Different Missions and Commitment Power in R&D Organization: Theory and Evidence on Industry-University Alliances*

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Abstract

This paper proposes a theory for why firms conduct some research activities in-house while outsourcing other projects to independent partners, and for why firms retain different degrees of control over collaborative research projects. The focus in on the determinants of a company's choice to outsource research projects to academic organizations. Due to the different institutional mission 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. An economic model that formalizes these arguments is developed. Empirical hypotheses are then formulated about the kind of research activities firms will outsource to universities, and activities on which they will exert stronger control. Evidence from a sample of industry-university research agreements, as well as from other large-sample and case studies, shows patterns consistent with the predictions of the model.

KEYWORDS: R&D Organization, Firm Boundaries, Industry-University Relations.

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Introduction

Understanding firms' organizational choices in the performance of R&D has long been a purpose of many scholars in Organization Theory, the Economics of Innovation, and Strategic Management. Despite the documented trend toward in-house R&D downsizing (Oldyzko 1995, Rosenbloom and Spencer 1996), there is vast evidence that firms still invest in scientific research, and that they perform the bulk of it within their boundaries (NSF 2002). At the same time, companies are experimenting with multiple, alternative organizational forms in R&D. In particular, they outsource research projects to other organizations. An increasing trend is for companies to collaborate with universities, especially for the performance of more general-purpose research (Mowery and Teece 1996, NSF 2002, Geiger 2004).[1]

This paper studies what leads firms to choose different organizational arrangements to perform R&D. A theory is proposed for why firms conduct some research activities in-house while outsourcing other projects to independent partners, and for why firms retain different degrees of control over collaborative research projects. In particular, this paper analyzes the determinants of the choice of a company to outsource research projects to academic organizations. The main insights of the analysis, however, are applicable beyond alliances with universities, toward a better understanding of the overall organization of R&D.

The focus of the analysis is on the different missions to which firms and universities are committed, and on the contractual differences between different organizational arrangements, in terms of the allocation of decision power. While firms aim to obtain economic profits, the objectives of academic organizations include the production and expeditious diffusion of scientifically-valuable knowledge, regardless of strict considerations about the economic value of a given research project (Merton 1973, Dasgupta and David 1994). Moreover, outsourcing a project implies some delegation of decision power to an independent party, to a greater extent than when a project is developed in-house. Due to the different institutional missions and to the formal 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

[1] Cohen et al. (1994), NSF (2002), and Geuna et al. (2003) provide evidence on the collaborations between companies and research institutions and the increasing trend over time. Kenney (1986), Press and Washburn (2000), and Lawler (2003) describe several research collaborations in detail.

hand, a firm has greater discretion through its higher formal authority: for example, it would be easier to terminate a project or to gear it toward alternative, more profitable directions.

This theoretical framework is then translated into empirical predictions. One prediction concerns the relation between the authority a firms retains over a research project, and the duration of the 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 equal, might want to retain higher control over the research agenda. Another prediction is that firms will be more willing to delegate control over the conduct of research, when the research has a broader applicability. If a research project is applicable to several areas, then it is less likely that a firm wants to switch to a different project with better economic prospects. Evidence from a sample of research contracts between biotech companies and academic organizations shows that companies retain more power for longer projects, and for projects whose outcomes are applicable to a lower number of diseases. The analysis of historical cases as well as of previous large sample studies shows patterns consistent with the model's predictions.

The theoretical claims and empirical findings of this paper have organizational and strategic relevance for companies. Guaranteeing greater autonomy to scientific workers over their activities, even when their objectives and priorities differ from those of the top management (and are closer to the objectives of their community of peers), is a powerful device for increasing scientists' incentives to supply productive effort. Among the devices a firm can use to make its commitment to research more credible, contracting out research to organizations whose main mission is aligned with that of the overall scientific community, is a particularly effective one. It may be beneficial for a firm to let the university partner "behave like a university", and not to interfere too much with its activities and the pursuit of its objectives. The advantage of a stronger commitment needs to be weighed against the cost of a loss of authority and flexibility over the performance and direction of research activities. The analysis is also relevant from a public policy standpoint. It provides a foundation to those who claim that universities should have research agenda of more actual, concrete relevance, but 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). Institutional diversity should be preserved in order to reap the benefits of each institutional configuration and contractual arrangement.

Costs and benefits of different organizational arrangements in R&D have been the subject of several previous analyses. A few studies have stressed the importance of having in-house research activities in order to better protect a company's intellectual property (Scherer 1964, Mansfield et al. 1977). Anecdotal evidence, surveys, case studies, and large-sample statistical findings, however, show that firms tend to collaborate with universities in more fundamental, general-purpose research.[2] These projects are likely to generate more serious appropriability concerns. Veugelers and Cassiman (2005), furthermore, do not find evidence that appropriability problems limit col-

[2] Mowery and Teece (1996), NSF (2002), Howitt (2003), Geiger (2004).

laborations with universities. 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 increase IP protection within universities, reduce the differences between performing research in-house and outsourcing it. Nonetheless, we still see companies choosing different organizational choices for different research activities. To the extent that we see these behaviors by companies, we should therefore look for explanations of these choices other than appropriability concerns.

A further argument brought in favor of the presence of an internal research force is that only through in-house research can companies develop absorptive capacity. Acquiring and exploiting external knowledge requires the development of firm-specific knowledge, and this can be done only in-house (Cohen and Levinthal 1990). This argument may rule out the viability of short-term research contracts with external agents, but it does not exclude the effectiveness of longer-term alliances. These alliances are not infrequent. Besides, an number of studies found that companies develop absorptive capacity also through external channels, including collaborations with academic scientists (Cockburn and Henderson 1998, Lim 2000, Markiewitz 2004). The framework of this paper offers theoretical arguments that stand up to these critiques, since the different in organizational choices are characterized in terms of the level of authority each party retains and not in terms of the type of knowledge that is produced.

Other studies have instead stressed the advantages that firms derive from collaborating with such partners as universities and other research organizations. Academic scientists are strongly motivated to produce high-quality science, thus potentially raising also the likelihood of economic success. The analysis in this paper assumes that academic and company scientists respond to the *same* incentives and motivations. It is the control structure, and the mission of different organizations, that change. This approach is motivated by several studies showing 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, for example through publication (Nelson 1962, Cockburn et al. 1999, Howitt 2003, and Stern 2004). A claim of the superiority of academia in performing some types of research, founded exclusively on the incentive systems, seems neither warranted nor satisfactory. It can also be argued that firms may contract some research projects out to other firms and universities also in order to overcome capacity constraints, or in order to share risks. 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.

The theory in this paper shares some aspects with a few other studies. Aghion et al. (2005) have independently and contemporaneously developed a closely related model. They assume that, in exchange for more freedom of inquiry, scientists accept lower wages in universities than in firms.

