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Breaking Up a Research Consortium

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Abstract

Inter-firm R&D collaborations through contractual arrangements have become increasingly popular, but in many cases they are broken up without any joint discovery. We provide a rationale for the breakup date in R&D collaboration agreements. More specifically, we consider a research consortium initiated by a firm A with a firm B. B has private information about whether it is committed to the project or a free-rider. We show that under fairly general conditions, a breakup date in the contract is a (second-best) optimal screening device for firm A to screen out free-riders. With the additional constraint of renegotiation proofness, A can only partially screen out free-riders: entry by some free-riders makes sure that A does not have an incentive to renegotiate the contract ex post. We also propose empirical strategies for identifying the three likely causes of a breakup date: adverse selection, moral hazard, and project non-viability.

Keywords: Optimal R&D contracts, adverse selection, breakup date, R&D collaboration

JEL-Classification: C72, D82, L20

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1 Introduction

The last three decades have witnessed a barrage of inter-firm collaborations on Research and Development (R&D), particularly in industries like pharmaceuticals, information technology, aerospace, defense, automotive, consumer electronics, chemicals, instrumentation, and medical equipment (Hagedoorn, 2002). Out of this increasing popularity of R&D collaborations, a noticeable change comes from their organizational arrangements: a majority of inter-firm R&D partnerships were established not through Research Joint Ventures — that have been the focus of numerous theoretical studies[1] — but through non-equity contractual agreements. Narula and Hagedoorn (1999) report that R&D collaborations via contractual arrangements account for more than 70% of all R&D partnerships.

The waves of R&D collaborations have attracted a lot of attention among economists interested in studying the impact of collaboration on R&D productivity. To their surprise, many R&D consortia broke up after a short period. Kogut (1989) finds a large number of R&D partnerships failed in the first year. Kale et al. (2002) notice that around 40% of R&D partnerships were judged as unsuccessful. Reuer and Zollo (2005) further find that more than half of R&D collaboration agreements were terminated by one partner or through contract expiration. In fact, the failure rate in biotech-pharmaceutical R&D alliances is as high as 70% (Hansen, 2003). The high incidence of failure has led some economists to caution readers about their empirical findings because of the selection effect due to only more promising research consortia being formed (Danzon et al., 2005).

Why would a firm initiate an R&D collaboration with another and then break up at a later time? Conventional wisdom points to the story of firms' finding out that their joint research projects are not viable during R&D collaboration. This, however, is not the case in many failed R&D collaborations since often the remaining partner continues the R&D project on its own.[2] Further, in some cases research partners voiced the suspicion that their partner was not truly committed to the success of the project, either because it could

[1]For example, Katz (1986), d'Aspremont and Jacquemin (1988), and Kamien et al. (1992). They and others have justified R&D cooperation on a number of grounds, such as internalizing spillovers, avoiding duplicate R&D efforts, and capturing technological complementarities. In contrast, the literature on R&D contracts is sparse. See Section 6 for a discussion of the related literature.

[2]For example, in 1993 Airbus and Boeing agreed to jointly conduct R&D on Very Large Commercial Transport. The cooperation was ended in 1995, after which Airbus continued to develop the super jumbo jet A380 by itself. Similar observations can be made in the pharmaceutical industry: after having terminated the R&D collaboration agreement with GlaxoSmithKline, Cytokinetics continues its drug development and clinical trials.

cannibalize one of its products or because of the intention to free ride on the other firm's effort.[3] Ample evidence indicates that R&D partners' private information about their own interests and willingness to commit to their joint projects are among the major causes of R&D collaboration failures.[4] Therefore, it is an interesting and insightful approach to consider how the anticipation of meeting a free-rider affects the choice of collaboration contracts *ex ante*. Above all, the termination clause is the most negotiated item in R&D collaboration contracts (Lerner and Malmendier, 2005).[5]

In contrast to conventional wisdom, we show that the breakup clause can be seen as an ex ante efficient measure — it serves as an effective screening device in an R&D collaboration contract. Using contract theory to analyze R&D collaboration contracts, we show that under fairly general conditions, a breakup rule in the form of a term limit is necessary and optimal in screening out bad partners. In particular, a breakup rule makes sure that only committed research partners agree to participate in a collaboration. The reason for this is that a breakup rule makes participation less attractive for non-committed types who are more inclined to drag out the project in order to reap private benefits.

