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On Managing Research Collaborations: Which Form of Governance?

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Abstract

Managing research collaborations remains challenging in many respects. The research efforts of the parties involved are hardly verifiable, and it is not possible to contract a clearly defined research output in advance. The parties negotiate to allocate potential gains, but the collaboration still is unstable and prone to disintegration. Although contractual forms of collaboration have become increasingly common and sophisticated, formal contracts are incomplete and produce a large variety of governance structures with specified ownership patterns and the configurations of control. In the context of a research collaboration between two parties with asymmetric positions, such as a large pharmaceutical company contracting with a small biotech, the company must decide how to allocate ownership and control rights while considering the effects on the biotech's bargaining position in the negotiation. This study shows that the forms of governance vary with the contractibility of effort and the stability of the collaboration, which suggests novel prescriptions for the management of research collaborations.

Keywords: research collaborations, governance, contracts, property rights, control rights.

1 Introduction

Contractual collaborations are an important mode of R&D partnerships, especially in the biopharmaceutical industry (Hagedoorn, 2002), and formal contracts play a key role in shaping the governance of research. Collaborations between pharmaceutical companies and biotech firms vividly exemplify how contracts can give rise to varied ownership patterns and control configurations. In addition to being a favorite target for the empirical analyses of research contracts (Lerner and Merges, 1998; Lerner and Malmendier, 2010), these collaborations provide a ideal context for studying the choice of governance in contractually challenging environments.

In this paper, we therefore explore the research collaboration between a large pharmaceutical company and a small biotech and use the lens of both complete and incomplete contract theory to address micro-level details of its governance. We maintain a theoretical perspective, but we tackle an issue of interest to practitioners in the field. According to the Bio Partnering report from 2004:[1]

> "Large pharmaceutical companies and biotechs have achieved a level of deal-making sophistication. Still, less than half of respondents reported that their alliances were successful. While 15% of alliance failures were attributed to reasons considered beyond the control of senior management, better alliance governance practices could salvage 85% of the value now lost to failed partnerships – a potential sum of US$2.7 billion."

[1] This biotech industry survey comes from the IBM Institute for Business Value. We thank Natalia Lyarskaya for bringing this report to our attention.

Even if failure represents a natural outcome of research, research collaborations terminate even absent failures; that is, they are very unstable. In one of the very few studies on the termination outcomes of research alliances in the biopharmaceutical industry, Reuer and Zollo (2005) show that one-third of alliances fail, but roughly half of them are terminated as a result of unilateral withdrawn or contract expiration. In only 15% of the cases were the parties' objectives achieved.

These figures might imply that instability is a symptom of inaccurate governance practices or a natural consequence of the limitations to contracting, such as contract incompleteness or the inability to verify research effort. We challenge these two assumptions though by asking : How does the inherent incompleteness of contracts affect the governance of research collaborations? How do accurate governance choices influence the instability of the collaboration? And how do things change when we remove the limits to contracting that result from some nonverifiable aspect?

To answer to these questions, we set up a simple model in which the pharmaceutical company contracts with the biotech to start an early-stage research project. Neither the biotech's research effort nor the final research outputs can be specified in the contract, contracts are incomplete, and the parties must negotiate in the future. Nevertheless, the company can allocate ownership and control rights contractually. Ownership might refer to intellectual property rights over inventions; control refers to the use of assets and resources or decision-making rights. The initial governance choice sets the boundaries of the negotiation in the future, and the company must allocate ownership and control to motivate the biotech to invest. By solving the company's governance design problem in different scenario, we obtain critical managerial implications.

At the start of an early-stage research collaboration, the company must separate ownership and control rights. First, when choosing the ownership pattern, the company should consider the value of the property rights in the best alternative outside the collaboration. If a single property right is more valuable to the biotech than to the company, it should be allocated to the biotech, even if doing so makes termination a more likely event. Such instability should be considered a natural and desirable aspect of collaboration, because it can motivate the biotech to invest more in research.

Second, the choice of the ownership pattern should not be sensitive to the verifiability of the biotech's research effort, and hence the stage of research, but the configuration of control should be. The company must share control with the biotech in the early stages of research, when the research effort is hardly verifiable, and opt for tight control when the effort is easily verifiable, as in the late stages. Third, the company must exert tighter control when the parties' best alternatives outside the collaboration are larger.

We derive these prescriptions within a simple contract theory framework. Thus, in Section 2, we illustrate the main aspects of contracting that we embed in the formal model and discuss a real collaboration between a pharmaceutical company and a biotech. We also provide a simple numerical example to illustrate the main results. The formal model is introduced in Section 3 and solved in Section 4. In Section 5, we discuss different streams of literature and offer a foundation for the role of control that we postulate. In Section 6, we discuss the testable implications of our results and conclude. The Appendix contains all the proofs.

2 Contractual background: Practice and theory

Designing contracts for research is challenging in many respects. Outside a research realm, contracts specify many aspects: the quality and quantity of the good to be exchanged, the price, the specific investments to be made, the timing, possible penalties in specified contingencies, and so on. Research contracts instead are incomplete on purpose: The efforts of the parties are hardly verifiable; the uncertainty due to technological shocks of different kinds precludes the parties from specifying the final output; and the parties must rely on negotiation to allocate future benefits. Moreover, research collaborations are unstable because depending on the situation, the parties can either continue the collaboration and share the benefits or break up and pursue the best option outside the collaboration.

The instability of collaborations between pharmaceutical companies and biotechs might reflect inadequate contracting efforts and bad governance practices. But despite their inherent incompleteness, actual contracts are quite detailed in the allocation of different categories of rights. One key focus in initial contracting involves the allocation of intellectual property rights (IPRs), which might be allocated to one party with the other party obtaining licensing rights, or they may be subject to joint ownership, such as in the case of co-assigned patents. Contracts also can specify that the financing party obtains broad property rights in the case of termination. We illustrate some of these aspects subsequently with an example case.

Actual contracts also allocate control rights that do not refer to ownership. Control might entail the use of physical assets and other resources or the decisions to be made in the course of research. For example, many biotechs push fundamental research, which reflects the preferences of the academics that funded them. In this regard, examples of control rights are the right to suppress publication, pursue certain research targets, establish a timeline for conducting additional research, and so forth. Other common rights include the right to expand the breadth of the collaboration or to co-invest and share profits for a certain number of products resulting from the collaboration. Control also may refer to the stage after research, when the parties must decide the destiny of the collaboration. Beyond the right to terminate the collaboration, parties may enjoy the right to change or delete the work to be performed, the right of first offer should a party seek additional partnerships, and the right to make a (take-it-or-leave) offer during later stages. Finally, research contracts specify the upfront payments from the financing firm to the biotech, participation fees in the partnering program, and other figures. Unlike many aspects of contracts, financial figures typically are not disclosed. Nor are these rights crucial to our analysis, in that our focus is on the allocation of ownership and control rights.

2.1 The Pfizer-Coley research collaboration

We provide a concrete case of a research contract involving a pharmaceutical company, Pfizer, and a biotech, Coley. Their contract is freely available from the SEC EDGAR database.[2] As in many other contracts of this kind, portions of the text are missing, such as the financial

[2] http://www.secinfo.com/.

figures, but most of the information that we need for our purposes is available.

