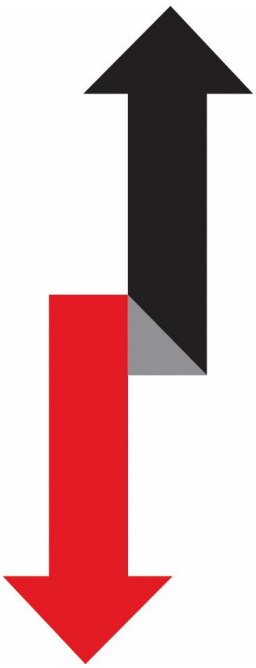


COLEMAN FUNG
RISK MANAGEMENT
RESEARCH CENTER

Working Paper # 2010 -02

Contractibility and the Design of Research Agreements

Josh Lerner, Harvard Business School
Ulrike Malmendier, University of California Berkeley

January 24, 2008

University of California Berkeley

Contractibility and the Design of Research Agreements

Josh Lerner

Ulrike Malmendier*

January 24, 2008

Abstract

We analyze how contractibility affects contract design. A major concern when designing research agreements is that researchers may use their funding to subsidize other projects. We show that, when research activities are not contractible, an option contract is optimal. The financing firm obtains the option to terminate the agreement and, in case of termination, broad property rights. The threat of termination deters researchers from cross-subsidization, and the cost of exercising the termination option deters the financing firm from opportunistic termination. We test this prediction using 580 biotechnology research agreements. Contracts with termination options are more common when research is non-contractible.

*Josh Lerner, Finance and Entrepreneurial Management, Harvard Business School, Rock Center 214, Soldiers Field Road, Boston, MA 02163, jlerner@hbs.edu; and Ulrike Malmendier, University of California–Berkeley and NBER, Department of Economics, University of California, Berkeley, 501 Evans Hall, Berkeley, CA 94720**,** ulrike@econ.berkeley.edu. We would like to thank Philippe Aghion, Susan Athey, George Baker, Pablo Casas-Arce, Pierre-André Chiappori, Jing-Yuan Chu, Bob Gibbons, Oliver Hart, Thomas Hellmann, Rebecca Henderson, Louis Kaplow, Robert Merges, David Robinson, Patrick Schmitz, David Sraer, Jean Tirole, Halla Yang, and Jeff Zwiebel, as well as workshop participants at the American Finance Association meetings, Columbia University, Harvard University, MIT, the NBER Organizational Economics Meeting, Simon Fraser University, and Stanford University as well as two anonymous referees for helpful comments. We especially thank Oliver Hart and Jean Tirole for their detailed suggestions. We also benefited from conversations with a number of practitioners, especially Prem Das, Richard Douglas, Peter Finn, and Michael Lytton. Nageeb Ali, Maruti Didwania, Burak Guner, Camelia Kuhnen, Charmaine Lee, Felix Momsen, Philip Tzang, Anant Vasudevan, Kyle Woodward, Chenling Zhang, and especially Joanne Yoong provided excellent research assistance. We gratefully acknowledge financial support from the Coleman Fung Risk Management Research Center and Harvard Business School's Division of Research. All errors are our own.

The analysis of contract design is central to numerous areas in economics, ranging from labor economics and corporate finance to macroeconomics. An important determinant of contract design, introduced by the literature on incomplete contracts, is the observability and verifiability of actions and outputs (cf. Oliver D. Hart (1995)). If key variables are not verifiable in front of judges, the contracting parties have to find alternative contractual mechanisms to induce the expected behavior, such as reallocating asset ownership.

We analyze how the design of contracts varies as underlying variables become harder or easier to verify. Specifically, we study both theoretically and empirically how the contractual rights of one party depend on the contractibility of innovative efforts to be performed by the other party.

Our empirical application is biotechnology research. Innovation in the biotechnology sector is frequently based on research agreements between a financing firm (typically a large pharmaceutical company) and a research firm (typically a smaller biotechnology company). Such agreements generally involve the financing firm providing support for a particular project in exchange for a share of ownership of any drugs that emerge from that project. A key difficulty for these collaborations is that the two parties have different goals. In particular, biotechnology researchers may use funds provided by the financing firm for other research projects or for refined analyses that are only academically relevant, an incentive problem that has been termed "project substitution" or "project cross-subsidization."

We analyze the contractual response to this incentive conflict and how it depends on the contractibility of research. We first provide a simple model based on the property-rights theory of the firm, in particular Hart and John Moore (1988) and Georg Nöldeke and Klaus M. Schmidt (1995), which allows for multi-tasking in the sense of Bengt Holmström and Paul Milgrom

(1991). If research effort is observable and verifiable, the incentive problem can be solved with a simple complete contract. Empirically, this is the case when the biotechnology researchers have to perform specifiable experiments on a lead product candidate. If, however, research is not contractible, option contracts are second-best optimal. The option contract gives the financing company the unconditional right to terminate the collaboration, in which case it also obtains broad property rights to the terminated project. The reversion of broad property rights from the research to the financing firm in case of termination provides incentives for the research firm not to divert effort to other projects. At the same time, the payments associated with termination prevent the financing firm from exercising the termination option opportunistically. The optimal option contract allows the financing firm to extract less profit, however, than a complete contract. Thus, the model predicts the use of such option contracts in contractually difficult environments, but not otherwise.

The model also implies that this prediction does not necessarily hold if the research firm is financially unconstrained. In that case, the parties can design an option contract that involves payments from the research firm to the financing firm upon termination. As a result, the contract with termination option is no more costly than any first-best contract: Option contracts with liquid research firms allow financing firms to extract the first-best payoff both when research is and is not contractible. Hence, in this case there is no predicted relationship between contractibility and option contracts.

We test the predictions of our model in a novel data set of 580 biotechnology research agreements. We first provide evidence of the underlying project cross-subsidization problem. We show that the number of simultaneous research alliances indicates that multi-tasking is commonplace for research firms in our sample. We then test whether research agreements are

indeed more likely to employ termination clauses, coupled with the transfer of broader property rights to the financing firm, when research is non-contractible. Using the lack of a 'specifiable lead product candidate' as a proxy for non-contractible research, we find the predicted relationship in the data. Moreover, the positive correlation of option contracts and non-contractibility is even stronger in the subset of the most financially constrained firms. It is insignificant for liquid research firms, though the differences in coefficients are not statistically significant.

We employ several additional tests to distinguish alternative explanations. One concern is that, in collaborations without a specifiable lead compound, the financing firm might be more likely to provide inputs into research beyond mere financing. The contract design might reflect this dual role rather than the lack of contractibility. Using a detailed analysis of the contractual language delineating the financing firm's role and the patents awarded to the financing firm to measure its expertise in the field of the research agreement, we identify financing firms who might provide such non-financial input. After excluding these firms, the results are, if anything, stronger. Other alternative explanations, such as heterogeneity in uncertainty, in informational asymmetry, or in the "abilities" of the research firm, predict a correlation with specific rather than unconditional termination clauses and no reversion of property rights. The data rejects these alternative correlations.

Overall, this paper makes three contributions. First, we shed light on a key incentive conflict in research collaborations, project cross-subsidization. We characterize this incentive conflict as moral hazard in a multi-tasking framework. Second, we provide new evidence on the empirical contract design of research agreements, in particular the use of unilateral and unconditional termination rights with broadened transfer of intellectual property. Third, we

explain how the combination of termination and broadened property rights may remedy contracting difficulties.

Much of the prior literature analyzing "real-world contract design" has focused on complete rather than incomplete contracts (Pierre-André Chiappori and Bernard Salanié (2003)). Notable exceptions are Steven Kaplan and Per Stromberg (2003 and 2004), who provide exhaustive descriptions of venture-capital contract design, and George P. Baker and Thomas Hubbard (2003 and 2004), who relate changes in contract design to a switch in the monitoring technology of truck drivers. Our approach resembles the latter: we relate an empirical proxy for contractibility to variations in contract design. Similar to previous work on strategic alliances (David Robinson and Toby Stuart (2007)), we focus on specific contractual clauses (namely option rights to terminate). Our large, hand-collected data set on research agreements allows us to address several concerns plaguing that literature, such as unobserved firm characteristics (via firm fixed-effects and firm-level controls), and to test directly competing explanations.

Prior empirical tests of the property-rights theory of the firm (e.g., Kirk Monteverde and David J. Teece (1982); Daron Acemoglu et al., (2004)) have largely focused on "make or buy" decisions. The theoretical literature, however, pioneered by Sanford J. Grossman and Hart (1986) and Hart and Moore (1988, 1990), suggests that the contracting parties may design *any* suitable decision right to govern non-contractible actions. Our paper attempts to help fill this gap by focusing on the role of termination rights.[1] Compared to previous work on strategic alliance and venture capital contracts (Francesca Cornelli and Oved Yosha (2003), Wouter Dessein (2005), Schmidt (2003), and Nöldeke and Schmidt (1998)), we de-emphasize the role of firm ownership.

[1] Similar to Baker, Robert Gibbons, and Kevin Murphy (2002) and Hart and Holmström (2008), we emphasize a contracting problem that differs from the classic problem of relationship-specific investment.

Our theoretical framework relates to the literature on financial contracting (Philippe Aghion and Patrick Bolton (1992), Aghion and Jean Tirole (1994)). Other papers address the selection of alliance projects, e.g., a "lemons" problem, whereby biotechnology companies license only their less promising drugs (Gary Pisano (1997)). Patricia M. Danzon, Sean Nicholson, and Nuno S. Pereira (2005) find no empirical support for this hypothesis. Ilan Guedj (2006) analyzes opportunistic *ex post* behavior after an agreement is signed. We ask how contract design can anticipate such behavior. The incentive conflict of "academic" versus "commercial" research has been analyzed by Iain Cockburn, Rebecca Henderson, and Scott Stern (1999).

The remainder of the paper is organized as follows. In Section I, we present stylized facts on biotechnology research collaborations. Section II presents a model that reconciles the empirical contract design with the observed incentive conflicts. Section III introduces the data. We test the predictions and alternative hypotheses in Section IV. Section V concludes the paper.

I. Incentive Conflicts in Biotechnology Research Collaborations

Innovative activities in the biotechnology sector increasingly take place as research collaborations. While the initial biotechnology firms relied primarily on capital raised on public markets, research alliances surpassed public offerings in the 1990s as the dominant source of financing.[2] These research collaborations consist of three phases: research, development, and marketing and sales. Typically, a pharmaceutical company provides the financing and a biotechnology company performs the bulk of the research. The development of the drug is undertaken jointly; marketing and sales mostly by the financing company. As the dominant research-performing entity, the biotechnology firm receives the intellectual property rights, but commits to license the relevant patents and know-how to its partner. The right to manufacture the

[2] See Josh Lerner and Robert P. Merges (1998).

product may be assigned to one of the parties or divided between the two. Most profits from the final project go to the financing company, though the research company reaps a percentage via the royalties from licensing.

The pervasiveness of research agreements in the biotechnology sector is puzzling since the interests of the two partners are often not aligned. From a number of interviews with executives specializing in management, technology transfer, and legal affairs, we learned that project substitution and project cross-subsidization by biotechnology researchers are, in fact, major concerns of financing firms entering into research agreements. While it is the objective of the financing firm to develop a certain viable and profitable drug, the research firm has multiple interests. On the one hand, the researchers are also interested in developing the proposed drug and ensuring future cash flows. On the other hand, they are typically juggling several research projects. Some projects may be in collaboration with other pharmaceutical or biotechnology firms. Others may be the development of wholly owned products, from which the research firm receives all the profits and whose success is particularly valued by equity markets as an indicator of the acumen of the research firm's management. As a result, researchers are tempted to employ resources from a specific research agreement on other projects. This was, for instance, the claim in the law suit Alkermes filed in 1993 against its contracting partner Cortex Pharmaceuticals. Alkermes alleged that Cortex's research on a calpain-inhibiting drug for cerebral vasospasm violated Alkermes' exclusive right to develop applications for neurological disorders.[3]

In addition to these commercial conflicts, researchers in biotechnology companies are often more academically oriented than the financing firms. Many biotechnology firms are founded by long-time academics who still want to impact the scholarly discussion. They often

[3] *Alkermes, Inc. v. Cortex Pharmaceuticals Inc.*, Civil Docket no. 93-CV-12532, U.S. District Court for Massachusetts (Boston), 1993. See Online Appendix A for more details.

employ post-doctoral students who are considering an academic career. Furthermore, their reputation in the market for future research agreements depends to a large extent on the external assessment of their research abilities. These pressures may lead to biotechnology firms pursuing research that is more fundamental than the financing firm would prefer and seeking publication before the financing company prefers the findings to become known.

The 1978 research agreement between ALZA, a California-based drug delivery company, and the Swiss pharmaceutical giant Ciba-Geigy illustrates the concerns about opportunistic behavior of the research firm. As described in more detail in Online Appendix A, numerous tensions arose over the type of collaborations that ALZA researchers sought to conduct with third parties and over publications by ALZA scientists. The parties were not able to remedy the divergence of interests contractually, leading to the dissolution of the research collaboration at the end of 1981.[4]

In a subset of cases, the parties can remedy this incentive conflict directly by specifying the exact research activities to be undertaken by the researchers. If the parties have identified a specific lead product candidate at the beginning of their collaboration, it is relatively easy to separate out unrelated research. In many cases, however, the exact lead product candidate is not yet specifiable and the research agreement is entered without a clear product in mind. The research agreements, then, have to account for contractual incompleteness – for having "too many" future contingencies that are "too hard to think of" to contract upon them. In these cases, it is difficult to delineate the boundaries of a project. In this paper, we exploit this variation in contractibility, both from a theoretical and an empirical perspective.

[4] Reinhard Angelmar and Yves Doz (1987–1989).

II. Model

We present a simple model that illustrates how variations in contractibility affect the design of research agreements. The model also illustrates the role of financial constraints.

II.A Baseline set-up

We consider a research firm *R* and a financing firm *F*, both risk-neutral. (All variable definitions are listed in Appendix A.) The model has four periods, depicted in Figure 1: contracting at $t = 0$, financing and research ($t = 1$), development ($t = 2$), and marketing and sales ($t = 3$). We initially assume that *R* is credit constrained. Hence, there is no possibility of monetary transfers from *R* to *F*. If, at $t = 1$, *F* provides financing *I*, then *R* can perform research. *R*'s research yields an intermediate product (a technology) at $t = 2$. If advanced through development, marketing, and sales, this technology generates two types of non-negative and non-contractible surplus: "narrow" (or "commercial") surplus *N* from the sales of the envisioned product, and "broad" (or "scientific") surplus *B*, which represents scientific reputation and profits from unrelated discoveries. For simplicity, we assume that both types of surplus are deterministic.[5]

The basic conflict arises from *R*'s interest in broad (scientific) surplus *B*, which does not benefit *F*. Specifically, we assume that, in the research phase ($t = 1$), *R* can either focus on the narrow project specified in the research agreement or engage in broader research. Narrow research effort e_N generates high narrow surplus, $\overline{N}$, but low broad surplus, $\underline{B}$, while broad research effort e_B results in low $\underline{N}$ and high $\overline{B}$. We assume $\overline{N} > I$. Both types of surplus are realized after commercialization at $t = 3$.

[5] The results are unchanged if we assume that surplus is stochastic and its expected value only depends on *R*'s effort.

The amount of surplus extracted in $t = 3$ depends on (i) whether the parties continue to collaborate at $t = 2$ and (ii) the allocation of property rights. As for (i), the full amount of narrow surplus N is generated only if the parties continue to collaborate. If they terminate the collaboration after $t = 1$, they generate strictly less, a portion αN, $\alpha \in (0,1)$. The ex-post efficiency loss from termination, $(1-\alpha)N$, reflects the specialization of biotechnology researchers and the search costs to find a new partner. Broad surplus B, instead, does not depend on continued collaboration as it captures the value of future projects with different partners and general scientific reputation.