Specifically, we consider a firm A, the principal, that owns the right to conduct R&D on a project and can choose whether to start an R&D consortium with a firm B, the agent. Firm B's type is its private information. It can be a committed research partner or a free-rider. We show that a breakup becomes necessary when there is a misalignment of incentives: while the principal prefers to collaborate with a committed agent because it generates higher profits for the principal, a free-rider actually has higher private benefits than a committed agent.[6] This misalignment of incentives turns out to be quite common in

[3]Esty and Ghemawat (2002) quote an Airbus employee suspecting that the research collaboration between Airbus and Boeing failed because Boeing had different objectives and did not want to see the new super jumbo jet cannibalize their 747 product line.

[4]For example, see Mahnke and Overby (2008). The authors observe that many R&D collaborations fail because "the participants maximize their private benefits at the expense of the common ones".

[5]Lerner and Malmendier (2005) find that "firms pay an enormous amount of attention to negotiating termination rights. These terms have been described as 'probably the most heavily negotiated (at least in terms of time) provision' in biotechnology research agreements." Hagedoorn and Hesen (2007) find that termination clauses in R&D collaboration contracts have attracted more attention in the recent economics and management literature. A termination clause usually includes both a termination date and post-termination arrangements such as payments and control right allocation. Termination dates are widely observed in R&D collaboration contracts. In an empirical analysis of 52 R&D collaboration contracts in the telecommunications equipment industry, Ryall and Sampson (2009) note that firms usually set a fixed termination date for joint R&D development. They also note that having an explicit termination clause ex ante could facilitate the smooth functioning of the R&D collaboration contract.

[6]We relax this assumption in the section on multidimensional types: breakup can be optimal as long as the agent's private benefit is not perfectly negatively correlated with the principal's profit.

the pharmaceutical industry where big pharmaceutical firms free-ride small research firms' R&D by accepting collaboration requests but providing little cooperation.[7] Upon success, the big pharmaceutical firm can reap much higher benefits due to economies of scale and scope in the industry. In this respect, our story is especially relevant in explaining the high frequency of breakups in pharmaceutical R&D consortia. In particular, we show in a setup with the possibility of commitment to a breakup that if the ratio of free-riders is large, the optimal contract is a single fully separating contract with a breakup date. The principal is willing to incur the cost of inefficient breakup with a committed research partner in order to avoid the cost of a likely cooperation with a free-rider. However, if the ratio of free-riders is small, then the principal is willing to take the small risk of cooperation with a free-rider rather than bearing the cost of an inefficient breakup with a research partner who is likely to be committed. Hence, the principal chooses a pooling contract without a breakup date.

Our second contribution concerns the time inconsistency problem of a breakup date as a screening device: while it is ex ante efficient to include a breakup clause to screen the committed agents, ex post – after the agent revealed its type – it may not be optimal to actually break up. We extend the setup to one with imperfect commitment: the principal cannot commit not to renegotiate the contract. We show that the solution of this contracting under imperfect commitment problem can take two forms: a pooling contract or a partially separating contract. The pooling contract is clearly renegotiation proof since the agent does not reveal its type. The partially separating contract (or equilibrium), in which free-riders randomize between participating and not, is renegotiation proof because the fraction of free-riders makes the principal (weakly) better off by not continuing the cooperation. Furthermore, we derive a necessary and sufficient condition under which a renegotiation proof single partially separating contract is feasible and is preferred by the principal to both the pooling contract and to the principal conducting research alone. If the ratio of free-riders is low, the principal cannot credibly commit to breakup. However, if commitment to a breakup is credible, i.e. a breakup clause is renegotiation proof, then breakup is optimal for the principal.