A "social planner" would therefore assign earlier phase research to universities, since the expected economic value of the project would low and it is therefore appropriate to save on wage. The planner would then move research to firms in later phases. Unlike Aghion et al., the point in view of this paper is that of a company deciding how to organize its research activities. The focus, moreover, is on the trade-off between authority and effort instead of the wage-freedom trade-off. The empirical predictions and findings in this paper differs from Aghion et al. They are concerned with the phase of research, while I focus on duration and breadth. Besides, for projects that are expected to last longer, the empirical analysis below shows that firms retain more control. If we interpret these projects as being longer because they start in earlier phases, then this result differ from Aghion et al. (their paper, in fact, does not analyze any empirical evidence). In a series of influential papers, Julio Rotemberg and Garth Saloner (Rotemberg and Saloner 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. With reference to open-source and technology sharing, Lerner and Tirole (2005) suggest that a corporation may not be able to credibly commit to keep 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. Manso (2006) claims that a firm needs to commit not to terminate a scientific worker, in order to provide him with incentives for "exploration" activities in addition to "exploitation" activities. However, it is not clear whether the worker is an employee or an independent contractor. If she is an employee, then it is hard to believe that a firm can credibly commit not to terminate.

Section 1 develops a qualitative theory of the choice of different organizational structures in the performance of research activities. An economic model of R&D organizational choices is presented and solved in Section 2. Section 3 presents case-based and large sample evidence on the allocation of decision power in research collaborations between companies and academic organizations. Section 4 discusses the broader organizational implications of the analysis and also its insights for public policy. Section 5 summarizes and concludes.

1 Authority, commitment, and the role of universities

> 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 [...] - strikes hard at the traditions of science (R. Nelson, 1962, p. 573).
>
> 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, Chevron Research and Technology Co. University of California President's Retreat, 1997)

1.1 Institutional and contractual differences

When a company outsources some of its activities to an independent contractor, the firm gives up on some authority it would have, were the activities performed in-house. Moreover, the independent contractor may have objectives and priorities that do not coincide with those of the company. For example, if the project if performed within the firm's legal boundaries, a firm might be able to shut down or modify a project, irrespective of the opinion of the agent. If the project is outsourced, however, a firm would be much more constrained in its ability to exert these powers unilaterally.

Differing objectives and delegation of power generate fundamental differences between research activities performed in-house and outsourced. This is particularly the case when research is outsourced to academic organizations. 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. Merton (1973) sees universities as repositories and institutional guardians of the CUDOS norms: communalism, universalism, disinterestedness, and organized skepticism (see also Dasgupta and David 1994 and David 2004). Ben-David (1977) stresses how freedom of inquiry is at the very foundation of the modern research university. Argyres and Liebeskind (1998) argue that academia is bound by an implicit contract with society to pursue its peculiar mission. 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. These characteristics of academic organizations put universities in marked contrast with profit seeking companies, in terms of their missions and priorities. A firm may be able to provide high-powered *incentive systems*, potentially consistent with those of the scientific community, to its researchers. However, a firm cannot, by its own nature, commit to the institutional *objectives* of the scientific community. The quest for knowledge may conflict with the quest for economic profits.

Evidence from several sources is consistent with the above claims. Lacetera (2006) analyzes research contracts between biotech companies and universities (or other non-profit research entities). The study finds 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. Strong control rights are granted to the firm only in a minority of contracts, and even in these contracts 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. 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 a deal between Exxon and MIT, 20% of funds had to be allocated according to the sole decision of MIT faculty members. In the 200 biotechnology research contracts (between

companies) 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 and companies are less likely to be aborted prematurely. Guedj (2004) finds that firms terminate in-house projects more frequently than outsourced projects. Private conversations and interviews 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 if the research is directly performed by the company. University researchers, when interviewed, expressed the belief that they would not have the same freedom to pursue scientifically-relevant projects if employed by a company.

Even companies known for their "science-friendly" environments, finally, do not seem to be able to commit to a complete adherence to scientific rules when research is in-house. The history of one such "science friendly" company, 3M, reveals that R&D managers have always retained (and often exerted) the direction over the choices of scientists and engineers about which projects to pursue (Bartlett and Mohammed 1995). Griffiths (2005) reports the following quote from a manager at Genentech, another company known for the freedom given to its scientists:

> '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.

1.2 Different missions and commitment power

If scientific workers 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.

In the following Section, a model is built that helps to clarify the informal arguments just made. In turn, this exercise will lead to the elaboration of empirical prediction and the analysis of several pieces of evidence, which will be the third step of this study.

2 A model

2.1 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 at a later date. The firm can work on only one project at a time.

The scientist's effort Think of effort e as a function of the intellectual investment 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.[3] The effort of the scientist has a cost of

$$C(e; \gamma) = \frac{e^2}{2\gamma}, \tag{1}$$

where $\gamma > 0$ is a scaling parameter.[4] The effort choice is not contractible and not observable. It is too complex to write in a contract what kind of activities the scientist is supposed to perform, and monitoring is very costly.

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) value of the research are realized.[5]

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 scientific value, at least

[3] Scientists working for companies and for universities are assumed to have the same capabilities. Several studies show that, especially in research-intensive industries, company scientists often are of a very high quality, to the point that some have received the highest honors, e.g. the Nobel Prize (Nelson 1962, Stephan 1996, Howitt 2003). One could also think of the model as studying the *same* scientist employed under different authority structures.

[4] The convexity of the cost function (together with a linear benefit function – see below) allows for internal solutions. More general convex cost functions could be used, but the quadratic form, allows for close (and easy to intepret) solutions.

[5] 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 $\rho_L = 0$. at a future date, the return may increase to ρ. Assuming $\rho_L = 0$ and $\rho > R$ is actually more restrictive than what necessary to obtain the results described below. However, relaxing these assumptions introduces complications (e.g. multiple equilibria) which do not add much insight.

from the point of view of the scientist. 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.

Scientific and economic value 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 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, e.g. on genetically modified plants and food, stem cells and cloning, or 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 provisions would make alternative economic opportunities more appealing than the original ones a firm might have undertaken. However, the scientific relevance of the original projects might be higher than the scientific attractiveness of these 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 competition is not modeled here). The economic value of the competing product may be very high, and the firm can obtain a license to commercialize it. 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, as the novel research in the different scientific base has been done by other actors. 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.[6]

2.2 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 $\omega = \{in\text{-}house,\ outsource\}$.

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. The boss cannot commit not to overrule any proposal of the agent (Simon 1951, 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, it is assumed that the firm cannot unilaterally terminate the original project "without cause", neither can it decide whether to undertake the alternative project (if available). This assumption is extreme, but it captures the essence of the contractual differences between the two possible organizational and contractual structures.

Define the project choice as a binary variable: $d \in \{0,1\} = \{stay\ on\ old\ project,\ switch\}$. 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 (Gibbons 2005). The discretion over d is lost when the project is outsourced.

2.3 Timing of the game

The game has five stages:

1. The firm chooses $\omega \in \{in\text{-}house,\ outsource\}$.

2. The scientist chooses the effort level e.

3. The value of the alternative opportunity (if it arises) is revealed.

4. If the project is carried in-house, the firm chooses $d \in \{0,1\} = \{stay\ on\ old\ project,\ switch\}$.

5. The project is completed and the payoffs of the parties are realized.

[6] See for example Saltus (2000) on the case of the biotech company Entremed, whose research on tumors turned out to be more useful to treat some eye diseases than to treat cancer.

2.4 Payoffs

> A scientist might delight in a research failure [...] because [it] eliminates a range of theories and leads to new pathways. But from an appropriator's point of view, that does not look very attractive (Sharma and Norton 2004).