As for (ii), the surplus accrues to the holder of the intellectual property rights. Rights to narrow and to broad surplus can be contracted on separately. Narrow rights allow the holder to sell the envisioned product of the collaboration, i.e., to reap N. Broad rights allow the holder to claim the intellectual ownership and to develop and sell side products, i.e., to reap B. We assume that these rights are of different value for F and for R. If F obtains the narrow rights, it can extract the full amount, i.e., N in case of continuation and αN in case of termination. If R obtains the narrow rights, it cannot extract any portion of N. This assumption captures the fact that success in the final stages depends on the capacity of F to undertake large-scale manufacturing, as well as on F's marketing and distribution channels. On the other hand, R can extract the full broad surplus B if it has the broad rights while F extracts only a portion εB, $\varepsilon \in (0,1)$, if granted the broad rights. This assumption captures that future research that builds on the broad technology and enhances scientific reputation is more valuable to the academically oriented researchers than to the financing firm. For simplicity, we focus on the case[6]

[6] This assumption reduces the number of sub-cases (see Appendix B). It guarantees that, when F gets the broad rights, the value of B to F is always less than the minimal amount R requires to contract with F, i.e., R's outside option value.

(1) $$\underline{B} > \varepsilon \overline{B}.$$

We also assume that

(2) R chooses e_B if indifferent between e_N and e_B.

(1) can be interpreted as a reduced-form substitute for modeling non-transferable benefits for R from the broader research, such as acquiring non-transferable general human capital.

We assume that F makes a take-it-or-leave-it offer to R and that there is no renegotiation.[7] The assumption of a take-it-or-leave-it offer reflects that there are many research firms seeking funding, relative to the number of potential capital providers.

We do not model the costs of R's research effort explicitly. Rather, we set the cost of effort e_N or e_B equal to zero and assume that R is willing to sign a contract if and only if its payoff is at least the value of the broad rights after narrow effort, $\underline{B}$:

(3) The reservation utility of R is $\underline{B}$.

We consider three contractual scenarios. First, we derive the optimal contract under the assumption that e is contractible. Second, we derive the optimal no-option contract under the assumption that R's research is observable[8] at $t = 2$ but is not verifiable. Third, we introduce option rights and ask whether they allow the financing firm to extract a higher payoff. In particular, we consider the option to terminate the research collaboration after $t = 1$, i.e., after F

[7] There is scope for renegotiation after R has exerted the research effort e. We derive the solution with renegotiation in Online Appendix B. (See also the extended version in NBER working paper 11292, Appendix C.)

[8] We also developed an alternative model where F cannot observe e directly but infers it from the stochastic intermediate research output at the end of period 1. The alternative model also removes the assumption that the final surplus N is non-contractible (which is a simplified way to capture the role of F in the last phase of the collaboration and the potential moral hazard problems) and allows for royalty fees. Introducing signal extraction and surplus sharing complicates the model, but the basic trade-off and determinants of the use of option rights are the same.

has observed *e* and thus the (future) surplus resulting from *e*. This implies that the courts can observe termination, i.e., which party (if any) decided not to continue the collaboration. We assume

(4) *F* terminates if indifferent between termination and continuation.

The focus on termination rights reflects the empirical purpose of the model. We do not explore the optimality of other option contracts.[9] We derive the optimal contract among all option contracts that condition intellectual property rights on the decision to terminate.

In our framework, a contract specifies:

(i) the initial payment *I* of the financing firm at $t = 1$,

(ii) the termination rights (if any) at $t = 2$,

(iii) the payments *p* from *F* to *R* at $t = 2$, and

(iv) the narrow and broad property rights of *F* and *R*.

In the benchmark scenario of contractible effort *e*, the parties can condition (ii)–(iv) on *e*. If *e* is observable but not verifiable, (ii)–(iv) cannot be conditioned on *e*. If option contracts are used, it is verifiable whether the option-holder exercises the option to terminate, and (ii)-(iv) can thus be conditioned on continuation or termination. We denote payment in case of continuation *C* as $p_C \geq 0$ and in case of termination *T* as $p_T \geq 0$, and the property rights *o* assigned to *F* as o_C in case of continuation and o_T in case of termination. Hence, for a given action $a \in \{C,T\}$, $o_a = \emptyset$ denotes that *F* receives no intellectual property rights after action *a*, $o_a = B$ that *F* receives broad

[9] Most of the alternative option contracts are hard to implement practically. Consider, for example, a contract that gives *F* the option to seize intellectual property rights directly, without termination. In practice, *F* cannot simply "seize" rights from *R*, and it is hard to imagine a contract that obliges *R* to grant both narrow and broad rights at the will of *F* while continuing to collaborate.

rights, $o_a = N$ that *F* receives narrow rights, and $o_a = B + N$ that *F* receives both broad and narrow rights. Figure 2 summarizes the payoffs for both parties under each scenario.

Contractibility. If *e* is contractible, *F* obtains the maximum attainable payoff $\overline{N} - I$ by contracting on e_N, reserving the rights to *N* for itself, allocating *B* to *R*, and setting $p = 0$.

To see that $\overline{N} - I$ is the maximum attainable payoff, note that the minimum payment from *F* to *R* satisfying *R*'s participation constraint is $p = \underline{B}$ if *R* does not obtain the rights to *B* (i.e., for $o = B + N$ or $o = B$) and $p = 0$ if *R* obtains at least the broad rights (i.e., for $o = N$ or $o = \emptyset$). Employing the minimum price and maximizing *F*'s payoff over *e* and across the different contract scenarios, we find that *F*'s payoff is maximized under $e = e_N$, and $o = N$, resulting in a net payoff of $\overline{N} - I$ for *F* and of $\underline{B}$ for *R*.

Note that this is not the surplus-maximizing outcome if $\overline{B} + \underline{N}$ is larger than $\underline{B} + \overline{N}$. In this case, the financial constraints of the research firm (combined with our restriction of the contract space to non-stochastic contracts) prevent the parties from achieving the first-best outcome and having the research firm compensate its partner *ex ante*, akin to Aghion and Tirole (1994).

Limited contractibility without options. If *e* is observable but not verifiable, the parties cannot condition payments and actions on *e*. Thus, in contracts without option rights, *R* will always choose e_B (given A.4 and given $\overline{B} > \underline{B}$). As in the case of contractible *e*, it is profit-maximizing for *F* to acquire only the narrow rights since this dispenses with the need to pay *R*'s reservation wage. Thus, *F*'s payoff is $\underline{N} - I$, and *R* gets $\overline{B}$ if a contract is signed. However, if $\underline{N} < I$, *F* does not make any offer and the parties forgo the narrow and broad surplus. We denote the set of contracts that maximize *F*'s profit in the class of contracts without options (including "no

contract") as A^*_{NO} and the resulting payoff for *F* as Π^*_{NO}, with $\Pi^*_{NO} = \max\{\underline{N} - I, 0\}$. If a contract is signed, *R* extracts a rent of $\overline{B} - \underline{B}$ beyond the reservation utility.

Limited contractibility with options. We now ask whether a broader class of contracts allows *F* to reap a higher payoff. In particular, we consider the role of termination rights. We denote as $A_O = (i, p_C, p_T, o_C, o_T)$ contracts that assign the option right to terminate to party *i*, $i \in \{R, F\}$. We first show that the empirically observed option contract, i.e., an option contract that grants *F* the right to terminate after *R*'s initial research effort (*i* = *F*), and allocates both the narrow and the broad rights to *F* if *F* terminates ($o_T = N + B$), but only narrow rights if *F* continues ($o_C = N$), may yield a higher payoff for *F* than the second-best no-option contract A^*_{NO}. We start by showing which option contracts of this type induce the researchers to focus on the narrow surplus.

Lemma 1. *The empirically observed option contract (i = F, $o_C = N$, $o_T = N + B$) implements e_N iff*

(1) $$(1-\alpha)\overline{N} - \varepsilon\underline{B} > p_C - p_T \geq (1-\alpha)\underline{N} - \varepsilon\overline{B}.$$

Proof. See Appendix B.

To provide some intuition for double-inequality (1), note that the upper bound of the price differential $p_C - p_T$ between continuation and termination, $(1-\alpha)\overline{N} - \varepsilon\underline{B}$, ensures that *F* chooses continuation after e_N. The gain from continuation conditional on *R* performing e_N is the share of narrow surplus that would be lost under termination, $(1-\alpha)\overline{N}$, minus the share of broad surplus that *F* would gain under termination (after the reversion of broad property rights), $\varepsilon\underline{B}$. This gain has to be larger than the extra amount to be paid in case of continuation rather than termination. Similarly, the lower bound $(1-\alpha)\underline{N} - \varepsilon\overline{B}$ ensures that *F* chooses termination after e_B: the gain

from continuation conditional on *R* performing e_B does not justify the price differential to be paid in case of continuation. Note that the higher *F*'s outside options are, i.e., the shares α and ε of surplus *F* retrieves after terminating the collaboration with *R*, the cheaper it is for *F* to induce the desired effort e_N: the minimum extra amount to be paid in case of continuation becomes smaller.

We can now characterize, within the above class of incentive-compatible option contracts satisfying (1), the payoff-maximizing contracts. Denote the left-hand side of (1), $(1-\alpha)\overline{N}-\varepsilon\underline{B}$, as Γ and the right-hand side of (1), $(1-\alpha)\underline{N}-\varepsilon\overline{B}$, as Δ.

Lemma 2. *In the set of option contracts* (F, p_C, p_T, N, $N + B$) *that implement* e_N, *any contract with*

$$(2)\qquad p_C\begin{cases}=\Delta\\=0\\=0\end{cases}\ \textit{and}\ \ p_T\begin{cases}=0 & \textit{if } \Gamma>\Delta\geq 0\\ \in[0,-\Delta] & \textit{if } \Gamma>0>\Delta\\ \in(-\Gamma,-\Delta] & \textit{if } 0\geq\Gamma>\Delta\end{cases}$$

maximizes F's payoff.

Proof. See Appendix B.

Intuitively, Γ and Δ capture the differences in *F*'s payoff in case of continuation (relative to termination) if *R* chooses e_N or e_B respectively. To ensure that *F* does not choose continuation after the undesired broad effort e_B, an optimal contract requires *F* to pay the gain from continuation after e_B, Δ, to *R* upon continuation (if there is a gain, i.e., if $\Delta > 0$). If *R* were not financially constrained, *F* could implement termination at zero cost, i.e., with $p_C = 0$, by setting $p_T < 0$. But since such a contract is not possible, termination after e_B is not attractive unless *F* sets a positive continuation price. Similarly, to ensure that *F* does not choose termination after the desired effort e_N, an optimal contract requires *F* to pay more than the gain from termination, $-\Gamma$, to *R* upon termination (if there is a gain, i.e., if $\Gamma < 0$).

We now denote with $\hat{A}_O$ all option contracts (F, p_C, p_T, N, $N + B$) satisfying (2). F's payoff from a contract $\hat{A}_O$ is $\hat{\Pi}_O = \overline{N} - \max\{0, \Delta\} - I$, and R's payoff is $\underline{B} + \max\{0, \Delta\}$. Lemma 3 states the conditions under which $\hat{\Pi}_O > \Pi^*_{NO}$, i.e., under which F prefers any contract $\hat{A}_O$ to any second-best no-option contracts, A^*_{NO}:

Lemma 3. *The payoff of F under option contracts $\hat{A}_O$, is strictly higher than the payoff under no-option contracts A^*_{NO} iff $\overline{N} - \max\{\underline{N}, I\} > \Delta$.*

Proof. See Appendix B.

Lemma 3 shows that the profitability of an option contract relative to a no-option contract depends on two effects. First, it depends on how much e_N increases the narrow surplus relative to e_B, $\overline{N} - \underline{N}$. Only if the difference is large is it worthwhile for F to induce e_N at the cost of p_C (rather than paying p_T). Second, the profitability of the option contract depends on F's outside options in case of termination. The more surplus F can reap without the continued collaboration of R – either narrow surplus (high α) or broad surplus (high ε) – the greater is the threat for R that F will terminate and the cheaper is the option contract for F.

Lemmas 1-3 jointly imply that, if research effort is not contractible, an option contract that assigns F the right to terminate after $t = 1$ and, only in case of termination, broad property rights induces R to exert e_N and may allow F to reap a higher payoff than the maximum payoff from contracts without option rights.

We now consider the entire class of option contracts (i, p_C, p_T, o_C, o_T) and show that option contracts $\hat{A}_O$ are the payoff-maximizing choice. We denote with A_o all option contracts other than $\hat{A}_O$ and with Π_O their payoff. We show:

Proposition 1. *All other option contracts A_O lead to a strictly smaller payoff than $\hat{A}_O$ whenever $\hat{A}_O$ is preferred to the unconditional contract, i.e.,*

$$\Pi_O \leq \Pi^*_{NO} \quad \vee \quad \Pi_O < \hat{\Pi}_O .$$

Proof. See Appendix B.

Proposition 1 implies that, as long as *F* sticks to the unconditional contract whenever indifferent – e.g., due to other, unmodeled frictions in option contracting – we should observe either the unconditional contract or $\hat{A}_O$, but no other option contracts. This result implies the following empirical prediction:

Prediction 1. Option contracts assigning the right to terminate with reversion of broad property rights to the financing firm are more likely if research activities are not contractible.

The model illustrates that the incentive conflict between the financing firm and the research firm may prevent the parties from entering research collaboration whenever research activities are not contractible. The parties can overcome this problem using an option contract. However, to prevent opportunistic exercise of the option right to terminate, payments conditional on termination need to be specified. Given the financial constraints of the research firm and the required difference between continuation and termination payments, the financing firm may not extract the full profit $\overline{N} - I$. In other words, the preferred option contract is costly relative to the first-best outcome when *e* is contractible.

II.B Set-up with financially unconstrained research firms

We now introduce financially unconstrained firms into the model and show that the relationship between option contracts and contractibility does not necessarily hold. We assume that, as before *R* requires funding *I* at $t = 1$, but is liquid at $t = 2$ so that prices p_C and p_T can be negative.[10]

To show that Prediction 1 does not hold with liquid firms, we consider the case where it is socially optimal to implement e_N, i.e., $\overline{N} + \underline{B} > \underline{N} + \overline{B}$. Since Lemma 1 does not depend on the non-negativity constraint on *p*, e_N can be implemented, as before, using an option contract with $i = F$, $o_C = N$, and $o_T = N + B$ and prices p_C and p_T such that $(1-\alpha)\overline{N} - \varepsilon\underline{B} > (p_C - p_T) \geq (1-\alpha)\underline{N} - \varepsilon\overline{B}$. However, *F* can now set $p_T < 0$ if necessary to satisfy double-inequality (1). As a result, the set of option contracts that maximize *F*'s payoff (Lemma 2) changes:

Lemma 2′. *In the set of option contracts* $(F, p_C, p_T, N, N + B)$ *that implement* e_N, *setting* $p_C = 0$ and $-\Gamma < p_T \leq -\Delta$ *maximizes F's payoff.*

Proof. With $p_C = 0$ and $-\Gamma < p_T \leq -\Delta$, e_N is implemented by Lemma 1. Since *R*'s equilibrium payoff under this contract is its reservation utility $\underline{B}$, *F*'s profit cannot be increased further.

An immediate implication of the Lemma 2′ is that the option contract maximizes *F*'s payoff also if research effort is contractible: it achieves the maximum joint payoff for *R* and *F* while paying *R* just its reservation utility. Hence, in contrast to the setting with constrained firms, the use of option contracts is not correlated with contractibility for unconstrained firms.