Our results have relevance for the empirical study of R&D collaborations. Empirical studies on R&D cooperation often face a challenging problem — firms with strong R&D capabilities, which are typically more committed, are more likely to participate in R&D col-

[7] See Hansen (2003) for this asymmetric contractual arrangements in biotech-pharmaceutical industries. Danzon et al. (2005) provide evidence on counter-productive R&D when small firms collaborate with large firms with broad scopes.

laborations. This selection problem has become the "probably single greatest econometric problem facing any analysis seeking to measure the impact of government support on commercial R&D activity" (Branstetter and Sakakibara, 2002). The problem of asymmetric information has been recognized in the empirical studies of R&D collaboration contracts,[8] but little has been accomplished in disentangling hidden information, hidden action, and imperfect knowledge of the viability of the project. This is because the identification of adverse selection and moral hazard is widely considered a challenging problem since both of them are unobservable. Our model tells a story from the adverse selection perspective, although hidden action and unknown viability may also play a role empirically. A full-blown empirical analysis is beyond the scope of this paper. Nevertheless, we propose several empirical identification strategies to determine the role of termination dates (see Section 5). In addition, the closed form solution from our simple model generates many empirically testable hypotheses. For example, our results show that a firm that has better possibilities of commitment (e.g. because a firm is large or known to be a long-run player in the industry[9]) is more likely to include a breakup clause with its partner and to actually break up, once the breakup date is due.

The remainder of the paper is structured as follows. Section 2 lays out the model and Section 3 discusses the main results under perfect commitment. Section 4 considers contracts when commitment is not possible. Section 5 discusses several empirical strategies for identifying the role of the termination date. Section 6 discusses the related literature and concludes the paper.

2 The Model

We consider a principal-agent problem with two firms, A and B. Firm A, the principal, owns the right to conduct a certain R&D project and considers inviting firm B, the agent, to form a research consortium. Firm B has private information about its type. Firm B's type may either be "committed" (C) or "free-rider" (F). Firm A prefers cooperation with type C but not type F. The reason could be literally that a committed partner is valuable

[8] The right of termination has not been studied from a contract theoretical perspective in empirical literature until recently. Lacetera (2009) studies the control right among industry-university R&D collaboration contracts. Lerner and Malmendier (2010) test the cross-substitution problem in biotech research collaborations.

[9] Note that firm size or whether a firm is a long-run player as a proxy for commitment power may have some endogeneity issues if not all characteristics are controlled for.

to the project, but a free-rider is not. Alternatively, type F may know that it will not come out with a competing product in the future and only joins the consortium to free-ride firm A; in this case firm A would prefer not forming a research consortium with firm B. A type C firm is committed to the same market targeted by this R&D project and does have a potential competing product. As a result, getting it on board will ensure that competition will be less tough if a consortium is formed. We assume the probability that B is of type i is α_i, $i = C, F$, where $\alpha_C = 1 - \alpha_F$.

Further, in most of the paper we consider the case in which there is a misalignment of incentives: while A prefers cooperation with a committed type to cooperation with a free-rider, a free-rider has higher private benefits than a committed type. We will formalize this later on and also discuss the case without a misalignment of incentives.

More specifically, assume the arrival time of discovery is exponentially distributed. If A conducts the research alone, the arrival rate is λ, and if research is done in a consortium, it is λ_T. Because firm A is seeking to collaborate with a potential competitor, its payoff depends on firm B's type. In particular, for B having type $i = C, F$ the outcome of the project has value w_i for A if it conducts research together with B, and w_A^i if it conducts the research alone. B's value from the success of the project is v_i. B has a sunk cost k_i of joining the project, which can be interpreted as the cost of setting up a research lab or the cost of disclosing its existing knowledge to A. If B does not join the project, A incurs additional startup costs k_A. In each period that the research project is conducted, A has flow costs 1. B's flow costs are ε_i for $i = C, F$. Finally, let r be the discount factor.