2.4.1 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, e.g. the firm obtains an option to (exclusively) license, or the right to first refusal to any patentable invention. The firm's ex ante profit function, if the project is carried in-house, is:

$$\Pi^{in} = (1-\pi)[(1-d)eR + d^*0] + \pi[d\rho + (1-d)eR]. \tag{2}$$

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, as 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

$$\Pi^{out} = eR. \tag{3}$$

2.4.2 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. B can include private benefits, such as recognition among peers in the scientific community, job satisfaction, public legitimacy, as well as future job opportunities. These benefits are either difficult to translate in monetary terms, or at least they are not directly paid by the firm. The benefits are private and non-contractible: they cannot be transferred to other agents (in particular to the firm), and cannot be reliably verified by a third party, therefore they cannot be written down in a formal contract. 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).[7] 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:

[7] The assumption of the private and non-contractible nature of some benefits is similar to that in other recent works, such as Hart and Holmstrom (2002) and Gautier and Wauthy (2004). These benefits cannot be traded, thus making the incentive problem more complex. Appendix A below describes an extension of the model that includes the response of scientists to monetary incentives, reaching similar conclusions to the model presented here.

$$U^{in} = (1-\pi)(1-d)eB + \pi(1-d)eB - \frac{e^2}{2\gamma} = (1-d)eB - \frac{e^2}{2\gamma}; \tag{4}$$

$$U^{out} = (1-\pi)eB + \pi eB - \frac{e^2}{2\gamma} = eB - \frac{e^2}{2\gamma}. \tag{5}$$

U^{in} indicates the scientist's utility if the project is performed in-house, and U^{out} indicates the utility if the project is outsourced. The institutional mission of the university allows the scientist to pursue such objective without interference. The scientist and the university will not be willing to terminate the project and switch to the alternative one, if there is an opportunity to do so.[8]

2.5 Analysis

The model is solved by backward induction, starting from the firm's project choice.

2.5.1 The firm's project choice

Recall that the project's decision d is not contractible, therefore the firm cannot commit to a given project. Besides, 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. Renegotiation is assumed away in the model. 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.[9]

2.5.2 The scientist's effort

The scientist's optimal choice of effort e^{out} and e^{in}, for the project done in-house and outsourced respectively, is such that:

$$e^* = \begin{cases} e^{out} \in \left\{ \arg\max_e \left[Be - \frac{e^2}{2\gamma} \right] \right\} \\ e^{in} \in \left\{ \arg\max_e \left[(1-\pi)eB - \frac{e^2}{2\gamma} \right] \right\} \end{cases}. \tag{6}$$

[8] The interests of scientists and universities are perfectly aligned in this model. For detailed analyses of the relation between academic scientists and administrators, in particular Technology Transfer Offices, see Jensen and Thursby (2001). Lazear (1997), Arora et al. (1998) and Goldfarb (2006) argue that goal and incentive misalignment can occur also between scientists and public funding agencies, and not only between companies and scientists. In these two papers, conflicts derive specifically for differences in preferences. Here, potential disagreement over the course of action can be said as emerging either from preferences or from different institutional arrangements, since the goals of universities and scientists (regardless of their formal affiliations) coincide.

[9] 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 novel scientific content in it, since this would not respect the mission of the university.

The firm does not have the authority to move to the alternative path if the project is outsourced. Therefore, there is no action at stage 4, whatever the realization of the state. When the project is done in-house, the scientist has to consider the likelihood of emergence of the new economic opportunity because, if it emerges, the original project will not be brought to completion. If the firm shuts the original project down, the ex-post benefit of the scientist is zero. Solving for the (necessary and sufficient) first order conditions, we obtain

$$e^{out} = \gamma B; \tag{7}$$

$$e^{in} = \gamma B(1-\pi). \tag{8}$$

The choice of effort increases with the expected private benefit from the project. Furthermore, the absence of commitment by the principal to complete the project regardless of the state of the world weakens the scientist's incentives.

2.5.3 The firm's organizational choice

The firm's organizational choice ω is

$$\omega = \begin{cases} \text{in house if } (1-\pi)e^{in}R + \pi\rho > e^{out}R \\ \text{outsource otherwise} \end{cases} \tag{9}$$

2.5.4 Solution

We obtain the following result:

Proposition 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,*

$$\overline{\pi} = 2 - \frac{\rho}{B\gamma R}. \tag{10}$$

In addition:

$$\frac{\partial \overline{\pi}}{\partial B} > 0; \quad \frac{\partial \overline{\pi}}{\partial R} > 0; \quad \frac{\partial \overline{\pi}}{\partial \rho} < 0. \tag{11}$$

Proof. Consider the following difference:

$$\Delta\Pi = \frac{\left(\Pi^{in} - \Pi^{out}\right)}{\gamma R} = B\pi^2 - \left[2B - \frac{\rho}{\gamma R}\right]\pi + (B - B). \tag{12}$$

Now, $\Delta\Pi \geq 0$ (i.e. the project is done in-house) if $\pi \in [\overline{\pi}, 1]$, where

$$\overline{\pi} = 2 - \frac{\rho}{B\gamma R}. \tag{13}$$

From the assumption that $B\gamma R < \rho < 2B\gamma R$, it follows that $\overline{\pi} \in (0,1)$. The comparative statics in (11) follow straightforwardly. ■

Figure 1 below reports some examples of optimal allocation of research projects, for different values of the parameters. Each curve represents 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. Conversely, if the curve is below the zero line, then the firm outsources.

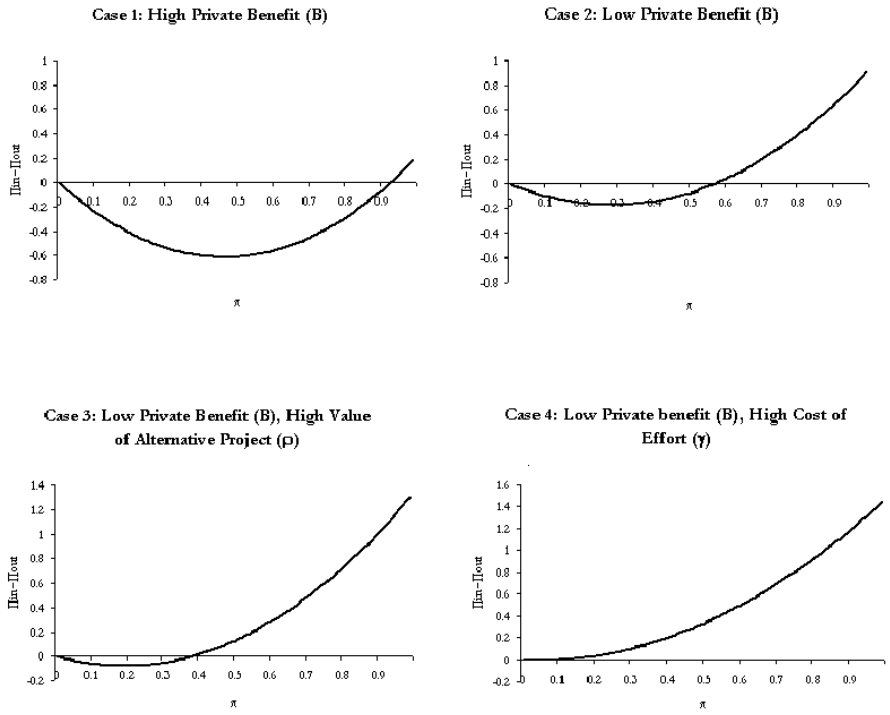

Figure 1: Examples from Proposition 1 (page 13). $R = 3$ in all cases. In case 1, $\gamma = .8$, $\rho = 3.1$, $B = 1.2$. In case 2, $\gamma = .8$, $\rho = 3.1$, $B = .9$. In case 3, $\gamma = .8$, $\rho = 3.5$, $B = .9$. In case 4, $\gamma = .6$, $\rho = 3.1$, $B = .9$.