In March 2005, Pfizer and Coley signed an agreement to design, screen, and discover a novel class of drug candidates. Pfizer, the world's largest research-based pharmaceutical company, has one of the largest drug pipelines in the pharmaceutical industry. In 2005, Coley was a biopharmaceutical company specializing in vaccine adjuvant technology and a pioneer in the class of drug candidates called TLR (Toll-like receptors) Therapeutics. When the research agreement was signed, the two parties had another license agreement in place for the development and commercialization of certain compounds. In 2008 Pfizer decided to acquire Coley.

This case exemplifies the kind of collaboration that we are interested in modeling; it (1) it refers to early-stage research, with new compounds yet to be designed and screened; (2) is a sponsored research program, in which the biotech conducts research and the company provides financial support; (3) features an incomplete research contract that cannot forecast or anticipate many future contingencies and leaves significant room for negotiation; (4) offers a detailed, if incomplete, contract with regard to the allocation of ownership of inventions and the configuration of control in the research process.

The contract specifies a plan for a screening cascade at the beginning to select the different compounds and allocate them through three steps. But it also makes reference to "Coley's good faith estimates" that still "cannot guarantee that... [it] shall meet the desired characteristics." That is, the contract leaves much room to change the initial planned work as needed; adaptations are the responsibility of a committee:

> "During the course of the Program, the Screening Committee may reevaluate the Plan and propose to the Parties that they amend the Plan....The Parties may amend the Plan by written agreement setting forth the specific changes. . . the amendment shall increase or decrease the cost-based compensation payable by Pfizer to Coley."

Yet the contract also specifies in detail the allocation of ownership over different defined classes of *ODNs* (an acronym for other than specific research compounds), as follows: (1) *Coley Screening Invention* (any technology developed *solely* by Coley, by Coley *jointly* with Pfizer, or by Pfizer *only* but with the data provided by Coley), (2) *Program ODNs* (any ODN designed and synthesized by Coley pursuant to the Program), (3) *Final Selection ODNs* (any Program ODNs selected by Pfizer for further research), and (4) *Rejected Program ODNs* (any Program ODN not selected by Pfizer as a Final Selection ODN). Coley can file applications for a patent for the compounds not selected by Pfizer:

> "...Coley may file at Pfizer's expense one or more patent applications encompassing Program ODNs ...and may at Pfizer's expense prepare, file and prosecute the Program ODN Patent Rights. Coley will own all right, title and interest in and to such Program ODN Patent Rights."

Yet Pfizer has the right to select compounds for additional research and obtain an exclusive license:

> "[Coley] shall provide Pfizer with information on such ODNs, shall permit Pfizer to select [*missing in the text*] ODNs as Research Compounds and shall

> grant to Pfizer an exclusive worldwide license in the Field in the ODNs excepted for those which become Rejected Program ODNs,"

even as Coley collects property rights over any compound not selected by Pfizer:

> "Coley shall be free to develop and/or commercialize any Rejected Program ODN, itself or with any third party subject to the limitations set forth in this Agreement and in the License Agreement. Furthermore, upon expiration of the Option Term, Pfizer shall either return or destroy any material containing the Rejected Program ODNs."

As for the Coley Screening Invention:

> "Coley shall be responsible, at its sole expense, for the preparation, filing, and prosecution of any Patent Right claiming any Coley Screening Invention. Pfizer agrees to cooperate fully with Coley in the preparation, filing, and prosecution of any Patent Rights claiming any Coley Screening Inventions."

Regarding the configuration of control, the latitude of the biotech in conducting research, managing of screening, negotiating the required changes, and the right to terminate the collaboration are well specified. Although Pfizer has the right to select the Program ODNs, Coley can use them also for its own purposes, with certain restrictions:

> "During the Term, Coley (i) may use any Program ODN for its own research purposes outside the Program at its own expense and shall promptly provide Pfizer

> with the results of any such research but (ii) shall not provide to any third party, or convey to any third party any right, title or interest in, any Program ODN or any data relating to any Program ODCs."

The committee is in charge of any decisions that go beyond the contracted decision rights and is delegated much of the control over the collaboration: It can monitor progress, agree to adjust the allocation of ODNs, agree to change or delete other work to be performed, facilitate the transfer of technology between parties, identify and discuss potential new inventions, and so on. The contract also specifies that Pfizer and Coley nominate an equal number of representatives to serve on this committee, which must agree on the course of actions. Because Coley is in charge of conducting research and can freely use the different compounds, it de facto influences the decisions to its advantage, if it so chooses. Thus, a complex mixture of aspects allocates the gains from the collaboration between the parties as new information arrives..

Finally, the contract includes termination clauses. Pfizer has the right to terminate the agreement either "following discussion with Coley, that the Program is unlikely to produce a Research Compound with sufficiently attractive properties," or unilaterally, if Coley fails to perform the screening set forth by the program or to use reasonable effort.

The Pfizer-Coley design and screening agreement thus is an excellent example of a collaboration for sponsored early-stage research. The collaboration is structured to give Pfizer the right to select the compounds that may be more valuable to it. Yet Coley collects the intellectual property rights on any other compound and has much latitude with regard to conducting research. Many of the details of the collaboration also are left to negotiation after the initial contracting.

2.2 From practice to theory

Having illustrated the contractual environment of research in general and in the particular context of our focal case, we now discuss the formal model and introduce some terminology. To represent the dynamics of the collaboration, we assume that it consists of three stages: initial contracting, research, and negotiation. We analyze the dynamics in reverse order, starting from the last stage of negotiation, which we model with a basis in property rights (PR) economics. If the company and the biotech decide to continue the collaboration after initial research, the continuation surplus gets shared, reflecting their outside options and relative bargaining power.[3]

In a standard PR setting, the parties share the surplus equally, their outside options depend on the ownership pattern, and they never terminate the collaboration. We assume instead that the parties' bargaining power is variable and that a party more in control has more power.[4] Moreover, the outside options, which depend on ownership, serve not only as threat points that are never chosen but also could lead to a break up because the quasi-rents are negative.

We therefore integrate ownership, control, and negotiation outcomes, which determine

[3] We illustrate the PR approach more fully in Section 5, but a note on the terminology is needed here to avoid confusion. The bargaining position of a party depends on its bargaining power, the share of captured surplus, and its outside option, that is what a party obtains when the collaboration ends. The difference between the continuation surplus and the parties' outside options is the quasi-rent.

[4] This important aspect of our analysis will be discussed in detail when we introduce the model and review the literature (Section 5).

the parties' expectation of future benefits from research and hence the biotech's incentives in the research stage. Moving backward to the initial contracting stage, we can address the company's problem in terms of choosing how to allocate ownership and control rights. The choice of the form of governance reflects agency theory, such that the large pharmaceutical company initially acts as the principal and makes a take-it-or-leave contractual offer. Then we can determine the contract that best motivates the biotech to invest in research. A simple numerical example illustrates the model and our main findings.

2.3 A numerical example

Consider an example in which the ownership pattern is fully specified by the allocation of four distinct IPRs. Let ϕ be the fraction of IPRs collected by the company, $\phi \in \left\{0, \frac{1}{4}, \frac{2}{4}, \frac{3}{4}, 1\right\}$, such that the larger (smaller) ϕ is, the larger the company's (biotech's) outside option in the negotiation. The configuration of control is determined by the fraction of control rights λ and $1 - \lambda$ allocated to the company and biotech, respectively.