If B joins the consortium and there is a breakup later on, A does not have to incur the setup costs k_A. This can be either thought of as the initial investment by B falling into the possession of A after termination or alternatively as B revealing some of its prior knowledge to A at the beginning of the collaboration. In the latter case, A can use the knowledge it acquired from B even after cooperation ends.[10]

The basic ingredients of the model become clearer if we write down expected net present value revenues in a first-best setup without informational asymmetries about B's type. Let T_i be the date at which firm A breaks up with firm B with type i. We will first look at A's profit. If discovery occurs before breakup at some time $t < T_i$, then

[10]With this interpretation, B revealing its prior knowledge can be viewed as sunk costs, since B irreversibly loses its competitive advantage that stemmed from this knowledge. One should think of knowledge which is not patented, but useful for a research project, e.g. the experience that a certain approach to a problem does not lead to a solution and that one should hence focus one's attention to other approaches.

A's discounted profit is $e^{-rt}w_i$, its discounted flow costs are $\int_0^t e^{-r\tau}\,d\tau$. Since t is exponentially distributed with hazard rate λ_T, A's expected profit in case discovery occurs is $\int_0^{T_i} \lambda_T e^{-\lambda_T t}\left(e^{-rt}w_i - \int_0^t e^{-r\tau}\,d\tau\right)dt$. With probability $\int_{T_i}^{\infty} \lambda_T e^{-\lambda_T t}dt$, no discovery is made before the breakup date. In this case A loses the flow costs of development before breakup $-\int_0^{T_i} e^{-r\tau}\,d\tau$. A continues to conduct research alone. If discovery occurs at $T_i + x$, the expected net present value of doing research alone after breakup at period T_i is $e^{-rT_i}\left(\int_0^{\infty} \lambda e^{-\lambda x}\left(e^{-rx}w_A^i - \int_0^x e^{-r\tau}\,d\tau\right)dx\right)$, which is derived by taking expectations over x and discounting the profit back to period 0.

Putting this together, A's profit is

$$
\begin{aligned}
&\left[\int_0^{T_i} \lambda_T e^{-\lambda_T t}\left(e^{-rt}w_i - \int_0^t e^{-r\tau}\,d\tau\right)dt\right] \\
&+\left[\left(\int_{T_i}^{\infty} \lambda_T e^{-\lambda_T t}dt\right)\left(-\int_0^{T_i} e^{-r\tau}\,d\tau + e^{-rT_i}\left(\int_0^{\infty} \lambda e^{-\lambda x}\left(e^{-rx}w_A^i - \int_0^x e^{-r\tau}\,d\tau\right)dx\right)\right)\right] \\
&= W_i + W_i^{\Delta} e^{-(r+\lambda_T)T_i}
\end{aligned}
$$

where $W_i = (\lambda_T w_i - 1)/(r + \lambda_T)$ is A's expected net present value of conducting research with B without a deadline, $W_A^i = (\lambda w_A^i - 1)/(r + \lambda)$ is A's expected net present value of conducting the project alone after breaking up with B, and $W_i^{\Delta} = W_A^i - W_i$ is the difference between the two. If A starts the research project on its own, A's profit will be $W_A^i - k_A$.

B's profit can be calculated the following way. If discovery occurs before breakup, B's profit is $\int_0^{T_i} \lambda_T e^{-\lambda_T t}\left(e^{-rt}v_i - \varepsilon_i \int_0^t e^{-r\tau}\,d\tau\right)dt$, by a logic similar to the one for computing A's profit. If breakup occurs before discovery, B has incurred flow costs $\varepsilon_i \int_0^{T_i} e^{-r\tau}\,d\tau$. Putting this together, B's profit (after subtracting the setup cost) is

$$
\begin{aligned}
&\left(\int_0^{T_i} \lambda_T e^{-\lambda_T t}\left(e^{-rt}v_i - \varepsilon_i \int_0^t e^{-r\tau}\,d\tau\right)dt\right) \\
&-\left(\left(\int_{T_i}^{\infty} \lambda_T e^{-\lambda_T t}dt\right)\left(\varepsilon_i \int_0^{T_i} e^{-r\tau}\,d\tau\right)\right) - k_i \\
&= V_i(1 - e^{-(r+\lambda_T)T_i}) - k_i
\end{aligned}
$$

where $V_i = (\lambda_T v_i - \varepsilon_i)/(r + \lambda_T)$ is the net present value of completing the project.