The model lends itself to a few empirical predictions. The following Section is dedicated to these predictions and their validation.

3 Empirical patterns

This section proposes some empirical predictions emerging from the discussion and the model above, and assesses them against different sources of evidence: cases of research collaborations between companies and academic organizations, issues in the internal organization of R&D in research oriented companies, patterns from large-sample studies, and trends in company funding of academic research over the past three decades. No single piece of evidence can be taken, in and of itself, as a conclusive test of the model. Nonetheless, the variety and the relevance of the evidence, as a whole, suggest that the issues on which this paper focusses are of broad empirical relevance and emerge as key variables the organizational and strategic choices of companies.

3.1 Predictions

An empirical prediction of the above analysis is that firms prefer to perform research in-house, or to bargain for stronger control rights, when projects have longer duration. 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. A second prediction is that firms will be more willing to delegate control over the conduct of research, when the research has a broader applicability. If a project's outcomes are expected to be applicable to several areas, then it is less likely that a firm wants to switch to a different project with better economic prospects.

3.2 Cases and examples

3.2.1 Novartis-Berkeley

In 1998, the agri-pharmaceutical company Novartis signed a $25M, five-year non-targeted research deal with the Department of Microbial and Plant Biology at Berkeley for the development of several projects (Press and Washburn 2000, Lawler 2003). The parties formed a committee that would allocate funds to the research projects the academic researchers proposed. Of the five seats of the committee, Novartis was granted only two. 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 more about providing the strongest possible incentives to the scientists, than being able to promptly stop a project. However, the growing popular as well as legislative opposition to genetically modified foods arguably reduced the breadth of application of the research funded by Novartis – an increase in π, in the model. These environmental changes might also have reduced the expected returns from the original projects. In the logic of the model, these factors would increase the incentive to perform projects under a stricter authority, thus making a deal with an independent academic partner less sustainable. The deal, in fact, was not renewed in 2003 (Lawler 2003, IFAS 2004).

3.2.2 Amgen-MIT

The biotech company Amgen and MIT agreed in 1994 on a multi-year research collaboration, with a financial commitment by Amgen of about $35M in nine years (Lawler 2003). 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.

3.2.3 DuPont-MIT

By contrast, MIT and DuPont have recently renewed their 2000 alliance for five more years (with $25M in addition to the original $35 committed in 2000). Interestingly, the agreement has been extended to cover other research areas beyond the original focus on biotechnology and biomaterials. These areas include nanotechnology, which is thought to have a vast range of applications (Brown 2005), and is in very early stages. Scientific progress is therefore close to economic value, and the model above predicts that these areas of research are more likely to be the subjects of collaborations between companies and academic research teams.

In the MIT-DuPont alliance, it is also 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.[10]

3.2.4 Internal organization at 3M

This paper's framework also contributes to understanding the internal organization of research activities in companies, not only the relations with academic organizations in the performance of R&D (see also Section 4.1 below). The evolution of the organization of R&D at 3M offers an illustration of the relevance of the issues at the core of the analysis. 3M had to deal, in different periods of its history, with major challenges regarding how much freedom to guarantee to its scientists and engineers. The increasing diversification of the company's product line, for example, led to a proliferation of labs, each focused on a narrow set of technologies. In order to keep such a focus, managers had to impose more discipline upon the lab workers, thus limiting their discretion. Similarly, the increased competition in more recent times led the managers to strengthen their authority over the scientists and the direction of R&D effort, in order to make it closer to the dynamics in the marketplace. Bartlett and Mohammed (1995) offer a description of these challenges. Consider the following quotes they report:

> 'Previously innovation was driven by management asking researchers: what rabbit can you pull out of the hat to meet our targets? [...] there were hundreds of initiatives – you could do anything. But as development became more expensive and riskier, we needed the focus and discipline of the new structure and precesses' (a 3M VP in 1993).
>
> 'Previously a scientist could work on a project for years [...]. Today we try to do a lot more sorting out early'. (Chuck Reich, VP of the Dental Product division).

[10] A conversation with Dr. Bruce Smart of DuPont on the features of this alliance was of great help. His collaboration is gratefully acknowledged. See also the alliance's web site: web.mit.edu/dma/www.

The management aware that an increase in authority over the scientists might negatively impact the effort provision of scientists:

> 'There is clearly less freedom in the labs that there was 10 or 15 years ago, and that means it's less fun for the researchers. As a result, there are more motivation and morale issues to deal with today'. (A division VP in the early 1990s).

A series of initiatives were undertaken in order to offset these motivation problems. These included the promotion of internal, recognition-based rewards, as well as keeping some research activities within large labs with multiple technologies. Consistent with the results of the model above, tensions over the granting of research freedom emerged as the research process became more risky and focused.

3.3 Evidence from research contracts

This section analyzes research contracts between biotech companies on the one hand, and universities, hospitals and other non-profit organizations on the other hand. The contracts were downloaded from rDNA, the database of Recombinant Capital, a San Francisco based consulting company. A detailed description of the data collection and variable construction process, and of the specifications of the econometric analysis is provided in Appendix B. The main tests concern whether the strength of control of the sponsoring company over the research is related to the expected duration of the research project, and to the breadth of applicability of the research. Note that, while the model above concerns "make-or-buy" decisions by companies, the data analyzed here all concern outsourced research, with different degrees of control by the sponsoring firm. The model can be easily extended to generate logically similar predictions when conditioning on outsourcing, as long as there is some positive cost of control.[11] More generally, rather than a formal, conclusive test of the theory, the following analysis should be interpreted only as descriptive and suggestive of whether the previous theoretical claims have empirical content. To be sure, further empirical work and statistical specifications are required in order to produce more compelling and tests.

Table 1 reports mean comparisons of the level of control exerted by companies, for different project durations and scope. Three measures of control power by the firm are used. The first measure is a dichotomous variable for whether the firm has unilateral termination rights without cause. This right is the closest empirical variable to the switching/terminating decision in the model above. The second measure is the sum of four major control rights given to the sponsoring

[11] Assume a firm has established a collaboration with a university. The firm decides how much control to retain over the research. Control over research, just as in the model of Section 2, gives the firm power to shut the current project down and move to a new one. The variable expressing control is called d, as before, but now it assumes a continuum of values between 0 and 1, where 1 indicates "full" control. Taking decisions is costly, say because the firm has to negotiate or put in place a monitoring structure. Define these costs as $\frac{d^2}{2\varphi}$, $\varphi > 0$. The firm decides how much control to retain. The reamining structure of the game is the same as above. It can be shown that the optimal degree of power is $d^* = \frac{\varphi\pi(\rho - 2RB\gamma)}{1-2RB\gamma\varphi\pi^2}$. Note in particular that $\frac{\partial d^*}{\partial \pi} > 0$: the higher the probability that a new project emerges (or the lower the alignment between sciantifically and economically optimal projects), the higher the degree of control retained by the firm. The main results and predictions of the model in Section 2 hold also in this case.