[10] *R* may become liquid due to the technology developed in $t = 1$ or inflows from other projects. Assuming that *R* is illiquid ex ante, but liquid ex interim (rather than liquid throughout) allows us to mirror the previous analysis: Research requires *F* to contribute initial funding.

Moreover, the set of payoff-maximizing option contracts changes. If R is liquid, option contracts that do not involve reversion of broad property rights upon termination also induce the maximum payoff for F, e.g. (F, p_C, p_T, N, $\varnothing$). (See Lemmas 1″ and 2″ in Appendix B.)

We conclude that the use of option contracts co-varies with the contractibility of research efforts for financially constrained firms but not necessarily for liquid firms. If a research firm is financially unconstrained, various types of option contracts *and* no-option contracts allow the financing firm to extract the full surplus. Thus, the option contract may or may not be employed, regardless of the contractibility of research efforts:

Prediction 2. While research agreements with financially constrained research firms employ the option contract only if research is non-contractible, research agreements with liquid research firms may employ the option contract with or without research contractibility.

III. Data

To test the predictions of the model we collected a novel data set of research agreements. We sought to employ as large a sample of biotechnology research agreements as possible, in which the financing firms are either pharmaceutical or large biotechnology firms.

Our main source is a database compiled by Recombinant Capital (ReCap), a San Francisco-based consulting firm that tracks the biotechnology industry since 1988. The data is typically licensed by major pharmaceutical, accounting, and law firms for a considerable annual fee.

Most contracts in ReCap's data are with publicly traded research firms. Public firms are required by the SEC to disclose 'material transactions.' Agreements representing 5 percent or more of a firm's revenues are typically considered material. Since most research firms have modest revenues, this criterion is often triggered. (The larger financing firms rarely file research

agreements.) Biotechnology firms tend to interpret the requirement conservatively and not only report that they enter into strategic alliances, joint ventures, and licensing agreements, but also file the contracts as amendments to 10-K, 10-Q, S-1, or 8-K statements.

Not all filings are by public firms. Research firms that subsequently go public (or file to go public and then withdraw the offerings) typically disclose research agreements signed earlier that are still active. In addition, a number of states require privately held companies with employee stock option plans to file material documents.

Recombinant Capital seeks to create a comprehensive data set of the agreements in the biotechnology industry, based on SEC and state filings, news accounts, and press releases. ReCap summarizes the basic information on all identified agreements, including the parties, the date of the agreement, the stage of the lead product at the time of signing, and the technologies and diseases that are the focus of the agreement. For a subset of the agreements that have been filed in a public document ReCap obtains more detailed information. The initial coding is often done at the request of clients. For example, a client may request that a number of transactions in a given technology or by a certain firm be analyzed. In other cases, ReCap analyzes agreements at its own expense. These tend to be particular "significant" agreements, either in terms of the science or the magnitude of the contractual payments.

An important question is what type of selection bias ReCap's procedure creates. Contracts with well-established and scrutinized research firms, in particular firms that are successful enough to go public later, are over-represented in our sample. As in virtually all studies examining the financing of and contracting by private firms, this implies some "backward looking bias." One way in which this selection might affect our analysis is that the types of information problems we highlight in this paper are *less* likely to be present. Factors triggering

the ex-post success of our sample firms might be partially observable ex ante and lead to less concern about project substitution. In that case, our sample is likely to under-represent the importance of contractual remedies to project substitution. Alternatively, ex-post successful firms might have had a better reputation and a greater ability to enter into a large number of alliances at the time of the research agreements. In that case, contractual remedies of the incentive misalignment may be more important than in a comprehensive sample of all research agreements. In both cases, however, the bias affects only the strength of the estimated effect and not, directionally, whether the use of option contracts helps remedy project substitution.

Based on the full ReCap database, we construct our sample using the procedure summarized in Table 1: We start from the set of all analyzed agreements through the end of 2001. We eliminate transactions that did not involve a biotechnology company as the research firm (overwhelmingly, these are agreements with universities, non-profit, government bodies, and hospitals and a few cases of agreements between two pharmaceutical firms),[11] those without research and product development components (i.e., contracts that do not fall into at least one of the ReCap classes "Collaboration," "Co-Development," "Development," and "Research"), renegotiations or extensions of existing agreements (i.e., using again the ReCap classification scheme and the actual text of the analysis, we determine if the two parties had a previous research collaboration covering the same set of technologies), contracts involving three or more independent parties (determined from the text of the agreements), and agreements where the

[11]We focused on (non-subsidiary) biotechnology firms as identified by ReCap and the industry classifications in two major databases of high-technology firms, Venture Economics (classes 4100 to 4390 and 4600 to 4900) and VentureOne (classes 2300 to 2499), which track firms backed by angel investors, corporate sponsors, and venture capitalists. As a diagnostic check, we examined whether the list of biotechnology firms would change when we used another source. We compiled the names of stand-alone firms dedicated to biotechnology listed in the various editions (through 2001) of the *BioScan Directory*, but found few differences.

financing firms held at least a 50 percent stake in, or a purchase option for, the research firm at the time the agreement was negotiated (determined through a review of securities agreements). We also eliminate three agreements that appear twice in the ReCap database and one agreement that was subsequently dropped from the database. The resulting sample consists of 580 contracts. We carefully examine the contracts and code the key features relevant to our analysis (see discussion below).

Table 2 summarizes the contractual features. The research agreements range from 1980 to 2001, with a disproportionate representation of later contracts due to the growth of activity in the industry. The research collaborations range widely in length, averaging about four years (in the smaller subset of contracts for which the information about duration is provided).

The focus of our analysis is to relate the differences in contract design to differences in the contractibility of the research activities. To measure variations in contractibility we rely on ReCap's description of how concretely the main research target is specified. Our primary distinction is between agreements that build upon a well-defined (contractible) lead product candidate and those where the research program is described in more general terms, without referring to a specifiable lead product candidate. Our rationale is that, in the latter settings, it is hard to specify the exact research tasks and, hence, the contractual partners cannot directly use contingent contracting to deal with the problem of cross-subsidization.

While we rely on ReCap's classification of more or less contractible research, the distinction is rather apparent from the language in the contracts. Research agreements that lack a specific compound or process are vaguer and involve a broader "discovery" phase. Online Appendix C provides excerpts from the "Field of Use" section or the preamble of four contracts, which define the scope of the collaboration (as specified by ReCap). Two excerpts are from

contracts with specified lead product (ISIS and Eli Lilly (2001); Celgene and Novartis (2000)), and two are from contracts without specified lead product (Cubist and Novartis (1999) and Millennnium BioTherapeutics and Eli Lilly (1997)). These excerpts illustrate that the level of detail and specificity is much lower in contracts without a specified lead product candidate. As a result, it is harder to pin down the concrete research tasks.

As shown in Table 2, the lead product is not specified in 37 percent of our observations and ambiguous in another 11 percent of our observations. We have also constructed alternative, more narrowly defined measures of contractibility, which we will discuss below (Section IV.B). The results are little changed.

Table 2 also shows some summary data on other characteristics of the research agreements. We identify contracts with diagnostic and veterinary products (13 percent and 5 percent) since the scientific and regulatory uncertainties are considered to be lower than for therapeutic products. We also separate out biotechnology financing firms (17 percent), who may employ different contracts. Most research firms have only very modest revenues and financial resources, though there are a few positive outliers. One useful summary statistic, denoted as "Financial Health Index," is defined as the ratio of the absolute value of the firm's cash flow (or, if unavailable, net income) to its cash and equivalents. It is the inverse of what venture capitalists often refer to as the "fume date"—the time until the firm will run out of financing if it continues to consume cash at the same rate and does not receive additional financing. If the firm has non-negative cash flow, the index value is set as zero. We also identify, in the U.S. Patent and Trademark Office database, the number of patents awarded to the research firm by the time the research agreement is signed.

The research firms in the agreements differ substantially in their research capabilities. For instance, there are sharp differences in the seasoning of the key executives and the scientific reputation of the advisors. These quality differences are important to control for since higher-quality firms might be more likely to have specifiable lead products and less likely to be confronted with far-reaching option rights for the financing firm due to stronger bargaining power. In addition, confining the sample to high-quality research firms would be helpful to address uncertainty or asymmetric information about research quality as alternative explanations: Ex ante, the financing firm cannot perfectly assess the abilities of the researchers and, in case of non-specifiable lead products, it might therefore reserves the right to end the relationship as soon as it recognizes a low type. Following previous literature, we attempt to parameterize research quality by using the reputation of the investment bank which takes a biotechnology firm public. For example, all else being equal, a biotechnology firm underwritten by Morgan Stanley rather than D.H. Blair is likely to be a higher-quality firm. We use the investment bank ratings compiled by Richard Carter and Steven Manaster (1990), Carter, Frederick H. Dark, and Ajai K. Singh (1998), and Tim Loughran and Jay R. Ritter (2004) from the time when the firm went public. If no rating is available for that period, we employ the rating in the most proximate period. We determine ratings for 526 firms in our sample, ranging from 1 to 9 with a median of 8.75.

IV. Empirical Analysis

The focus of our empirical analysis is the contractual response to variations in the contractibility of research activities. We begin the analysis by examining the empirical validity of two assumptions that underlie our multi-tasking model.

IV.A Evidence on incentive conflicts

The ability of researchers to multi-task gives rise to conflicts in two ways. First, for a given research project, researchers may emphasize more academic aspects and tests. Second, researchers might work on different projects, either with other collaborators or as stand-alone projects.

We test the first assumption, i.e., whether research firms are more oriented to academic science than the financing firms, by comparing the academic orientation of patented research of both parties. As a measure of the academic nature we use citations to non-patented prior art, which in these awards are overwhelmingly to articles in scientific journals. A higher number of citations of scientific journals indicate a more academic orientation.

To implement this analysis, we randomly choose 100 contracts in our sample. For each party, we retrieve the first patent applied for in the month of the contractual agreement.[12] We start with a placebo test, which compares citations to other U.S. patents. These rates should not differ unless the parties differ in citation proclivity more generally. (For instance, smaller companies are more likely to rely on outside counsel to prepare their patent applications, who may be more scrupulous in their citation practices than internal staff.) We find that patents of research firms contain on average 11.8 citations to other patents while the average for financing firms is 10.0. In a paired t-test, the means are not significantly different at conventional confidence levels.

We then compare citations to non-patented prior art, typically academic articles. The average patent of a research firm makes 26.9 such citations, while the mean is 13.7 for financing

[12] If a party made no application in that month, we use the first application in the year. If there was no patent application in that year, we use the first application in the prior year or, if there was none in the previous year, in the year after the research agreement.

firms, about half as many. The means are significantly different at the 1 percent confidence level.[13] Thus, the citation practices indicate that research firms rely more heavily on scientific research.

Second, we examine whether the research firm is juggling multiple projects. We collect data on all research agreements that the firm had entered into with other firms in the three years prior to the research agreement in question. (Three years is the median alliance life-span.[14]) We find that the research firms in our sample engaged in a mean of 6.4 and a median of 4 such research agreements in the previous three years. Hence, the typical research firm is indeed involved in more than one collaboration. Moreover, many of these competing collaborations are in closely related fields. ReCap lists up to six classes of technology (such as "Drug Delivery" or "Immunoassay") for each research agreement. We define a prior agreement as "technologically similar" if one or more of these classes overlap. We find a mean (median) of 4.8 (3) overlapping research agreements.

The evidence on research firms' scientific orientation and involvement in multiple projects suggests scope for misalignment of incentives between researchers and financing firms.

IV.B The use of termination and broad intellectual property rights

We now analyze how the contract design responds to the degree of contractibility. As the outcome variable, predicted by our model, we examine whether the financing firm is granted the unconditional right to unilaterally terminate the agreement and obtains broad rights to the product upon termination.

[13] The results are slightly more significant with unpaired tests, which allow for slightly larger samples.

[14] See Lerner, Hilary Shane, and Alexander Tsai (2003).

A wide variety of clauses allow the financing firm to terminate the agreement. However, most of them are conditional on specific events, such as bankruptcy or acquisition of the research firm. We identified three cases where the financing firm can terminate the agreement unconditionally, as predicted by the theory for cases of non-verifiable research effort:

1. The financing firm can terminate for any cause, either within a defined time period (e.g., after one year of the agreement's signing) or at any time.
2. The financing firm can terminate the agreement for "misbehavior" or "breach."
3. The financing firm can terminate if it believes that the continuation of the collaboration would be "unwise."

Note that, in theory, the second criterion differs from the others. When a party terminates because of "breach," a court may later find it to be the actual breaching party. With the other two termination provisions, this is almost impossible; no court would second-guess a firm's decision to terminate because continuing was "unwise." In practice, however, termination for "material breach" functions much like an open-ended termination. It allows the terminating party to employ various self-help remedies unless and until the other party goes to court to litigate the issue. In addition, the burden is on the non-terminating party to show the termination was not justified.[15]

The bottom rows of Table 2 show that termination rights are a widespread feature. In almost all contracts some kind of termination right is specified (97 percent) and is assigned to the financing firm or both parties (96 percent). More than half of those termination rights are conditional on specific events, while about 39 percent of the research agreements have provisions for the financing firm to terminate the collaboration unconditionally. In 11 percent of

[15] For a discussion of some of these issues in a recent licensing case, see Judge Easterbrook's opinion in *Baldwin Piano Inc. v. Deutsche Wurlitzer GmbH,* 73 USPQ2d 1375 (CA 7 2004).

the sample, unconditional termination rights are coupled with broad access to the intellectual property in case of termination. The latter contract design conforms exactly to the prediction of the theory: it excludes the research firm from retaining the value generated during the collaboration in case of termination. The model predicts that, while patents and other intellectual property rights are arguably worth more in the hands of the research firm, the threat of reassigning them to the financing firm ensures profit-maximizing research of the biotechnology researchers. Note that the 11 percent frequency likely understates the overall empirical importance of this type of contract design since our data, which relies on publicly filed documents, disproportionately samples larger research firms. The incentive and contractibility problems highlighted in the paper are less likely to bind in these more liquid firms than in the overwhelming majority of small, non-public research firms (Prediction 2). [16]

Based on those clauses, we construct the dependent variable in several ways. We use both a binary variable, which indicates if the financing company has at least one unconditional termination right, and an integer variable, which counts the number of termination rights of the financing company from 0 to +3. In both versions, we require that the financing party also obtains broad intellectual property rights upon termination. Alternatively, we consider only cases where the financing firm has the right to terminate (with broad rights) and the research firm has no right to terminate (with or without broadened rights). Again, we construct both the simple binary variable, which takes the value of 1 if the financing firm has at least one termination right

[16] Even if these terms were used only in 11 percent of the sample, they would be of significant practical importance. About 700 biotechnology alliances were signed in 2005, with an estimated total value (the sum of promised pre-commercialization payments) of $56 billion. In eight of the top ten biotechnology drugs in 2005, a strategic alliance played a key role in the development. Cumulative 2005 sales of these eight drugs were $23.3bn. (Source: http://www.recap.com/consulting.nsf/0/3545FA9FCBB76CEB8825719A007FB35C/$FILE/McCully_UCSC%20Extension%200606.pdf, plus the authors' analyses of the ReCap database.)

and the research firm has none, and as well as integer variables with values from –3 to +3, counting the "net" termination rights of the financing firm minus those of the research firm. All approaches deliver approximately the same results.

We begin by testing Prediction 1: Are agreements about projects without a contractible lead product candidate more likely to grant the financing firm the right to terminate the collaboration and broad access to the intellectual property involved?