The biotech exerts research effort $a \geq 0$, and more effort corresponds to better research outputs, producing both higher continuation surplus and higher outside options. The surplus is uncertain and depends on the realization of a certain technological shock, which can take values (say in M\$) of $a \cdot 3$, $a \cdot 2$, or $a \cdot \underline{k} > 0$ with an equal probability. We also specify the aggregate outside option (also expressed in M\$) that we define as $aB(\phi)$. Assume $B(\phi) = 1$, 1.25, 1.20, 1.10, and 1 when $\phi = 0$, $\frac{1}{4}$, $\frac{2}{4}$, $\frac{3}{4}$, and 1, respectively. Note that B reaches its maximum at $\phi = \frac{1}{4}$, with $B(\frac{1}{4}) = 1.25$, and its minimum value is 1.

How should the company allocate ownership and control and specify the value of ϕ and λ

in the contract? As a benchmark, we use the case when the research effort can be specified in the contract and the parties never prefer to break up their collaboration, such as when the surplus in the worst case scenario, $a \cdot \underline{k}$, is not lower than the maximum aggregate outside option, $a \cdot 1,25$. The company keeps broad property rights, $\phi = 1$, and broad control rights, $\lambda = 1$.

With the assumption that the research effort is contractible, allow for the possibility of observing a break-up, such as by setting $\underline{k} = 1.1$. The company could avoid break-up by collecting ownership rights: When $\phi = 1$, $a \cdot 1.1 - a \cdot 1 > 0$, and the quasi-rents are always positive. But this choice, or any other that avoids a break-up, is not optimal. The company must renounce to make the collaboration stable and allocate some IPRs to the biotech.

But why should such a choice be convenient? It seems counterintuitive that the company should increase the outside option in anticipation of the collaboration terminating. The reason is that the biotech expects a larger payoff from the negotiation, and the company can contract for a larger effort. Such effort is maximized when $B(\phi)$ is maximized, or $\phi = 0,25$. Not only must the company renounce to make the collaboration stable, it also must allocate the ownership rights to maximize the probability of a break-up.

Our model thus initially predicts that the company must allocate only ownership rights but retain the control rights. To motivate the allocation of control rights, it suffices to relax the assumption of contractibility of the research effort. Ownership, and hence the probability of a break-up, does not change, but control becomes more crucial for motivating the biotech. Even as it allocates most of the property rights to the biotech, $\phi = 0,25$, the company must keep the majority of control rights, $\lambda \simeq 0,77$.

3 Model set-up

We investigate the collaboration between a pharmaceutical company (C) and a small biotech (R). Both parties are risk neutral, and R is cash constrained.[5] The collaboration unfolds along three stages (see also Figure 1): contracting at $t = 0$; research at $t = 1$, and negotiation at $t = 2$. To address the micro-level details of the governance of the collaboration, we combine two branches of contract theory literature: agency theory, as developed for example by Holmstrom (1979), and property rights (PR) theory, in the spirit of Grossman and Hart (1986). To specify the model, we use functional forms that simplify the derivation of the main results and lead to closed-form solutions.

$Figure 1$ about here

When the collaboration starts, C acts as the principal and provides a governance offering to R as a fraction of ownership rights $1 - \phi$ and control rights $1 - \lambda$.[6] The initial contract also establishes the up-front payment $p \geq 0$ from C to R and possibly the research effort $a \geq 0$.

Remark 1 Asymmetry between contracting parties is a standard assumption in agency theory, and in our setting, it has two justifications. First, it captures asymmetry in the relative dimension of the company and the biotech and the likely presence of many cash-constrained biotechs seeking financial resources to conduct research. Second, our focus is on

[5] The assumption of risk neutrality provides a mean to disentangle the role of governance in the provision of incentives from the risk-sharing considerations.

[6] For modelling purposes both rights are assumed to be a continuum, so that $\lambda, \phi \in [0, 1]$.

the use of control to determine the biotech's bargaining power in the ex post negotiation, whereas most prior literature postulates that the relative power of the parties determines the allocation of control and the contract design. To separate the theoretical effects of the two alternative directions of causality, we assume that the biotech initially has no power and cannot influence the contract.

At $t = 1$, R exerts a research effort a and a technological shock k occurs. At $t = 2$, the parties negotiate, having learned the value of the continuation surplus $x(\cdot)$ and with outside options $V(\cdot) > 0$ for C and $v(\cdot) > 0$ for R. If they negotiate the allocation of $x(\cdot)$, the parties obtain negotiation payoffs in excess of their outside options, corresponding to the generalized Nash-bargaining solution.[7] We next elucidate the role and determinants of x, V, and v.

Payoffs and main definitions. R can refuse C's initial offer, in which case the collaboration does not start, and both parties obtain a reservation payoff of zero.[8] Otherwise, R initiates research and incurs a disutility from effort $\frac{1}{2}a^2$ that reflects the opportunity cost of giving up other activities.[9] The surplus $x(\cdot)$ depends on the technological shock k, and we assume that $x(\cdot) = ak$, where k is distributed uniformly over the support $[\underline{k}, \bar{k}]$, $\underline{k} > 0$, and $E(k) = \hat{k}$.[10] The outside options of the parties are increasing in a as well as with the

[7] See Remark 2 for more details.

[8] This normalization drives the finding in Propositions 2 and 5 that the biotech receives no upfront payment.

[9] We do not model the company's investment decision at this stage, because we remain focused on sponsored research programs, such as in our exemplar case. In an alternative setting, to support the biotech's research effort, the company might invest additional resources e beyond p, incurring a cost $c(e)$. This extension would not affect our results. Another extension would let the company exert an effort $A \geq 0$, incur a quadratic cost $\frac{A^2}{2}$, and obtain an outside option $A\sqrt{\phi}$. The biotech would still obtain an outside option $a(1 - \phi)$, and the surplus would be $x = f(A, a)k$, where f is a function that increases in both arguments. This extension would introduce an additional source of strategic interaction, which is beyond the scope of this paper.

[10] We could also consider a more general setting in which k has a cdf $F(k)$. This extension complicates

fraction of ownership rights. The allocation of ownership is relevant only in the case of a break-up. We assume[11]

$$V(\cdot) = a\sqrt{\phi},$$

and

$$v(\cdot) = a(1 - \phi).$$

It is also useful to introduce definitions of an aggregate outside option[12]

$$aB(\phi) = a[\sqrt{\phi} + (1 - \phi)],$$

of quasi-rents

$$aq(k, \phi) = a[k - B(\phi)],$$

and of expected quasi-rents,

$$aQ(\phi) = aE[q(k, \phi)] = a[\hat{k} - B(\phi)].$$

We start investigating the management of a stable collaboration, with the standard assumption that a break-up is never optimal. As in the example, B reaches its maximum at $\phi = \phi^* = \frac{1}{4}$, with $B(\frac{1}{4}) = \frac{5}{4}$, and the collaboration is stable if $\underline{k} \geq \frac{5}{4}$. Therefore, the ownership pattern only matters for the effects on the outside options, and as in PR economics, it does

the analysis but does not add much in terms of economic intuition.

[11] This specification leads to closed-form solutions. We have tested the robustness of our findings in a more general framework.

[12] Our model resembles Roider's (2004) work on asset ownership and quantity contract. Roider addresses the case when the parties can specify who has residual rights of control over a single asset and a quantity q of traded good. The variable q, which would be a in our model, affects the threatpoints outside the collaboration but not the surplus. Roider's analysis is more akin to a standard PR setting, because the contract specifies ownership over a single asset, the parties always share equally the surplus over the threatpoints, and there is no role for control.

not affect the relative bargaining power of the parties. Instead, control matters for who captures which share of the surplus[13] , and we assume that the share coincides with the fraction of control rights.[14]

Remark 2 We provide two examples to clarify the role of control and some hidden assumptions behind the model specification.