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. Based on this second variable, a third variable was created, taking value 1 if the firm has any of these control rights, and zero otherwise. The breadth of applicability is defined in terms of the number of diseases (or disease areas) the research is reported to deal with. A higher number of diseases is a proxy for broader scope of the research. Table 1 shows that the share of contracts where firms have more control is significantly higher for longer research projects.[12] For projects expected to have broader applicability, the share of contracts with stronger power by the firm is lower. In particular, in all of the instances where the number of diseases areas cover by the research is greater than two, the sponsoring firm does not retain any of the relevant control rights. While there are only few such cases of very broad applicability, this is a particularly suggestive result.

	Share of contracts with unilateral termination right without cause for the firm	Sum of major control rights to the firm*	Share of contracts with firm having at least one major control right
Project duration<=2yrs	**.16**	**.33**	**.27**
Project duration>2yrs	**.32**	**.62**	**.48**
Num of diseases=1	**.29**	.47	.37
Num of diseases>1	**.11**	.39	.32
Num of diseases<=2	**.25**	**.47**	**.37**
Num of diseases>2	**0**	**0**	**0**

Mean pairs reported in bold types are significantly different at least at the 10% level
*Sum of the following dichotomous variables expressing the rights of the firm to: termination right without cause; extend the duration of the project; modify the direction of the research; receive (and approve) periodically budget and research proposals submitted by the academic partner.

Table 1: Mean comparisons of firm's control rights, for different research durations and breadth. The unit of analysis is the research contract. the research contract.

Table 2 shows the results from probit and ordered probit regressions of the different proxies of firm authority on the measures of the breadth and duration of research. The control variables, and the relevance of including them in the analysis, are discussed in Appendix B. Duration is strongly and positively correlated with firm's authority. The scope of research and firm's authority show, in turn, a consistently and sizably negative correlation.[13] Among the control variables, one

[12] The cutoff for defining a ling project has been set at two years. This is a reasonable cut-off to distinguish "long" and "short" research projects. One year appears as too short, and three years would leave too few observations in the subset of long term contracts. The firms signing these contracts are very young, therefore a two-year commitment can be seen as long term.

[13] The sample has 171 observations, i.e. the maximum number of data points for which information is available on all of the variables, including the controls, out of an initial sample of 550 contracts. Regressions without control variables were also performed on a larger sample size, consisting of 229 observations, for which data on control rights, duration, and number of diseases are available. The results are unchanged for the duration variable. As for the number

that is worth mentioning here is a proxy for the Principal Investigator's ability, expressed by his or her cumulative impact factor of his/her publication up to the year the contract is signed. This (admittedly crude) proxy for PI's ability is not significant in the regressions. The findings are instead suggestive of the impact of the breadth of applicability and duration of the research, and are consistent with the theoretical predictions of the model.

	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**					
	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b	8a	8b	9a	9b
Regressors																		
Project duration	**.14** (.07)	**.22** (.08)	**.14** (.07)	**.22** (.08)	**.12** (.06)	**.18** (.07)	**.17** (.06)	**.25** (.06)	**.16** (.06)	**.25** (.06)	**.16** (.05)	**.24** (.06)	**.20** (.08)	**.26** (.08)	**.19** (.07)	**.26** (.08)	**.19** (.07)	**.25** (.07)
Num of diseases	**-.67** (.24)	**-.87** (.30)					**-.29** (.19)	**-.39** (.19)					**-.30** (.17)	**-.41** (.20)				
Dummy=1 if num of diseases>1			**-.70** (.28)	**-.88** (.31)					-.20 (.20)	-.33 (.24)					-.21 (.22)	-.33 (.25)		
Dummy=1 if num of diseases>2					**	**					**	**					**	**
Control vars.	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Method	Probit	Probit	Probit	Probit	Probit	Probit	Ord. Probit	Ord. Probit	Ord. Probit	Ord. Probit	Ord. Probit	Ord. Probit	Probit	Probit	Probit	Probit	Probit	Probit
Pseudo R_square	.07	.16	.06	.16	.02	.10	.04	.08	.03	.08	.05	.09	.05	.10	.03	.09	.04	.08
Chi-stat	**9.6**	**27.6**	**8.4**	**29.2**	**3.6**	19.3	**10.2**	**25.9**	**8.9**	**24.6**	**	**	**8.16**	19.5	**6.7**	17.9	**6.4**	17.1
Obs	171	171	171	171	163	163	171	171	171	171	171	171	171	171	171	171	163	163

Estimates in bold types are significant at the 10% level or more. Estimates in italics are significant between 10% and 15% level. Robust standard errors in parentheses.

Control variables are listed and dicussed in the text and in the Appendix. A constant is present in all models.

*Sum of the following dichotomous variables expressing the rights of the firm to: termination right without cause; extend the duration of the project; modify the direction of the research; receive (and approve) periodically budget and research proposals submitted by the academic partner.

** Eight observations (all those for which the number of diseases is >2) are dropped because they perfectly predict zero control rights to the firm, in models 3a, 3b, 9a, 9b. In models 6a and 6b, these same eight observations perfectly predict the dependent variable to be zero. Although estimates can be calculated and observations are not dropped in ordered probit, the estimates are inflated and the standard errors (as well as the chi-stat) are not reliable, hence they are not reported.

Table 2: Regression results. The unit of analysis is the research contract. Appendix B further discusses the data sources, variable construction, and the econometric specifications, and reports descriptive statistics.

of diseases, the strong result of no control rights to the firm when the diseases are more than two is confirmed. As for the other proxies, while the signs of the estimated parameters are still negative, in some cases the estimates are attenuated and less significant (e.g. at the 15% level) than in the smaller sample. There are a few reasons for this to be the case. First, both the smaller and the larger sample are just a small subset of an already limited sample of an "unknown" population. As a consequence, one should expect estimates to bounce. Second, as can also be seen from Table 2, the parameter estimates in the uncontrolled regressions are smaller (in absolute values) than those in the controlled regressions, suggesting downward bias if controls are not added. Third, and especially concerning the breadth variable, errors in variables may be more likely to have occurred in the larger sample (even though the distribution of values of the number of diseases variable is similar in the 171 observations and in the remaining 58 observations). Unlike the duration of the research, which is explicitly expressed in the original contracts, the number of diseases the research is supposed to address is *added* on the front page of each contract by Recombinant Capital analysts. The errors, moreover, are more likely to occur (though it is not clear in which direction) for those contracts where less information is available about other relevant characteristics, i.e. the additional 58 contracts. As it turns out, the attenuation in the larger sample is greater for the coefficients on the breadth variables: the estimates related to the duration variables are unchanged as compared to the (uncontrolled) regression on the smaller sample. For these reasons, the results on the smaller, 171 observation sample are reported here.