We first present a series of simple univariate comparisons (Table 3). Agreements are significantly more likely to assign both termination and broad property rights to the financing firm when there is no specifiable lead product candidate at the time the agreement is signed, as predicted by our model. This type of contract design is also more likely when the agreement does not involve veterinary and diagnostic products (which, as noted in Section III, are likely to have substantially reduced information problems) and when the agreement is between two biotechnology firms, though the differences in frequency are typically insignificant. The differences between firms with high and low net income are also insignificant. Firms that are ultimately underwritten by high-status underwriters are more likely to employ the termination and broad rights clause than those with low-status underwriters, though the p-value of the difference is 0.11.

The baseline regression analysis is reported in Table 4. We test whether the number of unconditional termination rights (combined with the assignment of broad intellectual property rights upon termination) is positively related to the lack of specified lead products. We employ a variety of control variables:

- To account for a possible time trend in the transactions, we control for the date of the agreement. We initially employ a continuous date variable and later year fixed effects.

- We include dummies for diagnostic and veterinary products, and the underwriter rank.
- We also identify, in the U.S. Patent and Trademark Office database, the number of patents awarded to the research firm by the time the research agreement is signed. As discussed below, the cross-subsidization problems may be more severe in research firms that hold many patents.
- To control for capital constraints, we use the "Financial Health Index" defined above.
- We include the number of previous research agreements between the same parties. Prior interactions may allow firms to accumulate reputational capital and ease the contracting.

The table presents a number of regressions, which use some or all of these independent variables, trading off completeness and sample size or selection. (The lower half of Table 1 documents how the use of different control variables affects the sample size.) We employ both ordered logit and ordinary least squares (OLS) specifications. The ordered logit is more suitable given the ordinal, non-negative nature of the dependent variable, though the estimation fails to achieve convergence in smaller subsamples or after including a large number of controls. Finally, we employ fixed effects for the thirteen most frequently represented financing firms in addition to the year fixed effects. The firm dummies are created for the entities that entered into the agreement, even if the firm was subsequently merged or acquired (e.g., American Home Products or Sandoz).[17]

Columns 1 and 2 present the ordered logistic estimations, with the reduced and the full set of control variables, respectively. In both specifications, we estimate a coefficient of 0.68, significant at the 5 percent confidence level. Hence, if an agreement does not specify the lead

[17] In addition, we re-ran the fixed-effects regression adding a dummy variable for the thirteen most represented financing firms, using the entity as it existed in 2003. Thus, we coded the Novartis dummy variable as one whether the agreement was signed by Ciba-Geigy, Novartis, and Sandoz. The results were essentially unchanged.

product the odds of having termination rights with broad property right reversion over the odds of having none increases by 97 percent compared to an agreement with specified lead product, consistent with the raw statistics in Table 3. The estimated odds ratio is larger than the raw odds ratio (that is, without controls): the frequency of contracts with at least one unconditional termination right (with broad property rights) is 15 percent among contracts without specifiable lead product and 9 percent otherwise, resulting in an odds ratio of 1.72. All other coefficient estimates are highly insignificant.

We observe a consistent pattern in the OLS estimations (and many dozens of similar unreported analyses). The estimated effect of not having a specifiable lead product is 0.13 when including the full set of controls and 0.14 when using all controls and year fixed effects instead of the continuous date variable. This result is not only statistically, but also economically significant, relative to the mean of the dependent variable (0.15).[18] Thus, regardless of the estimation method and specification, we find that research collaborations in which the research task is hard to contract on (due to the lack of a specifiable lead product) are associated with a significant increase in the termination and broadened intellectual property rights assigned to the financing firm.

As in the logistic analysis, all other explanatory variables have little predictive power. While none of our hypotheses predict that these control variables should have higher predictive power, one may still find it surprising that we fail to estimate any significant effects across all specifications (with the exception of year and financing company fixed effects). However, the poor power of the controls might simply reflect the imprecision of these measures. In fact, the

[18] The R^2 is similar to other empirical work analyzing non-standardized contracts, such as Robinson and Stuart (2007).

lack of explanatory control variables with high statistical power is rather common in the empirical analysis of real-world and non-standardized contracts.[19]

A natural concern in this analysis is endogeneity. For instance, a major issue that affects the entire empirical literature on alliances is the (endogenous) choice to sign a contract. Financing firms entering into research alliances are likely to be different from those not entering. These differences may affect the observed contract design. While there is no obvious reason why the endogenous entry decision would affect the relationship between specified lead products and option clauses, we attempt to address the selection issue directly. In particular, we check that our results are not driven by endogenous matching between low-ability research types and financing firms who (opportunistically) insist on termination rights.

A first step towards addressing these concerns is the inclusion of firm dummies in the estimation reported in Column 5 of Table 4. The inclusion of dummies for the thirteen most frequently represented financing firms, while jointly significant, has little impact on the other coefficients. In particular, both the statistical and the economic magnitude of the coefficient of interest, the estimated effect of "no specifiable lead product," are unaffected compared to the regression including only year fixed effects. These results support the interpretation that, for a given financing firm, the variation in termination and broad intellectual property rights is indeed related to the research program. The results also alleviate the larger endogeneity concerns pointed out before: The occurrence of different types of contracts within the same financing firm ensure that our results are not driven by the fact that certain types of companies only enter

[19] For example, in Abhijit Banerjee and Esther Duflo [2000], none of "contract" and "project characteristics" and only one of the "firm and client characteristics" are significant in the eight regressions analyzing contract design.

research agreements with specified lead-product candidates, while other types of companies only enter those without.[20]

We will further address the concern about endogeneity and omitted variables below, when testing Prediction 2 and comparing the results on various subsamples. Before turning to the second set of results, however, we evaluate more closely our proxy for "non-contractibility of research," the lack of a specifiable lead product candidate. The proxy is constructed to capture contracting situations, in which it is hard to describe and verify the tasks to be performed by the research firm. We test our interpretation of this proxy and of the baseline result by measuring more directly the research firm's incentives to work on different tasks. One alternative measure of the incentives for "project substitution" is the number of parallel projects that the research firm is involved in and that concern the same technology. We construct such a proxy using data on all other research agreements that the company had entered into or filed in the three years prior to the contract in our sample.[21] The summary statistics of the alternative proxy are in the lower half of Table 1 (and are discussed above).

In the first two columns of Table 5, we test whether the alternative measure predicts the use of contracts with termination option and product reversion. We include the full set of controls as well as year and firm fixed effects. In Column 1, we find that the proxy is associated with a significant increase in the use of such option contracts. As before, all other controls are insignificant. Thus, we replicate our main result using the alternative measure. In Column 2, we include this proxy along with our baseline measure of "no specifiable lead product." Here, our

[20] In unreported analyses, we repeat the regressions, clustering the standard errors in the analyses by research firm. This modification has little impact on the results.

[21] We also attempted to measure incentives for project substitution by examining the total number of projects, as well as the progress of their drugs through clinical trials. Unfortunately, neither of the two main data sources, the "Clinical Trials" section of the ReCap database and PharmaProjects, permits such an analysis, mostly due to missing dates.

baseline measure remains economically and statistically significant, while the new proxy becomes insignificant. We obtain similar results (i) when restricting the count to research agreements in similar technologies (defined as being classified by ReCap into the same technology classes), (ii) when also using research agreements signed in the three years after the sample contract was signed (on the grounds that they also introduce contracting challenges, and might have been at least partially anticipated), and (iii) when using cross-tabulations rather than regressions. Hence, our empirical proxy appears to capture the multi-tasking problem laid out in the theoretical analysis.

A second set of tests addresses the concern that the measure of "no lead product" may identify other variations in the contracting situation. For example, in agreements without a specifiable lead product, the financing firm might contribute more than money such as knowledge or methods, as noted in the ALZA case (see Online Appendix A).

To address the concern about unobserved heterogeneity, we restrict the sample of contracts in several ways. First, we exclude financing firms that appear to have technological know-how in the area of the contracted research. We identify the area of contracted research from the short contract description prepared by ReCap. This description is typically based on the introductory paragraphs of an agreement, which define its scope. We tabulate all words in the text strings of the descriptors by frequency and retain those words and abbreviations that describe either a disease or technology.[22] We then use U.S. Patent and Trademark Office data[23] to search for patent applications by the financing firm that contain either all of or any of the same

[22] As a robustness check to this mechanical strategy, we assigned the task of identifying disease and technology keywords in the descriptions to two biology students. The resulting lists of keywords were remarkably similar.

[23] The USPTO patent database can be accessed at http://appft1.uspto.gov/netahtml/PTO/search-adv.html and records all patents from 1976 onwards.

keywords in the patent abstract and that the financing firm had already applied for at the time of the research agreement. One subtle issue is whether one counts patent applications of the firm itself or also those of firms with which it had merged by the time of the research agreement. In the reported results, we include the research of the merged entities. (To identify the patent applications of those firms, we retrieved the history of all mergers and acquisitions for over the period 1975-2001, using the SDC Mergers and Acquisitions database. All results are robust to examining just the activity of the firm itself.) In each case, we only employ patent applications that were ultimately issued since, for the bulk of the sample period, the U.S. Patent and Trademark Office did not disclose unsuccessful patent applications.

Table 5 shows the results of the baseline analysis after eliminating contracts where the financing firm had already-filed patent applications with *any* of the same keywords (Column 3) or after eliminating the smaller number where a filing had *all* of the keywords (Column 4). In each case, the results are similar to our baseline specifications. We undertook a larger number of robustness checks, such as cross-tabulations and using different searches (for instance, altering the keywords employed, the sections of the patents to search, and the patents examined), and consistently found that the cases where the financing firms had significant technological capabilities were little different from the others in this regard.

We also addressed this concern by examining the responsibilities delineated in the contracts themselves and excluding those where the contractual language suggests a higher involvement. We employ two approaches. In Column 5, we report the results of an analysis where we eliminated agreements classified by ReCap as "joint ventures," "joint R&D," and "collaborations." In Column 6, we report the results of an analysis based on our own reading of the contracts. We classify the agreements into those where the role of the financing firm is

unambiguously only providing financing (214 cases), those where there is a role in the research process (150), and those where a determination could not be made with certainty (216). In the reported regression, we eliminate observations where the financing firm unambiguously played a role in the research process. With both approaches, we find that a strong relationship remains between a non-contractible lead product and the assignment of unilateral termination and broad intellectual property rights to the financing firm.

The final two columns of Table 5 address the heterogeneity concern by eliminating agreements about diagnostic and veterinary products, which may be different, e.g., due to the expedited review process (Column 7), and by adding controls for the various diseases that are the subject of the agreement (Column 8). In the reported regression, we employ the disease classifications undertaken by ReCap, but the results are robust to using our own, more detailed scheme, which we constructed with the help of two medical doctors. In both cases, the results are robust.

IV.C. The role of financial constraints

We now test Prediction 2 and examine the impact of financial constraints on the contract design. As discussed in Section 0B, our prediction about contract design depends on the assumption of an illiquid research firm. If the research firm is liquid, the parties can design the contract with termination option such that it grants the financing firm the same payoff as any first-best under full contractibility, namely by agreeing on a payment from the *research* firm to the financing firm upon termination. Hence, option contracts are not more costly than unconditional contracts and may be observed both when research is contractible and when it is not. As a result, we do not have a theoretical prediction for the subset of liquid research firms.

Prediction 2 suggests performing our core test only in the subsample of financially constrained firms. We started with the overall sample since we do not have a perfect measure of constraints and since research firms are generally considered to be illiquid. Our sample of research firms, however, includes many companies that have gone public. Large and established firms may be significantly less constrained than biotechnology start-ups. In the second step of our analysis, we re-estimate on the most constrained subset of firms.

We identify research firms that are constrained by examining their net income in the year prior to the research collaboration. We separate research firms with a net income above and below that of the median firm (in 2002 dollars).

In the regressions reported in Columns 1 and 2 of Table 6, below-median firms display a statistically significant relationship between the provisions of termination and broad intellectual property rights and contractibility. For above-median firms, the coefficient is roughly half the size and insignificant. The differences between the coefficients are not statistically significant at conventional confidence levels. As noted above, however, only the coefficient in the low net-income sample is relevant since the theory predicts a significant relationship only among financially constrained firms. We do not have a prediction for the high net-income sample. The lack of significance among high-income firms neither confirms nor contradicts our theory.[24]

We find the same basic pattern after adding year and financing-firm fixed effects (Columns 3 and 4). We also find the same pattern when we estimate a (more restricted) pooled regression that includes all observations and separate dummy variables for research firms above and below the median net income, as well as their interactions with indicators for "no" and "unknown specifiable lead product." In other (unreported) regressions, we explored the

[24] Variations of our model would predict significant differences, e.g., allowing for frictions or transaction costs arising from option contracts.

robustness of these results to other definitions of capital constraints. When we isolate the more extremely constrained subset of firms in the bottom quartile of net income, the results become even sharper. Also, when we divide firms on the basis of cash and equivalents on their balance sheets into above and below median, the results are qualitatively similar, though the divisions are weaker. This may reflect the fact that cash is a worse proxy for the financial constraints of biotechnology firms since they do not raise their financing all at once, but in a series of offerings. Thus, a firm with a strong investor clientele may have access to the capital markets even though its cash in hand is relatively modest.

IV.D Alternative explanations

We consider three alternative interpretations of the observed contract design.

Research abilities. The "unspecified lead product" variable may capture uncertainty or asymmetric information about the "type" of the researchers: Ex ante, the financing firm cannot perfectly assess the abilities of the researchers and the chances of a successful collaboration. Termination rights allow the financing firm to end the relationship as soon as it recognizes a low type.

In order to address this concern, we return to the underwriter control introduced in Section III. Higher-quality underwriters indicate higher-quality research firms. Research firms also benefit from the "certification" implicit in high underwriter quality, reducing the uncertainty about their "type." Following previous literature, we use a Carter-Manaster (1990) style score to proxy for underwriter reputation. If the difficulty of discerning the research firm's type explained the use of the option contract, the relationship between option contracts and (non-)contractibility should be stronger among the lower-reputation (below median) than among high-reputation firms.

In Columns 1 and 2 of Table 7, we find that the effects are instead economically larger and statistically significant only in the subset of research firms with the highly-ranked underwriters. The result is robust to the inclusion of year and firm fixed effects (Columns 3 and 4), though the significance diminishes. The same picture emerges in a pooled regression, including interactions of the high-rank and low-rank dummies with our lead-product proxy. The differences between the subgroups are, however, insignificant. We conclude that there is no evidence of stronger effects for lower-quality firms.[25]

The adverse selection hypothesis also fails to explain why the financing firm obtains "broader" rights upon termination. On the contrary, the reversion of broad intellectual property from low research types is likely to be of little value to the financing firm. Hence, for this alternative explanation to hold, our results would need to be driven by the termination right, not by the broad intellectual property rights. However, if we repeat the analysis above using the "termination rights only" (again coded as 0 to +3) as the dependent variable, without requiring the reversal of broad intellectual property rights, contractibility has no significant effect (see the first four columns of Table 8).

Variations in uncertainty, informational asymmetry, or incentive misalignment. The hypothesis put forward in this paper attributes variations in contract design to the lack of contractibility, holding uncertainty, informational asymmetry, and incentive conflicts constant. Alternatively, variations in the latter variables may determine the contract design. For instance, termination and broad intellectual property rights may be a response to higher uncertainty about the outcome or higher informational asymmetry between the financing and the research firm.

[25] While these results allow us to reject the alternative hypothesis, they raise the question as to why this relationship should be stronger among the high-quality firms. One possibility is that the observations of firms with lower-quality underwriters are much noisier. Endogenous selection may lead to only "safe" (contractible) cases being contracted.

