=6,000$, $B=500$, $\alpha=810$, $K=3,000$, $\lambda=.1$, we have $\tau^u=1$ and $\tau^f=0$. For $p=\delta=.5$, $R=5,000$, $B=500$, $\alpha=1,500$, $K=3,000$, $\lambda=.1$, we have $\tau^u=\infty$ (the university team never enters) and $\tau^f=1$.For $p=\delta=.5$, $R=7,000$, $B=250$, $\alpha=3,000$, $K=4,000$, $\lambda=.28$, we have $\tau^u=0$ and $\tau^f=1$. For $p=.7$, $\delta=.9$, $R=10,000$, $B=400$, $\alpha=1,900$, $K=6,000$, $\lambda=.4$, we have $\tau^u=5$ and $\tau^f=3$.

Appendix B

An extension of the model in Chapter 2 to monetary rewards

I propose an extension of the model described in Chapter 2, in which scientists derive utility also from monetary rewards, in addition to private benefits. I make two major assumptions. The first assumption is that the academic partner is cash constrained. This implies, as mentioned above, that the academic partner (or employee) cannot bribe the industrial partner in order to change the direction of the research and not terminate the original one. The cash constraint also implies that the principal cannot fine the agent with a negative wage (for example in case of poor performance). The second assumption is that, because of the academic mission or, equivalently, because of the specific values of scientists, researchers who respond to the rules of the scientific community will not undertake any research that has no scientific value. This implies that, if the academic partner is an independent contractor and a new opportunity, economically profitable but with no scientific value pops up, the industrial client will not be able to induce the research partner to shift to this new economic opportunity. The two assumptions rule out any form of renegotiation. While the first assumption is quite standard, the second assumption is more specific: on the one hand, it is somewhat realistic if we believe that the mission of academic is first to produce scientifically novel results, and this endeavor can never be sacrificed; on the other hand, this assumption simplifies this extended model and a full appreciation of the extension would need to deal with the relaxation of this assumption.

Consider a fairly general payment scheme. If the original project is brought to completion and is

successful, the firm pays the scientist a bonus b_s (where s stands for success); if the original projects is brought to completion and is not successful, then the firm pays an amount b_F (where F stands for failure). This bonus scheme is contractible ex ante. Remember, however, that the decision of whether to terminate the original project and switch to another one (if it occurs and is preferable for the firm) is non-contractible. Moreover, since the scientist does not respond to monetary incentives unless also scientific rewards are present, there is no incentive for the alternative project. As for the timing, the incentive contract is defined after the institutional structure is chosen, and before the scientist chooses the effort level.

This extension of the model produces results very similar to the basic model with no monetary incentives described above, and can be summarized in the following proposition.

Proposition B.1 *Consider the choice of the organizational form, for different values of* π. *Assume* $R > B$. *If* $\frac{\gamma}{4}(B+R)^2 < \rho < \frac{\gamma}{2}(B+R)^2$, $\exists\ \overline{\pi}\ \in (0,1)$ *s.t. the project is performed in-house if* $\pi \geq \overline{\pi}$, *and the project is outsourced to a university otherwise. More precisely,*

$$\overline{\pi} = 2 - \frac{4\rho}{\gamma(B+R)^2}, \tag{B.1}$$

where:

$$\frac{\partial \overline{\pi}}{\partial B} > 0;\ \ \frac{\partial \overline{\pi}}{\partial R} > 0;\ \ \frac{\partial \overline{\pi}}{\partial \rho} < 0. \tag{B.2}$$

Also, regardless of the authority structure chosen, the monetary bonuses are:

$$b_s = \frac{R-B}{2};\ \ b_F = 0 \tag{B.3}$$

Proof. As before, we solve the game by backward induction, starting from the agent's problem of the choice of the optimal effort.

When the scientist is an independent contractor, the original project will always be brought to completion. The scientist therefore chooses effort as:

$$e^{out} \in \left\{ \arg\max_e \left[(B + b_s)e + (0 + b_F)(1 - e) - C(e;\gamma) \right] \right\} \tag{B.4}$$