3.4 Further large-sample evidence

Some of the findings of Mansfield and Lee (1996) provide empirical validity to the model in this paper. They find that prestigious universities receive relatively less funding from firms than less prestigious universities. The authors 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. These costs notwithstanding, firms appear to value the higher abilities of scientists in top universities for projects that are less narrow and specific, and of more fundamental nature. Broader projects are indeed those in which a firm would be willing to sacrifice some authority in order to enhance the effort of the 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 major research universities is implicit also in the findings of Masten (2005), who shows that research-oriented universities have an internal authority structure very different from 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.

3.5 Explaining trends in R&D organization and industry-university relations

This study can also contribute to explaining some historical trends 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. The bulk of industry participation in academic research is, indeed, in the life sciences. Lately, a similar pattern seems to be occurring in emerging fields such as Nanoscience.[14] In science-based sectors, moreover, some scholars have noticed a process from the collaboration 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). In mature stages of an industry, more competitors are present, and alternative paths of research with lower scientific content might become available. Therefore a firm might prefer to exert stronger control over research in more mature fields rather than in younger fields.

The analysis of these different sources of evidence concludes the three-step approach – qualitative, formal, and empirical – to elaborating a theory of industry-university relations based on

[14] Legislative changes, such as the 1980 Bayh-Dole act and the 1986 Cooperative R&D Agreements Act, and the decline in public spending for research are other determinants of the increase in industry participation into academic research. The increase of industry funding, however, is occurring in research areas in which federal funding has not declined (Bok 2003). Additional explanations are in order.

different institutional missions and authority. The following section is dedicated to exploring the broader implications of the framework for the organization of R&D, and for public policy.

4 Organizational and public policy insights

4.1 Organizational issues

The trade-off between workers' empowerment and authority over agents is a pervasive issue in business organizations. Companies need to balance the provision high-powered incentives through the delegation of power to their workers, with the desire to keep flexibility and authority over their activities. Firms and workers might disagree over the best course of action for a given task. The model presented in this paper shows that, if the interests and priorities of a worker are well aligned with those of the firm, then 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 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 principal, she might be more willing to work hard on a given task, thus increasing the likelihood that a project succeeds.

The performance of research activities, on which this paper focusses, is a major example of these dynamics to occur, as companies and scientists are likely to disagree over the preferred course of action for a project, but a scientist's effort is of major importance in order for research projects to succeed. Companies may commit to a greater autonomy to scientists, thus eliciting greater effort, by contracting for the services of researchers employed by universities, since the main mission of universities and other research organizations is aligned with that of the overall scientific community.

Although it appears as an increasingly adopted organizational form to perform R&D and empower scientists, delegating projects to academic partners is not the only mechanism companies use to elicit strong motivation. Other mechanisms also show how crucial the trade off between workers' empowerment and firm authority is. Several companies, for example, have set up research labs in locations far apart from their headquarters. These labs are often near 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). This facilitates knowledge acquisition. Furthermore, a major reason for these location choices was that, being more isolated from the rest of the companies, scientists would feel 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. The investor Wallace Steinberg in 1993, for example, jointly founded the biotech company Human Genome Science (HGS), and the Institute for Genome Research (TIGR), a research foundation. TIGR was granted freedom of research without interference from the investors of HGS (Davies 2001). Novartis, similarly, has created a series of independent foundations. Through these foundations, the Novartis' website says, the company 'supports scientific research projects, particularly high-risk

projects in areas of new technologies[...]'.

4.2 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, will 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.[15] Other authors claim that industry-university relationships can be beneficial to both parties (see for example Gibbons et al. 1994). Others, finally, see industry-university relations as potentially beneficial but 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 (Beckers 1984, Rosenberg and Nelson 1994, Howitt 2003, Nelson 2004). This paper offers an economic rationale for this third, 'middle ground' view. It may be beneficial also for a firm (and not only for society) to let the university partner "behave like a university", and not to interfere too much with its activities and the pursuit of its objectives.

This paper 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. The consideration of these costs helps to explain why the majority of company research is performed in-house, while industry participation in university research, though increasing, is still low. A consequence of this low participation is that the ability of companies to influence the behavior of academic scientists would be limited.[16] Another consequence however is that, if industry participation remains at this relatively low level, public funding will remain the most important financial source for academic research, and should not be made 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).

5 Summary and Conclusion

This paper analyzed the choice by a firm of the organizational structure for the conduct of R&D, and the decision by a firm to outsource research project to academic and other research organizations. Through a combined qualitative, formal theoretical, and empirical analysis, it was argued that, by outsourcing a project to a university allows a firm to commit not to terminate or alter a

[15] Dasgupta and David (1994), Powell and Owen-Smith (1998), Bok (2003).

[16] The model also implies that a firm has a bias toward "excessive" integration, i.e. it would opt for in-house research even when the overall (both monetary and non monetary) benefit to the parties would be greater under outsourcing. This result is available from the author upon request.

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. An economic model that formalizes these arguments is developed. Empirical predictions were derived about the kind of research activities firms will outsource to universities, and activities on which they will exert stronger control. These hypotheses were corroborated by with a vast body of evidence, including a novel analysis of industry-university research contracts, previous large sample studies, and several cases concerning industry-university alliances as well as the internal organization of company R&D. The analysis also defines a framework to discuss and assess some policy positions on the desirability of stronger ties between industry and academia in the performance of research, the importance of public funding of academic research, and the role of social legitimation of the academic mission.

The theory in this paper can be the starting point for a series of further analyses. One such analysis would be a comparison among a "continuum" of organizational forms, from in-house research with tight control to outsourcing. This would make the model applicable to a broader set of R&D organizational problems. Similarly, accounting for a broader array of incentive mechanisms beyond delegation of control would enrich the model. These additional mechanisms include incentive pay as well as different designs for awarding research grants (Lazear 1997). It would be interesting to study whether and how the presence of multiple incentive instrument affect the trade-off between scientist motivation and company flexibility, and what is the impact of any constraints universities may impose to their scientists, such as the extent of royalty sharing. The theory, finally, could be applied beyond the case of industry-university relations. Many academic researchers receive grants from state and federal sources (NSF, NIH, NASA). Some of these grants are for "directed" research, thus potentially leading to goal conflict between the researchers and the funding agencies (Goldfarb 2006).

Further empirical investigation is also in order. The ideal test of the model would include information both about project performed in collaboration with research organization, and project performed in-house, in order to compare their characteristics. Detailed information about the internal organization of research would be needed. A first step in this direction would be a series of case studies of a small set of companies, such as those described above as having relationships with academic partner: How do the research activities they instead carried out in-house (or in collaboration with other companies as opposed to research organizations) differ from those performed through academic researchers?

The conceptual framework employed in this paper could be applied also other settings and activities beyond R&D. The trade-off between authority and motivation may be a relevant one also in other activities where creative individuals, possibly responding to an heterogenous set of incentives, operate. An example is given by advertising activities (Von Nordenflycht 2007).

In addition to stimulating further theoretical and empirical work, the present study offers also a methodological contribution, in that it includes qualitative arguments, economic modeling, and a

broad set of empirical evidence. Further works and extensions should share this multiple approach to complex organizational problems.