Additional empirical results cast doubt on these interpretations. A first indication is our prior finding that controls for the type of research program (therapeutic, diagnostic, and veterinary) do not affect the results even though, as noted above, the scientific and regulatory uncertainty is substantially higher for therapeutic products. Even if we eliminate undesired heterogeneity and examine only agreements about therapeutic products (Table 5, Columns 7 and 8), our baseline results hold, with a coefficient of 0.16-0.17 (and a standard error of 0.05-0.06).[26]

Second, we have already shown that "termination rights only" are not related to contractibility (first four columns of Table 8), casting doubt on the interpretation that termination rights are a response to mere informational asymmetries.

Third, heterogeneity in information or incentives would also predict variation in *specified* termination provisions, which are triggered by distinct events such as a change in control, a bankruptcy, or the termination of another agreement. We test for such a relationship using as the dependent variable the interaction between the number of termination provisions (here between 0 and 4) and an indicator of broad intellectual property rights reverting to the financing firm. The results, shown in Columns 5 and 6 of Table 8, are quite different from our baseline finding. *Specified* termination rights and broad intellectual property rights are not more frequently assigned in transactions without a specified lead product. This result is consistent with our theory: unconditional termination rights substitute for conditional contracting.

Bargaining power. Another explanation for the contracting pattern is the relative bargaining power of the two parties: Research firms without well-developed products may be subjected to stronger control rights. We cannot observe bargaining power directly and thus cannot reject this possibility with certainty. Some of the evidence above, however, is hard to reconcile with this

~~tivities.~~

interpretation. First, we found that our core results (Tables 4 and 5) are robust to including an increasing number of control variables. In particular, the number of patents of the research firm, its financial strength, the number of other research agreements, and the financing environment for biotechnology firms more generally should at least partially capture variations in the bargaining power, and thereby reduce the partial correlation between the "No specifiable lead product" variable and the unobserved bargaining power. Instead, as we add independent variables, the magnitude and significance of the "No specifiable lead product" *increases*. Note, however, that the generally low explanatory power of the control variables limits the viability of this argument.

Second, underwriter reputation also serves as a plausible proxy for bargaining power. We found the strongest effect on contract design for research firms with higher-reputation underwriters and thus, supposedly, more bargaining power, contradicting the bargaining interpretation.

V. Conclusion

The design of biotechnology research agreements provides insights into the contractual response to limited contractibility. If the precise task to be performed by one of the parties cannot be specified in the contract, firms respond by assigning unilateral decision rights. Differently from the emphasis on the allocation of asset ownership rights analyzed in previous literature, the parties utilize endogenous decision rights (namely, termination clauses) to solve the problem of contractual incompleteness.

Part of the contribution of this paper is that it sheds light on the nature of the incentive and contracting problem in research alliances, in particular the problem of project substitution or project cross-subsidization. Moreover, we provide new details on the contractual design in

research agreements, which are consistent with the theory proposed in this paper, but which also may help to better understand inter-firm organizations more generally.

The right to terminate is only one of a complex array of decision rights inherent in research collaborations. There may well be other empirical approaches to testing the theoretical hypotheses in this paper: for instance, examining the shifting terms of agreements that are renegotiated. The analysis underscores the promise of combining theoretical and empirical approaches to understand contract design.

Appendix A. Notation of Model

R	Research firm
F	Financing firm
t	Time period in the model (0, 1, 2 and 3)
I	Initial investment, required to generate any research surplus
e_N	"Narrow" research effort by R
e_B	"Broad" research effort by R
N	Narrow surplus, i.e., profits from product targeted in the collaboration.
$\overline{N}$	High value of narrow surplus
$\underline{N}$	Low value of narrow surplus
B	Broad surplus, i.e., profits from other products and collaborations with other firms.
$\overline{B}$	High value of broad surplus
$\underline{B}$	Low value of broad surplus
ε	Share of B that F captures if it has the rights to the broad surplus.
α	Share of N that F captures after termination if F has the rights to the narrow surplus.
p	Payment from F to R
p_T	Payment from F to R conditional on termination
p_C	Payment from F to R conditional on continuation
Δ	$(1-\alpha)\underline{N}-\varepsilon\overline{B}$
Γ	$(1-\alpha)\overline{N}-\varepsilon\underline{B}$
o	Property rights assigned to F; equal to ø (no rights), N, B, or $N + B$.
o_T	Property rights assigned to F in case of termination

o_C	Property rights assigned to F in case of continuation
A	Contract or set of contracts between F and R
A^*_{NO}	Set of non-option contracts that maximizes F's profit when e is not contractible
A_O	Option contract, defined by the party i who has the right to terminate prices p_C and p_T and ownership rights o_C and o_T, $A_O = (i, p_C, p_T, o_C, o_T)$
$\hat{A}_O$	Option contract (F, $\underline{N}$, 0, N, $N + B$).
Π	Profit of F
Π^*_{NO}	Profit of F from option contract A^*_{NO}, equal $\max\{\underline{N} - I, 0\}$
Π_O	Profit of F from an option contract A_O
$\hat{\Pi}_O$	Profit of F from option contract $\hat{A}_O$

Appendix B.

Proof of Lemma 1. To induce e_N given the allocation $o_C = N$ and $o_T = N + B$, F needs to terminate after e_B and to continue after e_N; under any other termination rule, R would choose e_B because of assumption **(2)** and $\overline{B} > \underline{B}$.

Under the contractual provisions $i = F$, $o_C = N$, and $o_T = N + B$, F terminates after e_B iff $\underline{N} - p_C \leq \alpha \underline{N} + \varepsilon \overline{B} - p_T$ and continues after e_N iff $\overline{N} - p_C > \alpha \overline{N} + \varepsilon \underline{B} - p_T$. Solving these two inequalities for p_C - p_T yields (1). Given F's conditional termination decisions, R receives payoff p_T after e_B and $\underline{B} + p_C$ after e_N. Hence, R chooses e_N if and only if $p_C - p_T > -\underline{B}$, which holds given (1) and **(1)**. Hence, prices (p_C, p_T) satisfying (1) are necessary and sufficient to induce F to terminate iff R chooses e_B.

Proof of Lemma 2. The maximization program of F within the set of option contracts satisfying (1) is

$$\begin{aligned} &\max_{p_C, p_T} \overline{N} - p_C - I \\ &s.t. \; \Gamma > p_C - p_T \geq \Delta \\ &\quad p_C + \underline{B} \geq \underline{B} \\ &\quad p_C \geq 0, \; p_T \geq 0 \end{aligned}$$

where the first constraint is simply double-inequality (1) from Lemma B1, which ensures incentive compatibility for R and F; the second is the participation constraint for R given reservation utility $\underline{B}$ from assumption **(3)**, and the constraints in the last line capture R's financial constraints. We can simplify this program to

$$\min_{p_C, p_T} p_C$$
$$s.t.\ p_C < \Gamma + p_T$$
$$p_C \geq \Delta + p_T$$
$$p_C \geq 0,\ p_T \geq 0$$

We distinguish three sub cases. (a) If $\Gamma > \Delta \geq 0$, then $p_C \geq 0$ is redundant and setting $p_C = \Delta$ and $p_T = 0$ is optimal. (b) If $\Gamma > 0 > \Delta$, then the non-negativity constraint on p_C is binding if $p_T < -\Delta$. Therefore, setting $p_C = 0$ and picking any $p_T \in [0, -\Delta]$ is optimal. (c) Similarly, if $0 \geq \Gamma > \Delta$, the non-negativity constraint on p_C is binding for $p_T < -\Delta$, and setting $p_C = 0$ requires $-\Gamma < p_T \leq -\Delta$.

Proof of Lemma 3. If $\underline{N} - I \geq 0$, then $\hat{\Pi}_O > \Pi^*_{NO} \Leftrightarrow \overline{N} - \underline{N} > \max\{\Delta, 0\} \Leftrightarrow \overline{N} - \underline{N} > \Delta$, where the last biconditional follows from $\overline{N} > \underline{N}$. If $\underline{N} - I < 0$, then $\hat{\Pi}_O > \Pi^*_{NO} \Leftrightarrow \overline{N} - I > \max\{0, \Delta\} \Leftrightarrow \overline{N} - I > \Delta$, where the last biconditional follows from the assumption $\overline{N} > I$. The two cases can be summarized as $\hat{\Pi}_O > \Pi^*_{NO} \Leftrightarrow \overline{N} - \max\{\underline{N}, I\} > \Delta$.

Proof of Proposition 1. We consider separately option contracts with *i* = *F* and with *i* = *R*.

1. Among option contracts with *i*=*F*, we distinguish (i) contracts inducing termination in equilibrium, (ii) those inducing continuation in equilibrium but with $o_C \neq N$, (iii) those inducing continuation in equilibrium and with $o_C = N$ but with $o_T \neq N + B$. We compare, in turn, the payoffs *F* reaps under each of these sets of contracts with *F*'s payoff under the best possible no-option contract and under a contract $\hat{A}_O$ and show that these payoffs – if they exceed the best possible no-option payoff Π^*_{NO} at all – are strictly smaller than the payoff under $\hat{A}_O$, $\hat{\Pi}_O$.

(i) For option contracts inducing termination in equilibrium, we distinguish four cases.

If $o_T = \text{ø}$, then $\Pi_O = -p_T - I < 0 \leq \Pi^*_{NO}$ (given $p_T \geq 0$).

If $o_T = B$, then $\Pi_O = \varepsilon B - p_T - I$ where R's participation constraint implies $p_T \geq \underline{B}$ and thus (with **(1)**) $\Pi_O < 0 \leq \Pi^*_{NO}$.

If $o_T = N$, then $\Pi_O = \alpha N - p_T - I \leq \alpha N - I < \hat{\Pi}_O$.

If $o_T = N + B$, then $\Pi_O = \alpha N + \varepsilon B - p_T - I$ where R's participation constraint implies $p_T \geq \underline{B}$ and thus (with **(1)**) $\Pi_O < \alpha N - I < \hat{\Pi}_O$.

(ii) Among option contracts inducing continuation in equilibrium but not allocating (only) the narrow rights to F, $o_C \neq N$, we distinguish three cases.

If $o_C = \text{ø}$, then $\Pi_O = -p_C - I \leq 0 \leq \Pi^*_{NO}$.

If $o_C = B$, then $\Pi_O = \varepsilon B - p_C - I$, where R's participation constraint implies $p_C \geq \underline{B}$ and thus $\Pi_O < 0 \leq \Pi^*_{NO}$.

If $o_C = N + B$, then $\Pi_O = N + \varepsilon B - p_C - I$, where R's participation constraint implies $p_C \geq \underline{B}$; **(2)** implies that F needs to terminate after e_B (else R would choose e_B and the resulting payoff for F is strictly smaller than Π^*_{NO}); the incentive-compatibility constraints such that F continues iff $e = e_N$ are

$$\left.\begin{array}{l} \overline{N} + \varepsilon \underline{B} \\ \overline{N} \\ (1-\alpha)\overline{N} + \varepsilon \underline{B} \\ (1-\alpha)\overline{N} \end{array}\right\} > p_C - p_T \geq \begin{cases} \underline{N} + \varepsilon \overline{B} & \text{if } o_T = \text{ø} \\ \underline{N} & \text{if } o_T = B \\ (1-\alpha)\underline{N} + \varepsilon \overline{B} & \text{if } o_T = N \\ (1-\alpha)\underline{N} & \text{if } o_T = B+N \end{cases}$$

and the incentive-compatibility constraint ensuring that R chooses e_N is

$$p_C - p_T > \begin{cases} \overline{B} & \text{if } o_T = \text{ø} \\ 0 & \text{if } o_T = B \\ \overline{B} & \text{if } o_T = N \\ 0 & \text{if } o_T = B+N \end{cases}$$

An equilibrium exists, i.e., all four conditions (participation constraint, the two inequalities of F's incentive constraint, R's incentive constraint) are satisfied if

$$\begin{aligned} &\overline{B} < \overline{N} + \varepsilon \underline{B} \quad \text{and} \quad \overline{N} - \underline{N} > \varepsilon(\overline{B} - \underline{B}) && \text{for } o_T = \text{ø} \\ &\underline{B} < \overline{N} && \text{for } o_T = B \\ &\overline{B} < (1-\alpha)\overline{N} + \varepsilon \underline{B} \quad \text{and} \quad (1-\alpha)(\overline{N} - \underline{N}) > \varepsilon(\overline{B} - \underline{B}) && \text{for } o_T = N \\ &\underline{B} < (1-\alpha)\overline{N} && \text{for } o_T = B+N \end{aligned}$$

In these cases, the maximization problem of F amounts to minimizing p_C under the above constraints, and we can bound the optimal p_C^* (if it exists):

$$p_C^* \geq \begin{cases} \max\{\overline{B}, \underline{N} + \varepsilon \overline{B}\} & \text{for } o_T = \text{ø} \\ \max\{\underline{B}, \underline{N}\} & \text{for } o_T = B \\ \max\{\overline{B}, (1-\alpha)\underline{N} + \varepsilon \overline{B}\} & \text{for } o_T = N \\ \max\{\underline{B}, (1-\alpha)\underline{N}\} & \text{for } o_T = B+N \end{cases}$$

It is easy to check that the payoff $\Pi_O = \overline{N} + \varepsilon \underline{B} - p_C^* - I$ is smaller than $\hat{\Pi}_O$ in all four cases, even if we set p_C^* equal to its lower bound.

(iii) For contracts inducing continuation with $o_C = N$ but $o_T \neq N + B$ note first that $o_C = N$ implies that the participation constraint for R is not binding since R receives $\overline{B}$. Also, as above, **(2)** implies that F needs to terminate after e_B (otherwise, R would choose e_B and the resulting payoff for F is strictly smaller than Π_{NO}^*). The incentive compatibility constraints ensuring that F continues iff e_N is

$$\left.\begin{array}{l}\overline{N}\\ \overline{N}-\varepsilon\underline{B}\\ (1-\alpha)\overline{N}\end{array}\right\} > p_C - p_T \geq \begin{cases}\underline{N} & \text{for } o_T = \text{ø}\\ \underline{N}-\varepsilon\overline{B} & \text{for } o_T = B\\ (1-\alpha)\underline{N} & \text{for } o_T = N\end{cases}$$

and the incentive compatibility constraint ensuring that *R* chooses e_N is

$$p_C - p_T > \begin{cases}\overline{B}-\underline{B} & \text{if } o_T = \text{ø}\\ -\underline{B} & \text{if } o_T = B\\ \overline{B}-\underline{B} & \text{if } o_T = N\end{cases}$$

The constraints imply additional conditions for existence in two cases:

$$\overline{B}-\underline{B} < \begin{cases}\overline{N} & \text{if } o_T = \text{ø}\\ (1-\alpha)\overline{N} & \text{if } o_T = N\end{cases}$$

The maximization problem amounts to minimizing p_C under the above constraints and yields:

$$p_C^* = \begin{cases}\max\{\overline{B}-\underline{B}, \underline{N}\} & \text{for } o_T = \text{ø}\\ \max\{\underline{N}-\varepsilon\overline{B};0\} & \text{for } o_T = B\\ \max\{\overline{B}-\underline{B}, (1-\alpha)\underline{N}\} & \text{for } o_T = N\end{cases}$$

and the resulting payoff $\Pi_O = \overline{N} - p_C^* - I$ is strictly smaller than $\hat{\Pi}_O$ in all three cases.

Summarizing cases (i) to (iii), we have shown that there is no alternative option contract with $i = F$ such that its payoff $\Pi_O > \Pi_{NO}^*$ and $\Pi_O \geq \hat{\Pi}_O$.

2. For the class of contracts with $i = R$, contracts that neither (i) induce continuation in equilibrium nor (ii) allocate narrow rights to *F* after continuation are ruled out the same way as for $i = F$. Contracts satisfying (i) and (ii) allocate at least narrow rights after continuation and will thus always induce *R* to choose e_B, since *R*'s payoff after continuation if choosing e_N is always weakly (for $o_C = N + B$) or strictly (for $o_C = N$) smaller than if choosing e_B. However the maximum payoff resulting from any contract inducing *R* to choose e_B is Π_{NO}^*. Thus, there is also no option contract with $i = R$ and payoff Π_O satisfying $\Pi_O > \Pi_{NO}^*$ and $\Pi_O \geq \hat{\Pi}_O$.