Let control be a single right: the right to make a take-it-or-leave-it offer to the other party when negotiating. In this case, $\lambda \in \{0, 1\}$, where $\lambda = 1$ means that C makes the offer to R, and $\lambda = 0$ indicates R makes the offer to C. In the former case, C provides R with its outside option $v = a(1-\phi)$ while keeping the difference $a[k-(1-\phi)]$. In the latter case, R makes the offer to C, giving it $V = a\sqrt{\phi}$ and keeping the difference $a[k-\sqrt{\phi}]$.

More generally, we can interpret $\lambda \in [0, 1]$ as a probability or the proportion of cases when C is entitled to make the offer to R. Then C's expected negotiation payoff (for a given k and ϕ) is

$$\begin{aligned} & \lambda a[k-(1-\phi)] + (1-\lambda)a\sqrt{\phi} \\ = \; & a\sqrt{\phi} + \lambda a q(k, \phi). \end{aligned} \tag{1}$$

Equivalently, R's negotiation payoff is

$$a(1-\phi) + (1-\lambda)aq(k, \phi). \tag{2}$$

Both payoffs correspond to a generalized Nash-bargaining solution. Controlling more contingencies, in the sense of being entitled to make the first offer, is equivalent to having more bargaining power.

In addition, control allows for more rent-seeking, as discussed in Section 5. If control refers to decisions when conducting research or assets, more control by one party means that a larger portion of decisions aim to specialize research, which increases bargaining power. To the extent that it involves costly time and effort, rent-seeking can be wasteful, and a party could end up reducing the total surplus in its attempt to increase its share. In our analysis, we put these inefficiencies aside and assume that the configuration of control influences the allocation of the surplus, not its level, which is the alternative interpretation of the payoff equations.

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[13] In principle, ownership and control can affect both outside options and the relative bargaining power of the parties. In line with many PR models, we assume the share of the quasi-rents captured by the parties is independent of the ownership pattern. To maintain symmetry, we assume that the configuration of control does not affect the outside options, which allows us to streamline our main arguments and the derivation of the results.

[14] The assumption that control determines bargaining power directly is not crucial; in a more general setting, the company's bargaining power is $\alpha = g(\lambda)$, and g is a function increasing in λ.

Having clarified the role of ownership and control, we turn to the case of an unstable collaboration, when the quasi-rents are negative for some realization of the technological shock k, such as when $\underline{k} < \frac{5}{4}$. Because k distributes uniformly, the probability of a break-up for a given ϕ is

$$\Pr[q(k,\phi) \leq 0] = \Pr[k \leq B(\phi)] = \frac{B(\phi) - \underline{k}}{\bar{k} - \underline{k}}.$$

Although $\underline{k} < \frac{5}{4}$ is a necessary condition to observe a break-up, it might not be sufficient, because C could choose ϕ to avoid it. But this choice is never optimal choice, which implies that $\underline{k} < \frac{5}{4}$ is a necessary and sufficient condition for a collaboration to be unstable, as proved formally in Proposition 3.

Contractibility assumptions. The parties can contract on p, ϕ, and λ, and we distinguish between the case when a is verifiable by a third party, and hence contractible, or not. In the first case, it is possible to specify R's research effort in the initial contract, and there is no incentive issue. In the second case, C must provide R with the incentives to exert a nonverifiable effort, which adds a constraint to the problem of designing governance.

Forms of governance. We distinguish four forms of governance. The first is the reference point when C collects both ownership and control rights, $\phi = \lambda = 1$. In *ownership-based governance*, C shares ownership with R and transfers to it a portion $1 - \phi$, while collecting control rights $\lambda = 1$. In *control-based governance*, control is shared with R, which keeps a portion $1 - \lambda$, but C collects the ownership rights, $\phi = 1$. Finally, with *mixed governance,* C allocates to R a portion of ownership and control rights.

We assume that whenever two forms of governance allow for the same expected payoff,

C chooses the one that economizes on the allocation of rights. Thus, C prefers to collect ownership and control rights as opposed to allocating them to R if it does not change its expected payoff. In the same conditions, it prefers ownership or control-based governance to mixed, which reflects that the costs of contracting increase with greater complexity of the governance to be specified in the initial contract.

4 Choosing the form of governance

4.1 Managing a stable collaboration

We start by considering how to manage a stable collaboration, when $\underline{k} \geq B(\phi^*) = \frac{5}{4}$, and how the governance choice depends on the verifiability of the biotech's research effort.

4.1.1 A verifiable research effort

As a preliminary result, we prove the following:

Proposition 1 *To manage a* stable *collaboration when the research effort is* verifiable*, C must collect both ownership and control rights, $\phi = \lambda = 1$. R exerts an effort $a = \hat{k}$, receives an upfront payment $p = \frac{\hat{k}^2}{2}$, and is left at its zero reservation utility, while C obtains an expected payoff of $\frac{\hat{k}^2}{2}$.*

In the ideal case when the research effort is contractible and the parties do not expect to break up in the future, there is no point in allocating ownership or control rights to the biotech. The company only provides an adequate upfront payment as to convince the biotech to participate to the collaboration.

4.1.2 A nonverifiable research effort

In this case, C can only induce R to exert a certain effort, and we can prove:

Proposition 2 *To manage a* stable *collaboration when the research effort is* nonverifiable*, C must choose:*

1) ownership-based *governance, where* $\phi = \tilde{\phi} = 1 - \frac{\hat{k}}{2}$*, if* $\hat{k} \leq 2$*;*

2) control-based *governance, where* $\lambda = \tilde{\lambda} = \frac{1}{2} - \frac{1}{2}\frac{1}{\hat{k}-1}$*, if* $\hat{k} > 2$*.*

In both cases, R exerts an effort $a = \frac{\hat{k}}{2}$*, receives the lowest payment* $p = 0$*, and obtains an expected payoff* $\frac{1}{8}\hat{k}^2$*, while C obtains an expected payoff* $\frac{\hat{k}^2}{4}$*.*

Unlike Proposition 1, C must reward R by setting its negotiation payoff to provide optimal incentives to invest. Whether this motivation should feature ownership or control depends on expectations about the surplus. If the surplus is expected to be large, or $\hat{k} > 2$, the company must collect ownership rights but only a share $\tilde{\lambda}$ of control rights. Control tends to be more equally distributed when the collaboration is expected to be more profitable. If the expected surplus is low though, $\hat{k} \leq 2$, the company must alter the governance to collect control rights, but only and a fraction $\tilde{\phi}$ of ownership rights. Ownership tends to be more concentrated when the collaboration is expected to be less profitable.[15] The payment is always set to the minimum level,[16] $p = 0$, and there is an underprovision of effort, because $a = \frac{1}{2}\hat{k}$ instead of $\hat{k}$. Moreover, there is a redistribution of payoffs, because the biotech obtains a positive rent $\frac{\hat{k}^2}{8}$, rather than zero, and C obtains $\frac{\hat{k}^2}{4}$, rather than $\frac{1}{2}\hat{k}^2$. Therefore, the non-contractibility of effort produces a deadweight loss of $\frac{\hat{k}^2}{8}$.