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A An extension of the model in Section 2 to monetary rewards

I propose an extension of the model described in Section 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 2 *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,*

$$\overline{\pi} = 2 - \frac{4\rho}{\gamma(B+R)^2}, \tag{14}$$

where:

$$\frac{\partial \overline{\pi}}{\partial B} > 0;\ \ \frac{\partial \overline{\pi}}{\partial R} > 0;\ \ \frac{\partial \overline{\pi}}{\partial \rho} < 0. \tag{15}$$

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

$$b_s = \frac{R-B}{2};\ \ b_F = 0 \tag{16}$$

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:

$$e^{out} \in \left\{ \arg\max_{e} \left[(B + b_s)e + (0 + b_F)(1 - e) - C(e;\gamma) \right] \right\} \tag{17}$$

Given the form of the cost function (as in (1) at page 8), we have the following equality:

$$b_s - b_F = \frac{e}{\gamma} - B \tag{18}$$

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 (18), 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:

$$\underset{e,b_F,b_s}{Max} \Pi^{out} = e(R - b_s) + (1 - e)(0 - b_F) \tag{19}$$

subject to

$$b_s - b_F = \frac{e}{\gamma} - B \tag{20}$$

$$(B + b_s)e + (0 + b_F)(1 - e) - C(e;\gamma) \geq 0 \tag{21}$$

$$b_F \geq 0 \tag{22}$$

$$b_s \geq 0 \tag{23}$$

To solve this program, let us begin by substituting (20) into (21). We obtain

$$\left(\frac{e}{\gamma}+b_F\right)e+(1-e)b_F-\frac{e^2}{2\gamma}=b_F+\frac{e^2}{2\gamma}\geq 0 \tag{24}$$

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 (19), and let us not consider, for the moment, the constraint (23). Using again (20) 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 (19) and obtain

$$e_*^{out}=\frac{\gamma}{2}(R+B) \tag{25}$$

Therefore,

$$b_s=\frac{e_*^{out}}{\gamma}-B=\frac{R-B}{2}. \tag{26}$$

Since we assume $R>B$, also constraint (23) 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

$$\Pi^{out}=e_*^{out}(R-b_s)=\frac{\gamma}{4}(B+R)^2 \tag{27}$$

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:

$$e_*^{in}\in\left\{\arg\max_e\left[(B+b_s)e(1-\pi)+(0+b_F)(1-e)(1-\pi)-C(e;\gamma)\right]\right\} \tag{28}$$

Given the form of the cost function (as in (1) at page 8), we have the following equality:

$$b_s-b_F=\frac{e}{\gamma(1-\pi)}-B \tag{29}$$

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:

$$\underset{e,b_F,b_s}{Max}\,\Pi^{in}=(1-\pi)\left[e(R-b_s)+(1-e)(0-b_F)\right]+\pi\rho \tag{30}$$

subject to

$$b_s-b_F=\frac{e}{\gamma(1-\pi)}-B \tag{31}$$

$$(B+b_s)e(1-\pi)+(0+b_F)(1-e)(1-\pi)-C(e;\gamma)\geq 0 \tag{32}$$

$$b_F\geq 0 \tag{33}$$

$$b_s\geq 0 \tag{34}$$

As before, we substitute (31) into (32). We obtain

$$(1-\pi)\left[b_F+\left(\frac{e}{\gamma(1-\pi)}\right)\right]e+b_F(1-e)(1-\pi)-\frac{e^2}{2\gamma}=(1-\pi)b_F+\frac{e^2}{2\gamma}\geq 0 \tag{35}$$

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:

$$e_*^{in}=\frac{\gamma}{2}(R+B)(1-\pi) \tag{36}$$

and

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

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

$$\Pi_*^{in}=e_*^{in}(R-b_s)(1-\pi)+\pi\rho=\frac{\gamma}{4}(1-\pi)^2(B+R)^2+\pi\rho \tag{37}$$

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 (14) and, straightforwardly, the comparative statics in (15). ■

B Description of the industry-university contract data and analysis in Section 3.3

B.1 Main data source and selection criteria

The primary source of data is 550 research contracts 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: Lerner and Merges (1998), Higgins (2004), and Lerner and Malmendier (2005).

Contracts in which one of the partners, more precisely the one performing the research, is a university or another non-profit research organization (hospital, foundation, etc.), were selected. The analysis here is limited to 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 agreements, joint ventures with research purposes), therefore excluding, for example, "pure" license deals. A large percentage of the collected contracts, unfortunately, could not be used for the analysis because of missing information. Besides, 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. These contracts were excluded because they may be inherently different from those between "private" actors.

The contracts for which all of the relevant information for this study is available are 171.[17] Each contract was read at least twice, in different periods, in order to ensure some consistency in the coding.

B.2 Control variable construction and additional data sources

The main dependent variables of the analysis and the independent variable of main interest and their constructions – duration and number of disease areas – have also been discussed above. Regarding the number of diseases as proxy for breadth of applicability of the research, a similar measurement choice has been made by Kocabiyik-Hansen (2004). Examples of disease areas are Infection - AIDS, Infection - Antibiotics, Central Nervous System, Wound Care, Transplantation. The analysis also includes as series of control variables, most of which have been used in other studies on contractual provisions, including Lerner and Merges (1998), Lerner and Malmendier (2005), Robinson and Stuart (2005), and Lacetera (2006).

The front page generated by ReCap 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. The phase was categorized by distinguishing the discovery phase from the later phases. The previous experience of the partners in similar deals was also recorded and accounted for. Using all of the downloaded contracts as the "universe", variables were built that recorded whether the open-science partner had previous collaborations with companies, whether the companies had previous deals with research partners, and whether a given firm - research partner pair had previous deals with each other. Previous contractual relations may affect, for example, the degree of trust among the parties, and therefore the necessity to have formal authority being expressed in a contract. The year in which the contract was signed was also coded, distinguishing between contracts signed before and after 1990. In the 1980s, research agreements were much less frequently, and arguably of a potentially different type than those of more recent years.

Additional information was obtained from several other sources. In order to define measures of the bargaining power of the open-science partner, proxies for the "prestige" of the whole organization as well as of the Principal Investigators (PIs) for the specific project were collected. At the organizational level, data from the National Institutes of Health (NIH) about the annual overall ranking of each organization in terms of funds received by the NIH were used. At the individual level, the entire publication history of all of the PIs mentioned in each contract was recorded. Information includes publication counts and the impact factor of each PI's publications on a yearly basis. The calculation of the impact factor - weighed measures was limited to the publications 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), and excluded such publications as book reviews or letters, with no real scientific novelty content.

[17] The contracts for which all of the relevant information is available may not be a representative sample of the original 550 contracts – which, in turn, might not be representative of the whole population of industry-university research deals. The ReCap data source has been used in other studies too, such as Lerner and Merges (1998), Lerner and Malmendier (2005), and Robinson and Stuart (2005). In these previous studies, however, only firm to firm contracts are considered. Furthermore, the analysis is limited to the summaries of the contracts, or even only to the front pages. The summaries and the front pages are elaborated by ReCap analysts and not by the contracting parties. In this study, instead, the analysis is based also on the readings of the actual contracts.