Lemma B1. *An option contract (i, p_C, p_T, o_C, o_T) with i = F, o_C = N, and o_T = ø implements e_N iff*

(B1) $$\overline{N} > p_C - p_T \geq \underline{N} \quad \textit{and} \quad p_C - p_T > \overline{B} - \underline{B}$$

Proof. Notice that the set of admitted values for $p_C - p_T$ described in (B1″) is non-empty since we are considering the case $\overline{N} + \underline{B} > \underline{N} + \overline{B}$.

The condition $p_C - p_T \geq \underline{N}$ guarantees that *F* chooses to terminate when $e = e_B$. The condition $\overline{N} > p_C - p_T$ guarantees that *F* chooses to continue when $e = e_N$. Finally, $p_C - p_T > \overline{B} - \underline{B}$ guarantees that *R* chooses e_N..

Moreover such a contract can be implemented with the following prices:

Lemma B2. *In the set of option contracts* (*F*, p_C, p_T, *N*, ø) *that implement e_N, setting* $p_C = 0$ and $-\overline{N} < p_T \leq -\underline{N}$ *and* $p_T < -(\overline{B} - \underline{B})$ *maximizes F's payoff.*

Proof. The prices implement e_N by Lemma B1. Since the equilibrium payoff of *R* under this contract is its reservation utility $\underline{B}$, the profit of *F* cannot be increased further without violating the participation constraint of *R*.

Lemma B2 illustrates that there are several types of option contracts achieving the same maximum payoff for *F* as option contracts in $\hat{A}_O$.

References

Acemoglu, Daron, Philippe Aghion, Rachel Griffith, and Fabrizio Zilibotti. 2004. "Vertical Integration and Technology." National Bureau of Economic Research Working Paper No. 10997.

Aghion, Philippe, and Patrick Bolton. 1992. "An Incomplete Contracts Approach to Financial Contracting." *Review of Economic Studies*, 59(3): 473–494.

Aghion, Philippe, and Jean Triole. 1994. "On the Management of Innovation." *Quarterly Journal of Economics*, 109(4): 1185–1207.

Angelmar, Reinhard, and Yves Doz. 1987–1989. "Advanced Drug Delivery Systems: ALZA and Ciba-Geigy." INSEAD, Fontainebleau Cedex, France unnumbered case study series.

Azoulay, Pierre. 2004. "Capturing Knowledge within and across Firm Boundaries: Evidence from Clinical Development." *American Economic Review*, 94(5): 1591–1612.

Baker, George P., Robert Gibbons, and Kevin J. Murphy. 2002. "Relational Contracts in Strategic Alliances." Harvard University, Massachusetts Institute of Technology, and University of Southern California. Unpublished.

Baker, George P., and Thomas Hubbard. 2003. "Make or Buy in Trucking: Asset Ownership, Job Design, and Information." *American Economic Review*, 93(3): 551–572.

Baker, George P., and Thomas Hubbard. 2004. "Contractibility and Asset Ownership: On-Board Computers and Governance in U.S. Trucking." *Quarterly Journal of Economics*, 119(4): 1443–1479.

Banerjee, Abhijit, and Esther Duflo. 2000. "Reputation Effects and the Limits of Contracting: A Study of the Indian Software Industry." *Quarterly Journal of Economics*, 115(3): 989–1017.

Carter, Richard, Frederick H. Dark, and Ajai K. Singh. 1998. "Underwriter Reputation, Initial Returns, and the Long-Run Performance of IPO Stocks," *Journal of Finance*, 53(1): 285–311.

Carter, Richard, and Steven Manaster. 1990. "Initial Public Offerings and Underwriter Reputation." *Journal of Finance*, 45(4): 1045–1067.

Chiappori, Pierre-André and Bernard Salanié. 2003. "Testing Contract Theory: a Survey of Some Recent Work." In *Advances in Economics and Econometrics—Theory and Applications, Eighth World Congress*, eds. M. Dewatripont, L. Hansen, and P. Turnovsky, 115–149. Cambridge, U.K.: Econometric Society Monographs, Cambridge University Press.

Cockburn, Iain, Rebecca Henderson, and Scott Stern. 1999. "Balancing Incentives: The Tension Between Basic and Applied Research." National Bureau of Economic Research Working Paper 6882.

Cornelli, Francesca, and Oved Yoshi. 2003. "Stage Financing and the Role of Convertible Securities." *Review of Economic Studies*, 70(1): 1–32.

Danzon, Patricia M., Sean Nicholson, and Nuno S. Pereira. 2005. "Productivity in Pharmaceutical-Biotechnology R&D: The Role of Experience and Alliances." *Journal of Health Economics*, 24(2): 317–339.

Dessein, Wouter. 2005. "Information and Control in Ventures and Alliances." *Journal of Finance*, 60(5): 2513–2550.

Grossman, Sanford J. and Oliver D. Hart. 1986. "The Costs and Benefits of Ownership: A Theory of Lateral and Vertical Integration." *Journal of Political Economy*, 94(4): 691–719.

Guedj, Ilan. 2006. "Ownership vs. Contract: How Vertical Integration Affects Investment Decisions in Pharmaceutical R&D." University of Texas. Unpublished.

Hart, Oliver D. 1995. *Firms, Contracts, and Financial Structure*. Oxford: Clarendon Press.

Hart, Oliver D. and Bengt Holmström. 2008. "A Theory of Firm Scope." National Bureau of Economic Research Working Paper No. 14613.

Hart, Oliver D. and John Moore. 1988. "Incomplete Contracts and Renegotiations." *Econometrica*, 56(4): 755–786.

Hart, Oliver D. and John Moore. 1990. "Property Rights and the Nature of the Firm." *Journal of Political Economy*, 98(6): 1119–1158.

Holmström, Bengt, and Paul Milgrom. 1991. "Multitask Principal-Agent Analysis: Incentive Contracts, Asset Ownership and Job Design." *Journal of Law, Economics and Organization*, 7(Special Issue): 24–51.

Kaplan, Steven, and Per Stromberg. 2003. "Financial Contracting Theory Meets the Real World: An Empirical Analysis of Venture Capital Contracts." *Review of Economic Studies*, 70(2): 281–315.

Kaplan, Steven, and Per Stromberg. 2004. "Characteristics, Contracts, and Actions: Evidence from Venture Capitalist Analyses." *Journal of Finance*, 59(5): 2173–2206.

Lerner, Josh, and Robert P. Merges. 1998. "The Control of Technology Alliances: An Empirical Analysis of the Biotechnology Industry." *Journal of Industrial Economics*, 46(2): 125–156.

Lerner, Josh, Hilary Shane, and Alexander Tsai. 2003 "Do Equity Financing Cycles Matter? Evidence from Biotechnology Alliances." *Journal of Financial Economics*, 67(3): 411-446.

Loughran, Tim, and Jay R. Ritter. 2004. "Why Has IPO Underpricing Changed Over Time?" *Financial Management*, 33 (3): 5–37.

Monteverde, Kirk and David J. Teece. 1982. "Appropriable Rents and Quasi-Vertical Integration." *Journal of Law and Economics*, 25(2): 321–328.

Nöldeke, Georg and Klaus M. Schmidt. 1995. "Option Contracts and Renegotiation: A Solution to the Hold-Up Problem." *RAND Journal of Economics*, 26(2): 163–179.

Nöldeke, Georg and Klaus M. Schmidt. 1998. "Sequential Investments and Options to Own." *RAND Journal of Economics*, 29(4): 633–653.

Pisano, Gary P. 1997. "R&D Performance, Collaborative Arrangements, and the Market-for-Know-How: A Test of the 'Lemons' Hypothesis in Biotechnology." Harvard University. Unpublished.

Robinson, David and Toby Stuart. 2007. "Financial Contracting in Biotech Strategic Alliances." *Journal of Law and Economics*, 50(3): 559–596.

Schmidt, Klaus. 2003. "Convertible Securities and Venture Capital Finance." *Journal of Finance*, 58(3): 1139–66.

Table 1. Sample construction

Sample Construction, starting from ReCap universe	Observations
Agreements analyzed by ReCap, entered into through end of 2001, as of January 2003	1108
Less agreements involving universities, non-profits, and hospitals (311)	797
Less "marketing only" agreements (127)	670
Less agreements involving renegotiations of existing agreements (62)	608
Less agreements involving three or more parties (14)	594
Less non-arm's length agreements (10)	584
Less duplicated agreements (3)	581
Less agreements no longer present in Recap as of July 2006 (1)	580
Additional data gathering steps	**Observations**
ReCap disease/keyword data available	580
Financing category determined from contract analysis	580
Patent data available*	580
Carter-Manaster rank data available	526
Financial Health Index data available	551
Data on previous alliances between two firms available	551
All above data available	483

*5 agreements with insufficient keywords coded as 0

Table 2. Summary statistics

Variable Name	# Obs.	Mean	Stan. Dev.	Min.	Max.	Median
Date	580	1995.85	3.73	1980.04	2001.71	1996.88
No specifiable lead product	580	0.37	0.48	0	1	0
Unknown if specifiable lead product	580	0.11	0.31	0	1	0
Agreement involves diagnostic product	580	0.13	0.34	0	1	0
Agreement involves veterinary product	580	0.05	0.23	0	1	0
Agreement between two biotechnology firms	580	0.17	0.37	0	1	0
Research firm's revenue in prior fiscal year	558	11.47	37.21	0	523.22	0.71
Research firm's cash flow in prior fiscal year	535	2.57	176.14	-331	2398.26	-6.66
Research firm's net income prior fiscal year	558	1.38	189.12	-351.95	2474.34	-7.48
Research firm's cash holdings in prior fiscal year	551	46.04	134.69	0	1452.36	12.53
Financial Health Index	551	0.62	0.27	0	1	0.67
Patent awards to the research firm at the time of the research agreement signing	580	8.66	20.12	0	178	1
Number of previous research agreements between financing and research firms	551	0.11	0.40	0	3	0
Total number of research agreements signed by research firm in previous 3 years	580	6.39	6.78	0	45	4
Total number of research agreements signed by research firm in previous 3 years with any technology match	580	4.77	6.56	0	53	3
Total number of research agreements signed by research firm in previous 3 years with exact technology match	580	1.95	2.92	0	18	1
Any unilateral termination rights?	580	0.97		0	1	1
Any termination rights for financing firm?	580	0.96		0	1	1
Any unconditional termination rights for financing firm?	580	0.39		0	1	0
Any unconditional termination rights for financing firm and broad intellectual property rights?	580	0.11		0	1	0
Carter-Manaster rank of lead bank in research firm's IPO	526	7.71	1.99	1	9	8.75

Table 3. Contract characteristics

Mean number of unconditional termination rights assigned to the financing firm
(combined with broad intellectual property rights)

If no specifiable lead product	Otherwise	t-Statistic, Test of Difference	p-Value
0.21	0.11	2.66	0.008
If research agreement involves diagnostic technologies	Otherwise	t-Statistic, Test of Difference	p-Value
0.05	0.16	-2.02	0.044
If research agreement involves veterinary technologiess	Otherwise	t-Statistic, Test of Difference	p-Value
0.03	0.16	-1.49	0.136
If research agreement between two biotechnology firms	Otherwise	t-Statistic, Test of Difference	p-Value
0.25	0.13	2.34	0.020
If research firm has above median net income	Otherwise	t-Statistic, Test of Difference	p-Value
0.14	0.15	-0.10	0.923
If research firm has high-status underwriter	Otherwise	t-Statistic, Test of Difference	p-Value
0.20	0.13	1.55	0.114

Table 4. Regression analysis of contract design

	Ordered logit	Ordered logit	OLS	OLS with year fixed effects	OLS with year and firm fixed effects
	(1)	(2)	(3)	(4)	(5)
Date	0.012	0.032	0.005		
	[0.039]	[0.043]	[0.006]		
No specifiable lead product	0.678	0.680	0.126	0.140	0.139
	[0.292]**	[0.315]**	[0.047]***	[0.049]***	[0.050]***
Unknown if specifiable lead product	-0.11	0.031	0.002	-0.011	0.014
	[0.516]	[0.527]	[0.070]	[0.073]	[0.075]
Agreement involves diagnostic product	-0.889	-0.794	-0.096	-0.103	-0.097
	[0.540]	[0.545]	[0.061]	[0.064]	[0.065]
Agreement involves veterinary product	-1.413	-1.336	-0.12	-0.123	-0.107
	[1.034]	[1.037]	[0.090]	[0.095]	[0.096]
Carter-Manaster rank of lead underwriter of research firm's IPO	0.003	0.032	0.01	0.009	0.009
	[0.070]	[0.077]	[0.011]	[0.011]	[0.011]
Number of patents of research firm		0.006	0.001	0.001	0.001
		[0.007]	[0.001]	[0.001]	[0.001]
Financial Health Index		0.732	0.075	0.119	0.119
		[0.557]	[0.077]	[0.083]	[0.084]
Number of previous research agreements		-0.016	-0.005	-0.004	-0.019
between financing and research firms		[0.352]	[0.051]	[0.053]	[0.054]
Constant			-10.739	0.027	-0.12
			[11.783]	[0.490]	[0.513]
Year Fixed Effects				X	X
Financing Firm Fixed Effects					X
Number of observations	526	483	483	483	483
R-squared			0.04	0.07	0.09

Notes

Dependent variable is the number of unconditional termination rights assigned to financing firm (combined with broad intellectual property rights).

Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%

Table 5. Regression analysis of contract design: alternative proxies and additional controls

	Alternative proxy for incentive conflicts (multi-tasking): other research agreements		Sample excludes financing firms with related patents		Sample restricted to agreements not defined as joint ventures by ReCap	Sample excludes agreements where text indicates that financing firm is also involved in research	Sample excludes agreements on veterinary and diagnostic products	With fixed effects for disease categories
			Broad definition	Narrow definition				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
No specifiable lead product		0.124	0.141	0.103	0.143	0.192	0.172	0.163
		[0.051]**	[0.085]*	[0.049]**	[0.058]**	[0.059]***	[0.059]***	[0.052]***
Unknown if specifiable lead product		0.012	0.009	0.002	0.011	0.014	0.038	0.032
		[0.075]	[0.115]	[0.073]	[0.084]	[0.080]	[0.093]	[0.094]
Agreement involves diagnostic product	-0.091	-0.095	-0.088	-0.086	-0.077	-0.070		-0.091
	[0.066]	[0.065]	[0.098]	[0.063]	[0.072]	[0.073]		[0.067]
Agreement involves veterinary product	-0.105	-0.110	-0.185	-0.080	-0.112	-0.081		-0.099
	[0.096]	[0.096]	[0.155]	[0.094]	[0.100]	[0.111]		[0.097]
Carter-Manaster rank of lead underwriter of research firm's IPO	0.014	0.009	0.013	0.011	0.009	0.016	0.008	0.008
	[0.011]	[0.011]	[0.017]	[0.011]	[0.013]	[0.013]	[0.013]	[0.012]
Number of patents of research firm	0.000	0.000	0.000	0.000	0.002	0.002	0.001	0.001
	[0.001]	[0.001]	[0.002]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
Financial Health Index	0.082	0.091	0.104	0.048	0.139	0.155	0.139	0.118
	[0.086]	[0.086]	[0.131]	[0.081]	[0.092]	[0.091]*	[0.099]	[0.085]
Number of previous research agreements between financing and research firms	-0.040	-0.029	0.031	0.003	0.020	0.019	-0.021	-0.018
	[0.055]	[0.055]	[0.102]	[0.052]	[0.060]	[0.061]	[0.066]	[0.055]
Total number of alliances signed by research firm in 3 years before alliance	0.008	0.006						
	[0.004]**	[0.004]						
Constant	-0.164	-0.103	-0.146	-0.107	0.059	-0.079	-0.231	-0.120
	[0.515]	[0.513]	[0.517]	[0.488]	[0.497]	[0.503]	[0.526]	[0.520]
Year Fixed Effects	X	X	X	X	X	X	X	X
Financing Firm Fixed Effects	X	X	X	X	X	X	X	X
Disease Category Fixed Effects								X
Number of observations	483	483	235	458	371	360	394	483
R-squared	0.08	0.10	0.20	0.10	0.09	0.13	0.09	0.11

Notes

Dependent variable is the number of unconditional termination rights assigned to financing firm (combined with broad intellectual property rights).