These results integrate familiar results from agency theory with insights into the allocation of ownership and control from a PR economics perspective. We also consider how these

[15] As proved formally in the Appendix, by switching from one governance form to the other, the company can avoid corner solutions in the governance design problem.

[16] We have normalized the biotech's reservation payoff to zero when the collaboration starts. Should we allow for a positive value $\bar{U} > 0$, the optimal payment would be $p = \bar{U}$. The same comment holds for Proposition 5.

results change when we introduce break-up potential.

4.2 Managing an unstable collaboration

A break-up can happen when the quasi-rents are negative for some realization of the technological shock k.

Lemma 1 *When contracting at $t = 0$, the expectation about the quasi-rents, provided that they are positive, is $\Gamma(B(\phi)) = \frac{(\bar{k}-B(\phi))^2}{2(\bar{k}-\underline{k})}$, and the expectation about the aggregate payoff from the negotiation is $\Phi(B(\phi)) = B(\phi) + \Gamma(B(\phi))$.*

In principle, there are two cases to consider: $1 < \underline{k} < \frac{5}{4} < \bar{k}$, when C could stabilize the collaboration, and $\underline{k} \leq 1 < \frac{5}{4} < \bar{k}$, when it cannot.[17] But we can prove:

Proposition 3 *Even if it is feasible to make a collaboration stable, it is never in the company's interest to do so. Therefore, $\underline{k} < \frac{5}{4}$ is a necessary and sufficient condition for a collaboration to be unstable.*

The company should never aim at stabilizing the collaboration, irrespective of whether the research effort is contractible. Adding such a constraint on the allocation of ownership induces lower effort and thereby reduces the expected payoff. It remains then to determine how to design the ownership pattern properly to account for the probability of a break-up.

4.2.1 A verifiable research effort

We can prove:

Proposition 4 *To manage an* unstable *collaboration when the research effort is* verifiable, *C must choose an ownership-based governance where $\phi = \phi^* = \frac{1}{4}$. R exerts an effort $a = \Phi(\frac{5}{4})$ and remains at its zero reservation utility, while C obtains an expected payoff $\frac{1}{2}\left(\Phi(\frac{5}{4})\right)^2$.*

[17] In a third case, the probability of break up is one, and $\bar{k} < 1$. However, this case is not interesting, because there is no role for the allocation of control.

Note the difference between Proposition 4 and Proposition 1. Allowing for break-up changes the ownership pattern but not the configuration of control. In contrast, common intuition holds that the form of governance is irrelevant when all the variables are contractible. Moreover, the ownership pattern does not change when we allow for non-contractible effort.

4.2.2 A nonverifiable research effort

This last case is the only case for which mixed governance performs strictly better than any other form:

Proposition 5 *To manage an* unstable *collaboration when the research effort is* nonverifiable*, C must choose mixed governance, where $\phi = \phi^* = \frac{1}{4}$ and $\lambda = \lambda^* = \frac{1}{2} + \frac{1}{8}\frac{1}{\Gamma(\frac{5}{4})}$. R exerts an effort $a = \frac{1}{2}\Phi(\frac{5}{4})$, receives the lowest payment $p = 0$, and obtains an expected payoff $\frac{1}{8}[\Phi(\frac{1}{4})]^2$, while C obtains an expected payoff $\frac{1}{4}[\Phi(\frac{1}{4})]^2$.*

Both ownership and control must be carefully allocated to the biotech, but the ownership pattern coincides with the benchmark when a is contractible. Thus, the probability of a break-up does not change because of the more challenging contracting environment. Similar to Proposition 2, ownership and control combine to induce a lower research effort, there is a redistribution of payoffs from the company to the biotech, and there is a deadweight loss of $\frac{1}{8}[\Phi(\frac{1}{4})]^2$.

4.3 Main results and the example reconsidered

We incorporate the main aspects of contracting illustrated in the case and example in Section 2 into a formal model, which provides three contributions. First, by comparing the cases when the research effort is verifiable and when it is not, we show how limits to contracting affect the company's governance choice with the assumption that the collaboration is stable.

In the first case, the company can just command optimal effort, and there is no need to allocate ownership and control (Proposition 1); in the second case, it can only induce the biotech to exert a certain effort. Either ownership or control must be allocated to provide the right incentives (Proposition 2).

Second, we show that the problem of managing a collaboration, and the relative governance design problem, is very different when we allow for the possibility of a break-up. We highlight a new role for ownership that has not been analyzed previously. It is never in the company's interest to constrain ownership as to make the collaboration stable (Proposition 3). On the contrary, ownership must be allocated to maximize the aggregate outside option and the probability of break-up, whether the research effort is verifiable or not. Although in the first case it suffices to allocate only ownership rights (Proposition 4), the second case demands that control be properly allocated (Proposition 5). Therefore, mixed governance is needed only in challenging environments with nonverifiable research effort and instability.

We can also justify the values of ϕ and λ in the example for managing an unstable collaboration. Consider $[\underline{k}, \bar{k}] = [1.1, 3]$. Ownership must be allocated to maximize the probability of break-up, $\phi = \phi^* = \frac{1}{4}$, but at the same time, the company must collect the majority of control rights. By Lemma 1,

$$\Gamma(\frac{5}{4}) = \frac{(3 - 1.25)^2}{2(3 - 1.1)} \simeq 0,46,$$

and by Proposition 5

$$\lambda^* = \frac{1}{2} + \frac{1}{8}\frac{1}{\Gamma(\frac{5}{4})} \simeq 0,77.$$

Having derived the main results, we now relate our framework to prior literature.

5 A broader view of ownership, control, and governance design

Two main pillars in economics literature refer to the role of governance in a transaction: transaction cost economics (Williamson, 1975), which considers how governance structures vary with the nature of the transaction and related costs, and the property rights (Grossman and Hart, 1986, Hart and Moore, 1990). We developed our framework by starting with Grossman and Hart's main insight: When only incomplete contracts can govern a transaction, ownership protects the parties by granting them a larger negotiation payoff ex post, thereby providing incentives to invest ex ante. Ownership therefore should go to the party whose investment has the greater marginal effect over the final outcome.

Building on the PR view, Aghion and Tirole (1994) explore the relationship between a company and a research unit when the contract specifies the allocation of property rights for any forthcoming innovation. An inefficient allocation of ownership may arise when the unit is financially constrained and initially has no bargaining power. The company could transfer ownership to the unit if doing so were efficient, but this transfer requires compensation that the cash-constrained unit cannot afford.

The PR models provide important insights but ignore the role of instability and typically do not distinguish between ownership and control. Only residual control rights can be transferred by changing the underlying ownership pattern, and control refers to ex post decisions. But in practice, the residual control rights can be restricted or enlarged by means of certain specified control rights, such as those formally specified in the contract, separately from the ownership. As our exemplary case revealed, control rights also may refer to the interim stage that precedes negotiation. But what role do control rights play exactly, and how do they differ from ownership rights? This crucial aspect of our analysis demands further clarification.

5.1 On the relationship between power and control

We argue that greater control enables a party to use resources and make decisions, which makes that party more fundamental to the relationship, such that it captures a larger share of the surplus. Ownership can protect a party by granting it a greater outside option through ex post decision rights, but control can serve a similar purpose by granting more bargaining power to be acquired via interim decision rights. Both ownership and control must be properly allocated when only incomplete contracts can be used to govern a transaction. In advancing this argument, we build on different streams of literature.