Given the form of the cost function (as in (2.1) at page 86), we have the following equality:

$$b_s - b_F = \frac{e}{\gamma} - B \tag{B.5}$$

The firm does not have the power to terminate the original project and undertake the new one even if it becomes available. The problem of the company can be though of as one of choosing the optimal amount of effort e and the bonus b_F. Equation (B.5), which represents the incentive compatibility constraint for the agent, will then determine b_s. The company chooses the optimal level of these variables taking also into account the reservation utility of the scientist (her utility in the next best available option), which we normalize to be equal to zero for simplicity, and the non negativity constraints on b_s and b_F. The problem of the firm is therefore:

$$\underset{e,b_F,b_s}{Max}\Pi^{out} = e(R - b_s) + (1 - e)(0 - b_F) \tag{B.6}$$

subject to

$$b_s - b_F = \frac{e}{\gamma} - B \tag{B.7}$$

$$(B + b_s)e + (0 + b_F)(1 - e) - C(e;\gamma) \geq 0 \tag{B.8}$$

$$b_F \geq 0 \tag{B.9}$$

$$b_s \geq 0 \tag{B.10}$$

To solve this program, let us begin by substituting (B.7) into (B.8). We obtain

$$\left(\frac{e}{\gamma} + b_F\right) e + (1 - e)b_F - \frac{e^2}{2\gamma} = b_F + \frac{e^2}{2\gamma} \geq 0 \tag{B.11}$$

The inequality is verified for any non-negative b_F. Therefore b_F will be set equal to 0. Let us then substitute these results into the objective function (B.6), and let us not consider, for the moment, the constraint (B.10). Using again (B.7) and the fact that $b_F = 0$, we write $b_s = \frac{e}{\gamma} - B$. Therefore we have an unconstrained maximization problem with only one choice variable, e. We determine the first order condition for the problem in (B.6) and obtain

$$e_*^{out}=\frac{\gamma}{2}(R+B) \tag{B.12}$$

Therefore,

$$b_s=\frac{e_*^{out}}{\gamma}-B=\frac{R-B}{2}. \tag{B.13}$$

Since we assume $R > B$, also constraint (B.10) is satisfied and indeed is not binding. Notice that the first best effort in this organizational form is $e^{FB}=\gamma(R+B) > e_*^{out}$. The return for the firm is

$$\Pi^{out} = e_*^{out}(R-b_s) = \frac{\gamma}{4}(B+R)^2 \tag{B.14}$$

When the scientist is an employee, the original project is brought to completion only if the alternative project does not become available. The scientist therefore chooses effort as:

$$e_*^{in} \in \left\{\arg\max_e \left[(B+b_s)e(1-\pi)+(0+b_F)(1-e)(1-\pi)-C(e;\gamma)\right]\right\} \tag{B.15}$$

Given the form of the cost function (as in (2.1) at page 86), we have the following equality:

$$b_s-b_F=\frac{e}{\gamma(1-\pi)}-B \tag{B.16}$$

Again, the problem of the company can be thought of as one of choosing the optimal amount of effort e and the bonus b_F, with b_s determined by the incentive compatibility constraint just derived. The problem of the firm is:

$$\underset{e,b_F,b_s}{Max}\,\Pi^{in} = (1-\pi)\left[e(R-b_s)+(1-e)(0-b_F)\right]+\pi\rho \tag{B.17}$$

subject to

$$b_s-b_F=\frac{e}{\gamma(1-\pi)}-B \tag{B.18}$$

$$(B+b_s)e(1-\pi)+(0+b_F)(1-e)(1-\pi)-C(e;\gamma)\geq 0 \tag{B.19}$$

$$b_F \geq 0 \tag{B.20}$$

$$b_s \geq 0 \tag{B.21}$$

As before, we substitute (B.18) into (B.19). We obtain

$$(1-\pi)\left[b_F+\left(\frac{e}{\gamma(1-\pi)}\right)\right]e+b_F(1-e)(1-\pi)-\frac{e^2}{2\gamma}=(1-\pi)b_F+\frac{e^2}{2\gamma}\geq 0 \tag{B.22}$$

The inequality is verified for any non-negative b_F. Therefore b_F will be set equal to 0 as in the previous case. Proceeding as above, we get:

$$e_*^{in}=\frac{\gamma}{2}(R+B)(1-\pi) \tag{B.23}$$

and

$$b_s=\frac{R-B}{2}$$

Notice that $e_*^{in}< e_*^{out}$. The return for the firm is

$$\Pi_*^{in}=e_*^{in}(R-b_s)(1-\pi)+\pi\rho=\frac{\gamma}{4}(1-\pi)^2(B+R)^2+\pi\rho \tag{B.24}$$

The firm will opt for having the scientist as an employee if $\Pi_*^{in}\geq\Pi_*^{out}$. This condition is equivalent to

$$\pi\geq 2-\frac{4\rho}{\gamma(B+R)^2}.$$

Hence the threshold in (B.1) and, straightforwardly, the comparative statics in (B.2). ■