The broad definition in regression (3) excludes any research agreement where the financing firm had a patent or pending patent application with any of the alliance keywords at the time of the agreement signing. The narrow definition in regression (4) excludes any research agreements where the financing firm had a patent or pending patent application with all of the alliance keywords at the time of the agreement signing.

Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%

Table 6. Separating research firms with high and low net income

	Low Net Income (1)	High Net Income (2)	Low Net Income (3)	High Net Income (4)
Date	0.003	0.011		
	[0.011]	[0.008]		
No specifiable lead product	0.171	0.07	0.200	0.092
	[0.070]**	[0.068]	[0.076]***	[0.074]
Unknown if specifiable lead product	0.029	-0.036	0.040	-0.038
	[0.104]	[0.097]	[0.114]	[0.110]
Agreement involves diagnostic product	-0.073	-0.084	-0.073	-0.074
	[0.090]	[0.087]	[0.097]	[0.103]
Agreement involves veterinary product	-0.106	-0.126	-0.096	-0.146
	[0.132]	[0.126]	[0.147]	[0.148]
Carter-Manaster Rank of lead underwriter of research firm's IPO	0.018	0.007	0.017	0.005
	[0.016]	[0.015]	[0.017]	[0.017]
Number of patents of research firm	0.001	0.004	0.001	0.003
	[0.001]	[0.004]	[0.001]	[0.004]
Financial Health Index	0.035	0.08	0.099	0.098
	[0.126]	[0.101]	[0.141]	[0.116]
Number of previous research agreements between financing and research firms	-0.03	0.021	-0.078	0.055
	[0.067]	[0.089]	[0.073]	[0.101]
Constant	-6.869	-22.205	0.125	0.101
	[22.562]	[15.196]	[0.589]	[0.561]
Year Fixed Effects			X	X
Financing Firm Fixed Effects			X	X
Number of observations	249	234	249	234
R-squared	0.05	0.04	0.13	0.14

Notes

Dependent variable is the number of unconditional termination rights assigned to financing firm (combined with broad intellectual property rights). Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%

Table 7. Separating research firms with high and low reputation underwriters

	High Rank Underwriter (1)	Low Rank Underwriter (2)	High Rank Underwriter (3)	Low Rank Underwriter (4)
Date	0.007	0.004		
	[0.012]	[0.006]		
No specifiable lead product	0.198	0.07	0.189	0.093
	[0.094]**	[0.054]	[0.105]*	[0.057]
Unknown if specifiable lead product	0.046	0.007	0.007	0.033
	[0.139]	[0.079]	[0.156]	[0.085]
Agreement involves diagnostic product	-0.21	-0.05	-0.217	-0.071
	[0.122]*	[0.066]	[0.148]	[0.070]
Agreement involves veterinary product	-0.19	-0.055	-0.201	-0.015
	[0.158]	[0.106]	[0.186]	[0.114]
Carter-Manaster Rank of lead underwriter of research firm's IPO	-0.874	0.005	-1.329	0.002
	[0.625]	[0.011]	[0.748]*	[0.011]
Number of patents of research firm	0.001	0.002	-0.001	0.001
	[0.002]	[0.002]	[0.002]	[0.002]
Financial Health Index	0.192	0.03	0.262	0.097
	[0.153]	[0.084]	[0.180]	[0.092]
Number of previous research agreements between financing and research firm	-0.032	0.02	-0.057	0.036
	[0.105]	[0.054]	[0.118]	[0.063]
Constant	-5.759	-7.938	11.856	-0.148
	[23.834]	[12.746]	[6.751]*	[0.314]
Year Fixed Effects			X	X
Financing Firm Fixed Effects			X	X
Number of observations	189	294	189	294
R-squared	0.07	0.02	0.17	0.12

Notes

Dependent variable is the number of unconditional termination rights assigned to financing firm (combined with broad intellectual property rights). Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%

Table 8. Regression analysis of contract design: different types of termination rights

	Termination rights of financing firm (without requiring product right reversion)				Conditional termination and property rights	
	Ordered logit	Ordered logit	OLS	OLS with year and firm fixed effects	OLS	OLS with year and firm fixed effects
	(1)	(2)	(3)	(4)	(5)	(6)
Date	-0.026	-0.023	-0.003		0.005	
	[0.023]	[0.025]	[0.010]		[0.003]	
No specifiable lead product	-0.28	-0.273	-0.104	-0.092	0.024	0.027
	[0.195]	[0.209]	[0.080]	[0.082]	[0.028]	[0.028]
Unknown if specifiable lead product	-0.248	-0.185	-0.001	-0.054	-0.026	-0.013
	[0.304]	[0.318]	[0.118]	[0.124]	[0.040]	[0.043]
Agreement involves diagnostic product	-0.878	-0.887	-0.287	-0.274	-0.043	-0.052
	[0.290]***	[0.296]***	[0.103]***	[0.108]**	[0.035]	[0.037]
Agreement involves veterinary product	-0.48	-0.406	-0.156	-0.129	0.029	0.024
	[0.411]	[0.418]	[0.152]	[0.158]	[0.052]	[0.055]
Carter-Manaster Rank of lead underwriter of research firm's IPO	0.003	0.004	-0.013	-0.009	0.006	0.01
	[0.046]	[0.048]	[0.018]	[0.019]	[0.006]	[0.007]
Number of patents of research firm		-0.003	0	-0.001	-0.001	-0.001
		[0.005]	[0.002]	[0.002]	[0.001]	[0.001]
Financial Health Index		0.873	0.264	0.235	-0.103	-0.08
		[0.346]**	[0.131]**	[0.138]*	[0.045]**	[0.048]*
Number of previous research agreements		0.041	0.002	-0.085	0.034	0.032
between financing and research firms		[0.210]	[0.086]	[0.090]	[0.030]	[0.031]
Constant			6.228	1.088	-8.996	-0.026
			[19.888]	[0.850]	[6.829]	[0.294]
Year Fixed Effects				X		X
Financing Company Fixed Effects (dummies for major pharmaceutical companies)				X		X
Observations	526	483	483	483	483	483
R-squared			0.03	0.12	0.03	0.1

Notes

Dependent variable in regressions (1) through (4) is the total number of unconditional termination rights assigned to financing firm. Dependent variable in regressions (5) and (6) is the number of conditional termination rights assigned to financing firm (combined with broad intellectual property rights).

Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%

Figure 1. Timeline

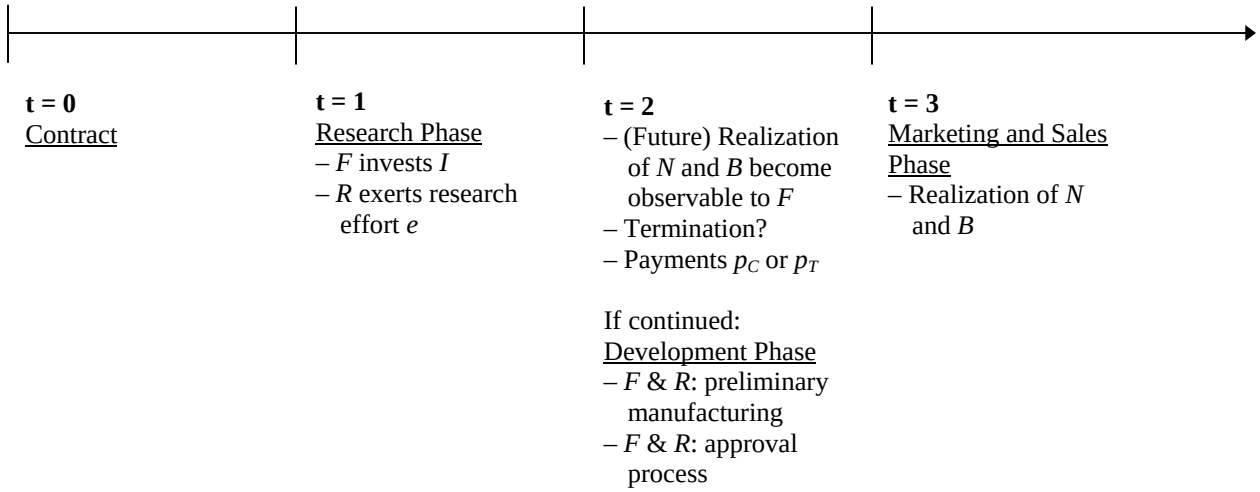


Figure 2. Table of Payoffs

	F's rights	*F*'s payoff	*R*'s payoff
Continuation	$o_C = \emptyset$	$-p_C - I$	$B + p_C$
	$o_C = N$	$N - p_C - I$	$B + p_C$
	$o_C = B$	$\varepsilon B - p_C - I$	p_C
	$o_C = N + B$	$N + \varepsilon B - p_C - I$	p_C
Termination	$o_T = \emptyset$	$-p_T - I$	$B + p_T$
	$o_T = N$	$\alpha N - p_T - I$	$B + p_T$
	$o_T = B$	$\varepsilon B - p_T - I$	p_T
	$o_T = N + B$	$\alpha N + \varepsilon B - p_T - I$	p_T

Online Appendix

Online-Appendix A: Case Evidence

Cross-subsidization. In our interviews with industry executives and lawyers, cross-subsidization was highlighted as a major concern in the negotiations leading to research agreements and in subsequent disputes. A lawyer frequently involved in these negotiations argued that, while formal dispute-resolution mechanisms partially address the problem, some disputes cannot be resolved in negotiations, and financing firms insist on the right to unilaterally back out of the agreements. He indicated that these terms are far more likely in a negotiation involving an early-stage technology.

One illustration of the difficulty of contracting in biotechnology alliances is a 1993 case, in which established biotechnology firm Alkermes sued its smaller contracting partner, Cortex Pharmaceuticals. It alleged that Cortex's research on a calpain-inhibiting drug for cerebral vasospasm violated Alkermes' exclusive right to develop applications for neurological disorders (*Alkermes, Inc. v. Cortex Pharmaceuticals Inc*., Civil Docket no. 93-CV-12532, U.S. District Court for Massachusetts (Boston), 1993).

Academic Interests. The concept that incentives of researchers may differ between firms has been well-discussed. Stern (2004) points out that scientists are willing to accept lower wages in return for undertaking more science-oriented research. To cite a characteristic example of the kinds of conflicts that are discussed in the practitioner-oriented literature, the biotechnology company may want to spend extra time and money running additional experiments to satisfy academic requirements for a publication in a top journal, when there is already sufficient evidence to start the approval process at the U.S. Food and Drug Administration.

ALZA case. The research collaboration between drug delivery firm ALZA and Swiss pharmaceutical manufacturer Ciba-Geigy illustrates both the cross-subsidization and publication issues.[1] The two firms signed a research agreement in 1978. ALZA also engaged in a variety of independent activities, including alliances to exploit technologies that did not conflict with the topics being jointly explored with Ciba-Geigy.

Due to ALZA's financial weakness, Ciba-Geigy was able to obtain vast control rights, such as eight of ALZA's eleven board seats, majority voting control, extensive information rights, and the ability to guide 90% of ALZA's research activities through a number of review panels that were dominated by Ciba-Geigy representatives. Despite these seemingly ironclad control rights, numerous tensions arose over the exact type of research the ALZA researchers should be conducting. In particular, Ciba-Geigy was concerned about other research projects and collabora-

[1] This account is based on Angelmar and Doz (1987-1989).

tions that ALZA representatives kept seeking to permission to establish with third parties. While the boards ultimately approved most of ALZA's requests, ALZA representatives became frustrated at the long delays associated with the process. As a result, ALZA scientists began bypassing the various review panels and directly contacting senior Ciba-Geigy officials for permission to engage in outside arrangements. While detailed reporting and monitoring processes had been stipulated in the original agreement, these proved very difficult to enforce. Ciba-Geigy officials were also concerned that ALZA scientists were publishing material in journals that disclosed their proprietary technology or might be employed in ALZA's collaborations with other pharmaceutical firms. As a result, Ciba-Geigy became increasingly reluctant to disclose its own technologies in the area of drug delivery to ALZA. Ultimately, these tensions led to the dissolution of the research collaboration at the end of 1981. These conflicts, while perhaps extreme, illustrate the importance of the types of problems delineated above on research collaborations.

Online-Appendix B: Renegotiation

The results in Section III have been derived under the assumption that the parties can commit not to renegotiate. We now allow for renegotiation after $t = 1$. As in Nöldeke and Schmidt (1995), we assume that, after R has exerted effort e in $t = 1$ but, before $t = 2$, both R and F can send signed offers to each other, specifying new prices $\tilde{p}_C$ and $\tilde{p}_T$ as well as a new (conditional) allocation of property rights. After F has decided whether to continue or to terminate at $t = 2$, the parties can present any signed offer they received in court. The court observes whether F initiated termination or not and enforces the respective payment as specified in the original contract unless

- exactly one party presents a signed renegotiation offer from the other party to the court, or
- both sides present the same renegotiation offer to the court.

In those two cases, the court enforces the renegotiated contract. We assume that

(A.5) R and F (i) accept the best renegotiation offer received from the other party if their own equilibrium payoff in the continuation game (after $t = 1$) under the renegotiated contract is weakly larger than under the original contract, and (ii) make a renegotiation offer if their renegotiated equilibrium payoff in the continuation game is strictly larger than the original equilibrium payoff.

We apply the concept of subgame-perfect equilibrium. Given this renegotiation mechanism, we can specify when the contract derived in Lemma 2′ is renegotiation-proof.

Lemma 4′. *For $\Delta \geq 0$, contracts in $\hat{A}_O$ are not renegotiation-proof. For $\Delta < 0$, contracts in $\hat{A}_O$ with $p_T < -\Delta$ are renegotiation-proof.*

Proof. We first determine in which subgames, after R has chosen e, renegotiation may occur.

(1) After effort choice e_N, the original contract allows for extraction of the full surplus $\overline{N} + \underline{B}$. Any reallocation is either a mere transfer or reduces the total surplus. Both parties can guarantee themselves the payoff resulting from the original contract by not making any renegotiation offers and not presenting any offers they receive. Thus, there is no scope for renegotiation.

(2) After effort choice e_B, the surplus under the original contract, $\alpha\underline{N} + \varepsilon\overline{B}$, is smaller than the surplus that can be extracted if F does not terminate. Hence, there is scope for renegotiation inducing continuation. (Since the original contract recommends termination, any other contract that leads to termination is a mere transfer.)

We now show that a necessary condition for R to exert e_B and for subsequent renegotiation to succeed is that R offers a new contract. Suppose, instead, that R exerts e_B but does not make a renegotiation offer. If F makes an offer, F will allocate exactly p_T to R since this suffices to induce R to accept the offer (with A.5). Anticipating this, R will exert e_N instead of e_B to ensure

a renegotiation-proof payoff of $\overline{B} + p_C = \overline{B} + \max\{0, \Delta\}$, which is strictly larger than p_T for all subcases specified in Lemma 2′. This contradicts the initial assumption that *R* exerts e_B. Successful renegotiation thus requires *R* to make an offer.