In sociological literature, power dependence theory (Emerson, 1962) indicates that the outcomes of an exchange relationship are a function of the dependence of one of the parties on the other, perhaps to obtain needed resources. According to resource dependence theory (Pfeffer and Salancik, 1978), bargaining power in inter-organizational settings derives from the possession or control of critical resources. In our setting, the allocation of control over resources is an instrument that can be used to set the relative bargaining power of the parties. But we reverse the common reasoning, according to which the initial bargaining positions of the parties in a relationship determine the allocation of control, and the features of the contract. This scenario is certainly reasonable if two firms with symmetric positions collaborate – exactly the opposite of the real situation we want to study. Thus, we argue that the relative levels of control over resources and decisions determines relative bargaining power in the negotiation, thereby affecting the parties' incentives to invest.

Bridging sociological and economics literature, Milgrom and Roberts (1988) analyze influence activities, such that an agent can push for the adoption of programs that serve its purpose and reject those that are harmful. Influence activities aim to redistribute the benefits of decisions among the parties, and though they can offer benefits, Milgrom and Roberts also stress their costs. In our analysis of the allocation of control, we focus on the redistributive role of decisions over activities and efficiency aspects so that we can focus on the incentive aspects. The allocation of control over decisions determines how the parties can advance their objectives and capture a greater benefit.

Moving to economics literature, the link between control and power has been studied by Rotemberg (1994) and Rajan and Zingales (1998). Rotemberg investigates how an employer can create a form of deferred compensation for employees by letting make (or making itself) the most preferred decisions. By controlling decisions, employees gain a position from which they might obtain a higher salary. Although not addressing what employees do ex ante, Rotemberg relates control over decisions to power ex post, in the same spirit of the analysis developed herein. Rajan and Zingales use the typical contracting environment of PR economics, but they de-emphasize the importance of ownership as a source of power. Within organizations, access to critical resources confers the opportunity to specialize and therefore obtain a share of future organizational surplus. Access, defined as the ability to use or work with a critical resource, determines power. Building on these insights, we note how to set the extent of control over resources to induce a certain power distribution.

Managerial literature also reveals a renewed interest in the determinants of bargaining power (Coff, 1999). Bowman and Swart (2007) provide an actual example of how control translates into bargaining power and thus into a share of the surplus. They illustrate the relationship between the owner of separable physical capital and the owner of non-physical embodied capital, in reference to the control over the deployment of embedded capital forms. The usual divergence of interests between parties takes a particular form, in that embedded capital may change subject to efforts to push it toward either separable capital or embodied human capital. Thus, more control over the embedded capital leads to a greater bargaining power and a larger share of the rent stream. Our formal model revolves around the same idea.

The link between control and bargaining power has been explored more recently by Panico (2009, 2010), who first compares the case of hidden action and hidden information, but without addressing the allocation of ownership in addition to control. He also uses a complete contract approach to determine how a principal should establish an allocation of control that is contingent on the agent's reported information. Thus, both the framework and the motivation for allocating control rights are very different from the current setting.

6 Discussion and conclusions

Many empirical studies have addressed the allocation of control and decision rights in different contexts, like automobile franchise contracts (Arruñada et al., 2001), venture capital contracts (Kaplan and Stromberg, 2003), research contracts in the biopharmaceutical industry (Lerner and Merges, 1998; Lerner and Malmendier, 2010), Internet portal alliances (Elfenbein and Lerner, 2003), and in strategic alliances in general (Baker et al., 2008).

Elfenbein and Lerner (2003, p. 358) stress that though theoretical literature does not distinguish clearly between ownership and control, they are treated differently in practice:

> "Specified control rights place boundaries on the set of decisions that contracting parties can make and thus serve a role similar to ownership in the property-rights approach in creating incentives. Empirical analyses of contracting should, therefore, analyze the allocation of specified control rights in addition to ownership."

Hagedoorn (2002) and Narula and Hagedoorn (1999) highlight the biopharmaceutical industry exhibits a tendency toward contractual forms of collaborations. Investigating these contracts in detail, Lerner and Merges (1998, p. 134) consider the allocation of control in collaborations between biotechs and pharmaceutical companies:

> "Actual alliances assign a wide variety of control rights, and control rights over various aspects of the alliance are assigned in different ways....Practitioners suggest that no single control right stands out as critical. Rather it is the accumulation of

> rights to control contingencies that makes an alliance particularly favorable to the R&D or the financing firm."

Not unlike other contexts, contract design starts by separating individual aspects of control that then can be allocated individually. In R&D collaborations, this aspect of contracting is critical because firms may have diverging interests. Lerner and Malmendier (2010) show that research firms realize "project substitution"or "project cross-subsidization" when the use the project and argue that the companies respond to this problem by using the unconditional right to terminate the research agreement.

Ownership rights also plays a key role. Hagedoorn and Hesen (2007) note that in research collaborations, the allocation of property rights over the research outcomes is crucial. Often ownership and the use of the results are defined through the grant of an intellectual property right to one party and a license to the other, as in the case we discuss. Arora and Merges (2004)also show how patents are used to structure collaborations between independent firms. Beyond ownership of assets required for production and commercialization, patents can limit the ability of one partner to act opportunistically after the other has specialized its technology.

Another important aspect that we address is the role of instability. Reuer and Zollo (2005) provide one of the very few analyses of collaboration termination, in which they discriminate termination due to failure, the achievement of the parties' objectives (only 15% of the cases), unilateral withdrawal, and contract expiration, while also accounting for the allocation of responsibilities between parties. But they do not address the details of the governance choice and the related incentive effects, which represents a key contribution in our analysis.

By introducing elements of instability in the collaboration, we identify a role for governance that has gone unnoticed in prior literature. We depart from the standard PR prescription that ownership depends on the marginal effect of the parties' effort. Ownership must reflect the parties' stakes outside the collaboration and should be chosen as to make a break-up more likely. Thus, instability is not necessarily a symptom of inaccurate governance practices. Control determines the share of the surplus captured in the negotiation.

By providing a finer-grained analysis of research collaborations, we produce the following testable implications:

1. The efficient allocation of ownership is sensitive to the parties' evaluation of the property rights outside the collaboration, and is not halted by the biotech's lack of cash.

2. Ownership is not sensitive to the contractibility of research and does not vary much across the different stages of research.

3. Control tends to be more concentrated in the company's hands, moving from the very early stage of research toward later stages.

4. Control tends to be more concentrated in the company's hands in the early stages of research when the parties' outside options are greater.

Existing empirical work do not provide a good direct test for our theory. Lerner and Merges (1998) investigate how the financial strength of a biotech affects the allocation of the most frequently specified rights, but their analysis is not meant to address the distinction between ownership rights and control rights. This gap could explain their lack of support for the theoretical relationship between control rights and the stage of research, according to which more ownership rights should go to the biotech in the early stages of research. Elfenbein and Lerner (2003) address the allocation of ownership and control rights in Internet portal alliances separately and find that they respond to different criteria, yet their focus remains on the relative bargaining power of the parties when the collaboration starts. Lerner and Malmendier (2010) focus on the allocation of a single right, the right to terminate the collaboration, and do not address the governance choices in detail.

To test our theoretical prescriptions, research might develop an ad hoc empirical strategy. A sample of research contracts between large pharmaceutical companies and biotechs could provide detailed information about how ownership rights and control rights are allocated in the contracts. This work currently is in progress.