The computations used the PublicationHarvester software, based on the Medline publication database and the ISI impact factor (see Azoulay et al. 2006). The measure of high PI prestige is a dummy with value 1 if the PI is among the top 25% PIs (within the sample) with the highest cumulative impact factor of his/her publication up to the year the contract is signed. Obviously, better measures from other sources of data could be defined, and future inquiry to define other measures of quality and prestige is in order. Dummy variables for different types of research partners –teams within hospitals, universities, and private universities in particular – were also defined. The age of the companies (from incorporation to the signing of the research contract), taken as a measure of a firm's bargaining power, with younger firms having less of it, was obtained from Annual Reports and SEC files. The geographical distance among the partners was also coded and controlled for, since one could imagine more distant companies wanting to detail their formal right more precisely, as they are less able to exert "informal" control. Tables 3 and 4 below report descriptive statistics and the correlation coefficients among the variables of interest.

B.3 Specifications

The results in Table 2 at page 19 are from Probit and ordered probit regressions. The unit of observation is the single contract and unconstrained heterogeneity in variances is allowed. OLS, logit, and linear probability models convey similar results. Fixed effects panel methods (with the cross-sectional unit being, for example, the research partner) would allow controlling for unobserved heterogeneity among research organizations. However, this would 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. Fixed effects analyses were not performed because of these reasons.

	Variable	Obs	Mean	Std.	Min	Max
1	Sum of major control rights	171	0.45	0.67	0	3
2	Sum of major control rights>0?	171	0.36	0.48	0	1
3	Firm has unilateral termination right without cause?	171	0.23	0.42	0	1
4	Num of diseases	171	1.36	0.59	1	4
5	Num of diseases>1?	171	0.31	0.46	0	1
6	Num of diseases>2?	171	0.05	0.21	0	1
7	Research project longer than 2 years?	171	0.43	0.50	0	1
8	Duration of the project (in years)	171	2.35	1.60	0.33	10
9	Project is in early (discovery) phase?	171	0.57	0.50	0	1
10	Research partner is a university (as opposed to hospitals, foundations, etc.)?	171	0.70	0.46	0	1
11	Research partner is a private university?	171	0.29	0.46	0	1
12	Research partner wihtin a hospital?	171	0.23	0.42	0	1
13	Research partner is among the 50 organizations receiving the highest dollar amount of NIH grants (in the year before the contract was signed)?	171	0.53	0.50	0	1
14	PI is among the top 25% (in the sample) in terms of cumulative impact factor until the year before signing the contract?	171	0.25	0.44	0	1
15	Year in which the contract was signed -1900	171	91.89	4.98	75	103
16	Deal signed after 1990?	171	0.70	0.46	0	1
17	Geographical distance among the partners (in miles)	171	1119.51	1732.80	0	10372
18	Distance between parties is equal to or less than 100 miles	171	0.35	0.48	0	1
19	Distance between parties is more than 100 miles and no greater than 1000 miles	171	0.29	0.46	0	1
20	Distance between parties is more than 1000 miles	171	0.36	0.48	0	1
21	Past collaborations between the company partners and other research partners?	171	0.58	0.49	0	1
22	Past collaborations between the research partners and other companies?	171	0.68	0.47	0	1
23	Past collaborations between the same two partners?	171	0.13	0.34	0	1
24	Both partners are US-based?	171	0.88	0.33	0	1
25	Age of the company at contract signing (current year-foundation/incorporation year)	171	4.11	3.27	0	18
26	Company founded at least 2 years before the contract is signed?	171	0.78	0.41	0	1

Table 3: Descriptive statistics

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1																									
2	0.91																								
3	0.72	0.74																							
4	-0.10	-0.11	-0.20																						
5	-0.05	-0.05	-0.19	0.92																					
6	-0.15	-0.17	-0.12	0.66	0.33																				
7	0.21	0.22	0.19	0.11	0.14	-0.02																			
8	0.22	0.23	0.15	0.09	0.12	-0.02	0.73																		
9	0.04	0.06	0.15	-0.02	0.02	-0.09	0.18	0.14																	
10	0.10	0.06	0.15	-0.03	-0.03	-0.04	0.07	-0.08	0.20																
11	0.07	0.06	0.13	-0.05	0.01	-0.14	0.15	0.05	0.22	0.42															
12	-0.10	-0.06	-0.14	0.04	0.03	0.08	-0.05	0.14	-0.17	-0.83	-0.35														
13	-0.10	-0.08	-0.06	-0.05	-0.07	0.04	0.01	0.02	0.09	-0.06	0.09	0.07													
14	0.05	0.05	0.03	-0.08	-0.10	0.00	0.18	0.28	0.04	-0.09	0.07	0.13	0.09												
15	-0.03	-0.08	0.03	-0.19	-0.19	-0.11	0.05	0.02	-0.05	0.17	0.06	-0.20	-0.10	-0.13											
16	-0.01	-0.04	0.03	-0.15	-0.16	-0.09	0.03	0.05	-0.09	0.15	-0.02	-0.16	-0.07	-0.12	0.77										
17	0.14	0.10	0.11	-0.11	-0.11	-0.05	0.20	0.03	0.06	0.10	-0.11	-0.07	-0.12	0.16	0.14	0.05									
18	-0.02	-0.04	-0.06	0.11	0.09	0.07	-0.06	0.08	0.05	-0.08	-0.04	0.07	0.03	-0.12	-0.05	-0.02	-0.47								
19	-0.07	-0.02	0.01	-0.05	-0.04	-0.02	0.02	-0.02	0.02	0.00	0.10	-0.01	-0.11	-0.08	0.04	0.03	-0.24	-0.47							
20	0.08	0.06	0.05	-0.06	-0.05	-0.05	0.05	-0.06	-0.06	0.09	-0.05	-0.06	0.07	0.19	0.01	-0.01	0.70	-0.55	-0.48						
21	0.05	0.03	0.07	-0.05	-0.03	-0.04	-0.11	-0.20	0.01	0.00	-0.01	0.01	-0.06	-0.14	0.17	0.19	0.07	0.02	0.02	-0.04					
22	-0.04	-0.06	0.06	-0.09	-0.08	-0.03	-0.11	0.03	-0.03	-0.07	0.03	0.08	0.32	0.08	0.30	0.25	-0.20	0.14	-0.11	-0.04	0.03				
23	0.07	0.06	0.11	-0.01	0.00	-0.01	0.11	0.04	0.03	-0.04	-0.10	-0.01	0.10	-0.07	0.06	0.11	-0.08	0.21	-0.03	-0.19	0.33	0.27			
24	0.04	0.02	0.00	0.05	0.06	0.00	0.18	0.07	0.04	0.05	0.24	0.03	0.39	0.03	0.16	0.09	0.50	0.05	0.12	0.17	0.01	0.24	0.01		
25	0.08	0.06	0.11	0.02	0.02	0.08	0.06	0.15	0.23	0.01	0.03	0.03	0.03	0.23	0.29	0.21	0.05	0.09	0.09	0.01	0.25	0.11	0.02	0.09	
26	0.01	-0.02	-0.01	-0.04	-0.02	-0.02	-0.15	-0.25	-0.06	0.00	-0.10	-0.02	0.01	-0.19	0.25	0.18	0.08	-0.09	0.06	0.04	0.48	0.19	0.12	-0.07	0.56

Table 4: Correlations coefficients. The numbers on the left and on the top of the table correspond to the variables as described in Table 3