With assumption A.5, two conditions need to be satisfied to induce *R* to choose e_B and to make a renegotiation offer upon which *F* continues and which *F* would enforce:

1. Conditional on *R* choosing e_B, *F*'s payoff after continuation and enforcing *R*'s renegotiation offer is weakly higher than after termination under the original contract.
2. *R*'s equilibrium payoff after e_B and continuation under the renegotiated contract is strictly higher than after e_N and continuation under the original contract.

We consider separately renegotiation offers that (re-)assign (i) both broad and narrow rights and (ii) only narrow rights to *F* upon continuation. We can rule out offers that assign no rights or only broad rights to *F* since the resulting payoff for *F* would be smaller than the original equilibrium payoff (given *R*'s financial constraints).

(i) *Broad and narrow rights*. In order to accept *R*'s renegotiation offer and to choose continuation, *F* requires a continuation payoff $\underline{N} + \varepsilon\overline{B} - \widetilde{p}_C$ that is weakly higher than the continuation payoff after termination under the original contract, $\alpha\underline{N} + \varepsilon\overline{B} - p_T$. The resulting upper bound of $\widetilde{p}_C$ is $\widetilde{p}_C \le (1-\alpha)\underline{N} + p_T$. Thus, *R* can at most ensure a payoff of $(1-\alpha)\underline{N} + p_T$ instead of $\overline{B} + p_C$ under the original contract. It is easy to check that, for all three subcases specified in Lemma 2′, *R*'s continuation payoff under the original contract is strictly higher. Hence, *R* will not choose e_B and then make a renegotiation offer specifying $\tilde{o}_C = N + B$.

(ii) *Narrow rights*. *F* accepts *R*'s renegotiation offer and chooses continuation if the continuation payoff $\underline{N} - \widetilde{p}_C$ is weakly higher than the continuation payoff after termination under the original contract, $\alpha\underline{N} + \varepsilon\overline{B} - p_T$, i. e. if $\widetilde{p}_C \le (1-\alpha)\underline{N} - \varepsilon\overline{B} + p_T$.

For $\Delta < 0$, we can find such a $\widetilde{p}_C$ only if the original p_T was set equal to the upper bound $-\Delta$ (namely $\widetilde{p}_C = 0$). For all other p_T the upper bound on $\widetilde{p}_C$, i.e. $(1-\alpha)\underline{N} - \varepsilon\overline{B} + p_T = \Delta + p_T$, is negative and, given the non-negativity constraint for prices, we cannot find a smaller $\widetilde{p}_C$. Hence, by choosing $p_T < -\Delta$ (within the ranges specified in Lemma 2′), *F* prevents renegotiation, induces *R* to exert e_N, and obtains the resulting higher payoff.

For $\Delta \ge 0$, any $\widetilde{p}_C \in [0, \Delta]$ satisfies the above condition and the non-negativity constraint. Conditional on having chosen e_B, *R* will thus make a renegotiation offer, proposing the highest possible $\widetilde{p}_C$, i.e., $\widetilde{p}_C = \Delta$, and receive $\overline{B} + \Delta$. Moreover, *R* prefers choosing e_B and renegotiating to choosing e_N, since $\overline{B} + \Delta > \underline{B} + \Delta$. **Q.E.D.**

Lemma 4′ implies that for $\Delta < 0$, where $\hat{\Pi}_O > \Pi^*_{NO}$ (Lemma 3), *F* will offer a contract from the set $\hat{A}_O$ with $p_T < -\Delta$. Similarly, for $\Delta \geq \overline{N} - \max\{\underline{N}, I\}$, where $\hat{\Pi}_O \leq \Pi^*_{NO}$ (Lemma 3), *F* will offer a (renegotiation-proof) contract from the set A^*_{NO}. It remains to be shown which contract generates the highest payoff for *F* in the range $0 \leq \Delta < \overline{N} - \max\{\underline{N}, I\}$. We focus on the choice between renegotiation-proof contracts in A^*_{NO} and option contracts (F, p_C, p_T, N, $N + B$) satisfying (1′), i.e., inducing e_N in a setting without renegotiation.

Denote with $\tilde{\Delta}$ the maximum of $\alpha\overline{N} + \varepsilon\underline{B}$, $\underline{N}$, and I, i.e., $\tilde{\Delta} = \max\{\alpha\overline{N} + \varepsilon\underline{B}, \underline{N}, I\}$. Using Lemma 4′, we can summarize *F*'s contractual choice as follows.

Proposition 2. *If* $\Delta < 0$, *F implements any option contract in* $\hat{A}_O$ *with* $p_T < -\Delta$ *and obtains payoff* $\hat{\Pi}_O = \overline{N} - I$. *If* $0 \leq \Delta < \overline{N} - \tilde{\Delta} - (\overline{B} - \underline{B})$, *F implements the option contract* ($i = F$, $p_C = \overline{B} - \underline{B} + \Delta$, $p_T = 0$, $o_C = N$, $o_T = N + B$) *and obtains payoff* $\tilde{\Pi}_O = \overline{N} - (\overline{B} - \underline{B}) - \Delta - I$. *If* $0 \leq \overline{N} - \tilde{\Delta} - (\overline{B} - \underline{B}) < \Delta$, *F implements any renegotiation-proof contract in* A^*_{NO} *and obtains payoff* $\Pi^*_{NO} = \max\{\underline{N} - I, 0\}$.

Proof. For $\Delta < 0$, any contract in $\hat{A}_O$ maximizes *F*'s payoff under the assumption of no renegotiation (Lemma 3). The subset of contracts with $p_T < -\Delta$ are renegotiation-proof (Lemma 4′). Since renegotiation reduces *F*'s payoff, *F* will choose a contract with $p_T < -\Delta$, resulting in payoff $\hat{\Pi}_O = \overline{N} - I$.

For $\Delta \geq \overline{N} - \max\{\underline{N}, I\}$, any contract in A^*_{NO} maximizes *F*'s payoff (Lemma 3), and *F* obtains payoff $\Pi^*_{NO} = \max\{\underline{N} - I, 0\}$.

For $0 \leq \Delta < \overline{N} - \max\{\underline{N}, I\}$, $\hat{\Pi}_O > \Pi^*_{NO}$ (Lemma 3) but no option contract in $\hat{A}_O$ is renegotiation-proof (Lemma 4′). We analyze whether *F* will implement a contract in A^*_{NO} or an option contract (F, p_C, p_T, N, $N + B$) that satisfies (1). We first compare Π^*_{NO} to the maximum payoff *F* can obtain from option contracts that <u>are not</u> renegotiation-proof. We then compare Π^*_{NO} to the maximum payoff from option contracts that <u>are</u> renegotiation-proof.

For both cases note that for any option contract (F, p_C, p_T, N, $N + B$) with prices p_C and p_T satisfying (1), *R* can find a price $\tilde{p}_C$ such that, conditional on *R* having chosen e_B, *F* accepts the renegotiation offer (F, $\tilde{p}_C$, p_T, N, $N + B$) and chooses continuation, namely any non-negative $\tilde{p}_C$ for which $\alpha\underline{N} + \varepsilon\overline{B} - p_T \leq \underline{N} - \tilde{p}_C$, i. e. $\tilde{p}_C \in [0, \Delta + p_T]$. Whether *R* chooses e_B and renegotiation

or, instead, e_N and the original contract, depends on the original prices (p_C, p_T). *R* prefers e_B (and the contract is thus *not* renegotiation-proof) iff $\underline{B} + p_C < \overline{B} + \widetilde{p}_C$ for some $\widetilde{p}_C \in [0, \Delta + p_T]$. Substituting $\widetilde{p}_C = \Delta + p_T$, we can rewrite the condition as $p_C < \overline{B} - \underline{B} + \Delta + p_T$.

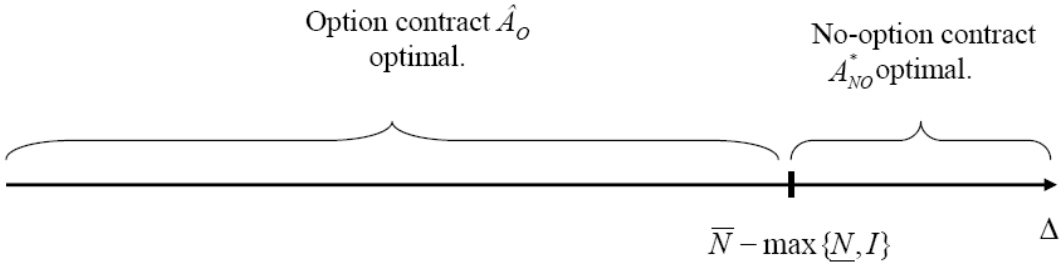
Consider now the first case (contracts that <u>are not</u> renegotiation-proof), i. e., option contracts (F, p_C, p_T, N, $N + B$) satisfying (1′) and $p_C < \overline{B} - \underline{B} + \Delta + p_T$. *F*'s payoff from implementing such a contract, after renegotiation, is $\underline{N} - \widetilde{p}_C - I$, which is weakly smaller than $\underline{N} - I$ and hence than Π^*_{NO}. Hence, *F* will not implement this type of option contract.

Consider now the second case (contracts that <u>are</u> renegotiation-proof), i. e., option contracts satisfying $p_C \geq \overline{B} - \underline{B} + \Delta + p_T$. *F* can find prices ($p_C$, p_T) satisfying both this inequality and (1′) iff $\Delta + \overline{B} - \underline{B} < \Gamma$, i. e. $\Delta < \overline{N} - (\alpha\overline{N} + \varepsilon\underline{B}) - (\overline{B} - \underline{B})$. Given any option contract satisfying these conditions, *R* will exert e_N and not renegotiate. The resulting payoff for *F*, $\overline{N} - p_C - I$ is maximized by setting $p_C = \overline{B} - \underline{B} + \Delta$ and $p_T = 0$. *F* prefers this option contract over a contract in A^*_{NO} if $\overline{N} - (\overline{B} - \underline{B}) - \Delta - I > \max\{\underline{N} - I, 0\}$, i. e. if $\Delta < \overline{N} - \max\{\underline{N}, I\} - (\overline{B} - \underline{B})$. We can thus summarize as follows: For $0 \leq \Delta < \overline{N} - \max\{\alpha\overline{N} + \varepsilon\underline{B}, \underline{N}, I\} - (\overline{B} - \underline{B})$, F chooses option contract (F, $\overline{B} - \underline{B} + \Delta$, 0, N, $N + B$) and obtains payoff $\widetilde{\Pi}_O = \overline{N} - (\overline{B} - \underline{B}) - \Delta - I$. **Q.E.D.**

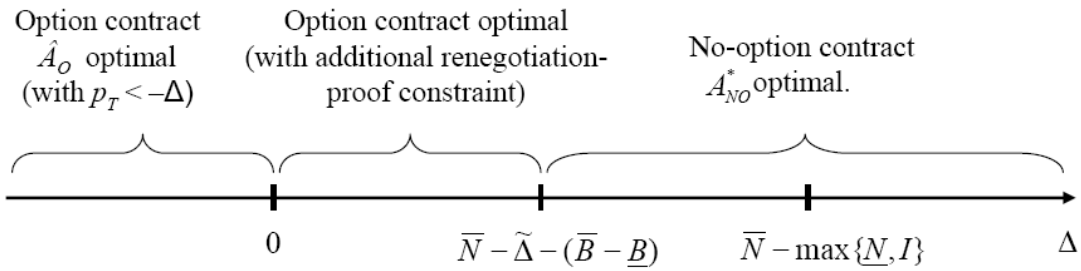
Proposition 2 shows that renegotiation may reduce the range over which an option contract with termination rights and reversion of intellectual property is optimal, namely if $\Delta < \overline{N} - \widetilde{\Delta} - (\overline{B} - \underline{B})$. We illustrate the difference between the case with commitment (no renegotiation) and the case without commitment (renegotiation possible) in Figure B1. As the graphs show, the basic finding remains unaltered: the option contract is optimal for small Δ and thus for high α and ε. The intuition is that large outside options of the financing firm correspond to a lower value of *R*'s cooperation in the development phase. As a result, it is less costly for *F* to induce *R* to exert e_N, and the option contract becomes profitable.

Figure B1. Ranges of Optimal Contracts

(a) Parties commit not to renegotiate



(b) Parties cannot commit not to renegotiate



Online-Appendix C: Contract Excerpts

We provide excerpts from the "Field of Use" section or the preamble of the contract (as specified by ReCap), which define the scope of the collaboration.

The first two excerpts are from agreements with a pre-specified lead product candidate:

- *ISIS has discovered ISIS 3521, an antisense oligonucleotide, and is developing a product containing ISIS 3521 for the treatment of cancer... ISIS will use commercially reasonable efforts to complete ongoing clinical trials and studies of the Product for non-small cell lung cancer and non-Hodgkin's lymphoma, as further described in the Development Plan set forth in Exhibit C hereto, and will participate in related activities, including the provision of consulting support to LILLY, in furtherance of the Development Program under the terms and conditions set forth in this Agreement.... "ISIS 3521" means the phosphorothioate oligodeoxyribonucleotide that targets human protein kinase C alpha disclosed and claimed (as SEQ IDNO 2) in U.S. Patent No. 5,703,054.* (Development and License Agreement, ISIS Pharmaceuticals and Eli Lilly & Co., August 14, 2001.)
- *The Parties desire to engage in a joint research effort to identify or discover, on the basis of Celgene's lead and library compounds, SERMs which are Er(alpha)Selective in U2OS cells, including, without limitation, compounds in the SP500263 Series (as defined below), as well as analogs thereof made by Celgene prior to the Effective Date as part of its internal research program in the Oncology Field (as defined below) to develop pharmaceutical products from such compounds for the treatment, prevention and diagnosis of osteoporosis and for other indications as described herein... "SP500263 Series" shall mean Celgene's proprietary compounds claimed in U.S. Patent Application Serial No. 09/475,776, filed December 1999 (or any continuation, continuation-in-part or division thereof), including, without limitation, SP500263, SPC0001422 and SPC0001426. The SP500263 Series shall specifically exclude Celgene's proprietary compound known as SPC0008490... "U2OS Cells" shall mean (a) Celgene's patent U2OS cell line, (b) Celgene's ER(alpha)-transfected U2OS cell line (clone #: B-11), or (c) Celgene's ER(beta)-transfected U2OS cell line (clone#: 10).* (Collaborative Research and License Agreement, Celgene Corp and Novartis Pharma AG, December 20, 2000.)

The following two excerpts are from agreements without a pre-specified lead product candidate:

- *Cubist and Novartis will establish a research program to identify and validate a limited number of antibacterial targets and to develop a select number of validated assays for high-throughput screening to identify new lead compounds active against such validated targets for the development of drugs... Cubist agrees to utilize its proprietary VITA(TM)*

technology in the Research Program as determined by the Joint Research Steering Committee... which couples the validation of the inhibition of a target in an animal model during an established infection with assay development and screening for the discovery of novel drug leads. (Collaborative and License Agreement, Cubist Pharmaceuticals and Novartis, February 3, 1999.)

- *The goals of the MBI Discovery Program are (a) to identify and characterize Level I Qualified Proteins employing various discovery methodologies, including without limitation secreted protein trapping, genomic cluster mapping and EST sequencing, (b) to identify the therapeutic utility of Program Proteins employing various methodologies, including without limitation transcription expression profiling, animal disease recovery modeling and use of transgenic and knock out models, and (c) to qualify selected Program Proteins for further development by the Parties as Therapeutic Products.* (Collaboration Agreement, Millennium BioTherapeutics and Eli Lilly & Co., May 28, 1997.)