From a more general perspective also shed new light on the well-known problems of governing a transaction through incomplete contracts. Our framework could be extended to other relationships that involve information – and knowledge – intensive activities, such as that between a parent firm and newly formed spinoffs. Arora and Merges (2004) stress the role of ownership in supporting these relationships and provide a few examples of parent firms that endow spinoffs with a portfolio of patents. Our model could provide an interesting means to investigate the combined use of ownership and control by the parent when dealing with a spinoff.

A few extensions also could add to our understanding of governance. First, we could introduce risk aversion to discern how optimal risk sharing, in addition to the provision of the incentives, influences governance design. Second, additional research should consider the role of hidden information in driving the allocation of ownership and control, such as when one party is privately informed about a key parameter. Third, it would be interesting to allow for a strategic interaction between the contracting parties when they both invest in the collaboration and jointly determine the surplus. Fourth, introduce more structure to the dynamics of the collaboration to study how ownership and control are reallocated between parties as the collaboration moves across different research stage. Efficiency-based explanations for the choice of the governance would enhance the incentive-based ones addressed in our analysis. We also leave the derivation of the optimal governance choice in more general environments and the empirical validation of our findings to further research.

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Appendix

Proof of Proposition 1.

Consider the case of ownership-based governance, when ϕ is set optimally and $\lambda = 1$. When negotiating, C offers to R its outside option $a(1-\phi)$ and keeps the difference $ak - a(1-\phi)$. Therefore, C maximizes its expected payoff

$$a\hat{k} - a(1-\phi) - p, \tag{3}$$

subject to the two constraints

$$p + a(1-\phi) - \frac{1}{2}a^2 \geq 0, \tag{4}$$

and

$$p \geq 0,$$

where (4) is the participation constraint, that ensures it is convenient for R to accept C's initial offer. C can leave R at its reservation utility, choosing

$$p = \frac{1}{2}a^2 - a(1-\phi). \tag{5}$$

Assume p is positive in equilibrium. Substituting (5) into (3), C maximizes

$$a\hat{k} - \frac{1}{2}a^2. \tag{6}$$

C then sets $a = \hat{k}$ and obtains an expected payoff $\frac{\hat{k}^2}{2}$, which does not depend on ϕ, and the payment is

$$p = \hat{k}(\frac{1}{2}\hat{k} - (1-\phi)). \tag{7}$$

C can freely choose ϕ to ensure that the payment is non-negative, such as when $\phi = 1$.

Consider the case of control-based governance, when C sets optimally λ and $\phi = 1$. Because $B(1) = 1$, by (1) and (2), C maximizes

$$a + \lambda a(\hat{k} - 1) - p, \tag{8}$$

subject to the two constraints,

$$p + (1 - \lambda)a(\hat{k} - 1) - \frac{1}{2}a^2 \geq 0, \tag{9}$$

and

$$p \geq 0.$$

C can leave R at its reservation utility, setting

$$p = \frac{1}{2}a^2 - (1 - \lambda)a(\hat{k} - 1). \tag{10}$$

Assume p is non-negative. Substituting (10) into (8), C obtains the same payoff as in (6), which does not depend on λ. Therefore, $a = \hat{k}$, and by (10),

$$p = \hat{k}[\frac{1}{2}\hat{k} - (1 - \lambda)(\hat{k} - 1)].$$

C must make sure the payment is non-negative, such as when $\lambda = 1$.

Finally, along the same line of reasoning, C cannot do any better when choosing a mixed governance, meaning that C optimally sets $\phi = \lambda = 1$ and $p = \frac{\hat{k}^2}{2}$.

Proof of Proposition 2.

Consider the case of ownership-based governance, where $\lambda = 1$. The proof is in the same vein of Proposition 1 but with an additional constraint: Instead of C commanding an effort level, a

is chosen optimally by R to maximize the payoff in (4). C then faces the incentive compatibility constraint,

$$a = 1 - \phi, \tag{11}$$

according to which the participation constraint (4) becomes

$$p + \frac{1}{2}\left(1 - \phi\right)^2 \geq 0, \tag{12}$$

which is always satisfied. Hence, C optimally sets $p = 0$; substituting (11) into (3), it obtains an expected payoff

$$\left[\hat{k} - 1 + \phi\right](1 - \phi) \tag{13}$$

that is maximized at

$$\phi = \tilde{\phi} = 1 - \frac{\hat{k}}{2}. \tag{14}$$

Thus, (14) identifies an interior solution provided that $\hat{k} \leq 2$, in which case, by (11), R exerts an effort $a = \frac{\hat{k}}{2}$, and by (12) and (13), R and C obtain expected payoffs $\frac{\hat{k}^2}{8}$ and $\frac{\hat{k}^2}{4}$, respectively. If instead $\hat{k} > 2$, we have a corner solution where $\phi = 0$, C obtains $\hat{k} - 1$, and R gets $\frac{1}{2}$.

For control-based governance, $\phi = 1$. By (9), the incentive compatibility constraint is

$$a = (1 - \lambda)(\hat{k} - 1), \tag{15}$$

and the participation constraint reduces to

$$p + \frac{1}{2}[(1 - \lambda)(\hat{k} - 1)]^2 \geq 0, \tag{16}$$

which is always non-negative. Hence, $p = 0$, and substituting by (15) into (8), C obtains an expected payoff

$$\left[1 + \lambda(\hat{k} - 1)\right]\left[(1 - \lambda)(\hat{k} - 1)\right] \tag{17}$$

that is maximized when

$$\lambda = \tilde{\lambda} = \frac{1}{2} - \frac{1}{2}\frac{1}{\hat{k}-1}. \tag{18}$$

Therefore, (18) identifies an interior solution if $\hat{k} > 2$. Substituting (18) into (15), the equilibrium effort is $a = \frac{\hat{k}}{2}$, and by (16) and (17), R obtains a payoff $\frac{1}{8}\hat{k}^2$, while C obtains $\frac{\hat{k}^2}{4}$. If instead $\hat{k} \leq 2$, we have a corner solution where $\tilde{\lambda} = 0$, C obtains $\hat{k} - 1$, and R gets $\frac{1}{2}$.

By comparing C's payoffs with ownership- and control-based governance, we immediately see that the former is preferred to the latter iff $\hat{k} \leq 2$, and C's payoff is always equal to $\frac{\hat{k}^2}{4}$.

Proof of Lemma 1.

Because k distributes uniformly, the probability of a break-up, corresponding to a certain ϕ, is

$$\Pr[q(k, B(\phi)) \leq 0] = \Pr[k \leq B(\phi)] = \frac{B(\phi) - \underline{k}}{\bar{k} - \underline{k}}, \tag{19}$$

while with probability $1 - \frac{B(\phi)-\underline{k}}{\bar{k}-\underline{k}} = \frac{\bar{k}-B(\phi)}{\bar{k}-\underline{k}}$, the parties negotiate and share the surplus. The expected values of the quasi-rents, provided they are positive, are

$$\begin{aligned} E[q(k,\phi) \mid q(k,\phi) \geq 0] &= E\left[k - B(\phi) \mid k > B(\phi)\right] \\ &= E\left[k \mid k > B(\phi)\right] - B(\phi) = \frac{B(\phi) + \bar{k}}{2} - B(\phi) = \frac{\bar{k} - B(\phi)}{2}. \end{aligned}$$

The period $t = 0$ expectations of the quasi rents, provided that they are positive, are

$$\begin{aligned} E\left[E[q(k,\phi) \mid q(k,\phi) \geq 0]\right] &= \Pr[q(k, B(\phi)) \geq 0] E[q(k,\phi) \mid q(k,\phi) \geq 0] \\ &= \left(\frac{\bar{k} - B(\phi)}{\bar{k} - \underline{k}}\right)\left(\frac{\bar{k} - B(\phi)}{2}\right) = \frac{\left(\bar{k} - B(\phi)\right)^2}{2(\bar{k} - \underline{k})} = \Gamma(B(\phi)). \end{aligned}$$

We can compute the payoffs from negotiation that the parties expect to obtain when contracting at $t = 0$. At $t = 2$, the parties obtain their outside options with a probability $\frac{B(\phi)-\underline{k}}{\bar{k}-\underline{k}}$, whereas with probability $\frac{\bar{k}-B(\phi)}{\bar{k}-\underline{k}}$, they obtain the continuation payoffs as in (1) and (2). Therefore, C's expectation is

$$a\sqrt{\phi}\left(\frac{B(\phi)-\underline{k}}{\bar{k}-\underline{k}}\right)+a\left(\sqrt{\phi}+\lambda\left(\frac{\bar{k}-B(\phi)}{2}\right)\right)\left(\frac{\bar{k}-B(\phi)}{\bar{k}-\underline{k}}\right)$$
$$=a\sqrt{\phi}+\lambda a\Gamma(B(\phi)).$$

Equivalently, R's expectation is

$$(1-\phi)+(1-\lambda)a\Gamma(B(\phi)). \tag{20}$$

Finally, summing up (**??**) and (20), the expected aggregate payoff from the negotiation for an unstable collaboration is

$$a\Phi(B(\phi))=a\left(B(\phi)+\Gamma(B(\phi))\right). \tag{21}$$

Proof of Proposition 3 and 4.

Consider the case of control-based governance. Setting $\phi=1$ in (**??**) and (20), C maximizes

$$a[1+\lambda\Gamma(1)]-p, \tag{22}$$

subject to the two constraints

$$p+a(1-\lambda)\Gamma(1)-\frac{1}{2}a^2\geq 0 \tag{23}$$

and

$$p\geq 0.$$

C can leave R at its reservation utility, choosing

$$p = \frac{1}{2}a^2 - a(1-\lambda)\Gamma(1)]. \tag{24}$$

Substituting (24) into (22) and using (21), C obtains

$$\begin{aligned} & a(1+\Gamma(1)) - \frac{1}{2}a^2 \\ = \; & a\Phi(1) - \frac{1}{2}a^2, \end{aligned} \tag{25}$$

which does not depend on λ. This solution is also true when allowing for a generic ϕ, with (24) and (25) reducing to

$$p = \frac{1}{2}a^2 - a(1-\lambda)\Gamma(B(\phi))] \tag{26}$$

and

$$a\Phi(B(\phi)) - \frac{1}{2}a^2, \tag{27}$$

respectively. Hence C's payoff never depends on the choice of control.

For the case of ownership based-governance, $\lambda = 1$, and ϕ is chosen optimally. C maximizes then (27) by choosing

$$a = \Phi(B(\phi)) \tag{28}$$

and obtains an expected payoff

$$\frac{1}{2}[\Phi(B(\phi))]^2. \tag{29}$$

We now prove that in equilibrium, $\phi = \phi^* = \frac{1}{4}$. Note first that

$$\begin{aligned} \frac{d\Phi(B)}{dB} &= \frac{d}{dB}(B+\Gamma(B)) = \frac{d}{dB}\left(B + \frac{[\bar{k}-B]^2}{2(\bar{k}-\underline{k})}\right) \\ &= 1 - \frac{\bar{k}-B}{\bar{k}-\underline{k}} = \frac{B-\underline{k}}{\bar{k}-\underline{k}} \end{aligned} \tag{30}$$

can be positive or negative, according to whether B is larger or lower than $\underline{k}$. There are two cases to analyze: $\underline{k} < B(1) = 1$ and $\underline{k} > B(1) = 1$. In the first case, B is always larger than $\underline{k}$, $\Phi(B)$ is increasing in B, and C optimally sets $\phi = \phi^* = \frac{1}{4}$. By (28), R exerts an effort $\Phi(\frac{5}{4})$, and by (29), C obtains an expected payoff $\frac{1}{2}[\Phi(\frac{5}{4})]^2$.

If instead $\underline{k} > B(1) = 1$, C could in principle set $B < \underline{k}$, the quasi-rents always would be positive, the collaboration becomes stabilized, and $\Phi(B)$ is decreasing in B. Therefore, $\phi = 1$ or 0, and we revert to the case of Proposition 1, where $\phi = 1$ and C's expected payoff is $\frac{\hat{k}^2}{2}$. But this scenario can never be an optimal choice, because $\Phi(B)$ is always larger than $\hat{k}$. In equilibrium, $\phi = \frac{1}{4}$, and the collaboration is never stabilized.

It only remains to prove that the equilibrium payment is non-negative. Substituting the equilibrium values of a and ϕ into (26),

$$\begin{aligned} p &= \frac{1}{2}\Phi(\frac{5}{4})\left(\Gamma(\frac{5}{4}) - \frac{1}{4}\right) \\ &= \frac{1}{2}\Phi(\frac{5}{4})\left(\frac{\left(\bar{k} - \frac{5}{4}\right)^2}{2(\bar{k} - \underline{k})} - \frac{1}{4}\right), \end{aligned}$$

and it is easy to verify that the term in brackets is strictly positive in the relevant range of the parameters.

Proof of Proposition 5.

We follow the same steps as in the proof of Proposition 2. Consider the case of mixed governance. The effort is chosen optimally by R to maximize the payoff in (23), and the incentive compatibility and the participation constraints are

$$a = (1 - \phi) + (1 - \lambda)\Gamma(B(\phi)) \tag{31}$$

and

$$p + a[1 - \phi + (1 - \lambda)\Gamma(B(\phi))] - \frac{1}{2}a^2 \geq 0. \tag{32}$$

Because (32) is always positive, C optimally sets $p = 0$; substituting (31) into (22), it obtains an expected payoff

$$\left[\sqrt{\phi} + \lambda\Gamma(B(\phi))\right][1 - \phi + (1 - \lambda)\Gamma(B(\phi))] \tag{33}$$

that is maximized when

$$\lambda = \frac{1}{2} - \frac{1}{2}\frac{\sqrt{\phi} - (1 - \phi)}{\Gamma(B(\phi))}. \tag{34}$$

Then, substituting (34), (33) reduces to

$$\frac{1}{4}[\Phi(B(\phi))]^2. \tag{35}$$

As proved in Proposition 3 and 4, C optimally sets $\phi = \frac{1}{4}$ and therefore, by (34),

$$\lambda = \frac{1}{2} + \frac{1}{8}\frac{1}{\Gamma(\frac{1}{4})}, \tag{36}$$

and by (31), R exerts an effort

$$a = \frac{1}{2}\Phi(\frac{5}{4}) \tag{37}$$

and obtains a payoff

$$\frac{1}{8}[\Phi(\frac{5}{4})]^2, \tag{38}$$

while C obtains an expected payoff

$$\frac{1}{4}[\Phi(\frac{5}{4})]^2. \tag{39}$$