The analysis can be further simplified by introducing the (discounted) probability of completing the project $p = 1 - e^{-(r+\lambda_T)T}$. A lower probability of completion implies an earlier breakup date. Using the one-to-one correspondence between p and the breakup date $T = -(\ln(1-p))/(r+\lambda_T)$, we can write firms' profits in terms of p rather than T. Specifically, A's profit can be rewritten as

$$W_i + (1-p_i)W_i^{\Delta} = p_i W_i + (1-p_i)W_A^i$$

and B's profit as

$$p_i V_i - k_i.$$

Joint profit resulting from cooperating is larger than joint profit when A conducts research alone if $W_i + (1-p_i)W_i^{\Delta} + p_i V_i - k_i > W_A^i - k_A$ for an agent of type i. This is equivalent to $p_i(V_i - W_i^{\Delta}) - (k_A - k_i) > 0$. In the following we will assume that cooperation with the committed type increases joint surplus, whereas cooperation with the free-rider does not.

Assumption 1 *(i)* $k_A - k_C > 0 > k_A - k_F$
(ii) $V_C - W_C^{\Delta} > 0 > V_F - W_F^{\Delta}$

Assumption 1 (i) means the net benefit of forming a research consortium is positive with a committed type and negative with a free-rider type. Assumption 1 (ii) means that joint surplus increases over time in a consortium with a committed type and decreases with a free-rider. As a result, Assumption 1 implies that for any breakup date, it is joint surplus maximizing to cooperate with the committed agent and not to cooperate with the free-rider.[11]

Note that only the setup costs k_i, the probabilities of completion p_i, and the derived quantities, W_i, W_A^i, V_i, matter for firms' optimization problems; the individual decompositions in w_i, w_A^i, v_i, ε_i, r, λ, λ_T, and T do not matter. Therefore, we will simplify the following exposition by basing the analysis on these derived quantities. That the individual decomposition of the derived quantities do not matter implies, e.g. that the hazard rate of discovery could be the same or different alone and together ($\lambda = \lambda_T$ or $\lambda \neq \lambda_T$) and that

[11] This is a sufficient condition for cooperation being attractive with a committed agent and unattractive with a free rider for any breakup date. A necessary and sufficient condition is $p(V_C - W_C^{\Delta}) + k_A - k_C > 0 > p(V_F - W_F^{\Delta}) + k_A - k_F$ for all $p \in [0,1]$, which is equivalent to $k_A - k_C > 0 > k_A - k_F$ and $V_C - W_C^{\Delta} + k_A - k_C > 0 > V_F - W_F^{\Delta} + k_A - k_F$. This weaker condition would allow for the case $V_F - W_F^{\Delta} > V_C - W_C^{\Delta}$, i.e. total welfare is lower with the free-rider, but once the free-rider has joined and the costs of starting the project sunk, it is better to cooperate with the free-rider. Our analysis could be extended by additionally considering this case. However, this would complicate the exposition without adding significant insights.

A's value of conducting the project alone may or may not depend on B's type ($w_A^F = w_A^C$ or $w_A^F \neq w_A^C$).

It is clear that by Assumption 1 it is first-best to cooperate with the committed type and to never break up. And it is first-best not to start cooperation with the free-rider. Hence, without informational asymmetries, breakup should never occur in this setup.

3 Informational Asymmetries

In this section, we will consider the contract firm A will design if firm B has private information about its type. Firm A may offer three types of contracts. First, a single separating contract for type C that makes sure that type F does not participate. Second, a single pooling contract that induces both C and F to participate and offers the same terms to both. Third, a menu of strictly separating contracts which induces both C and F to participate and gives them a (strict) incentive to reveal their types. We use the term *strictly* separating to have a clear distinction between the menu of strictly separating contracts and a single pooling contract. A pooling contract can be seen as a menu of *weakly* separating contracts: the principal offers two contracts with exactly the same terms, since the agent is indifferent between the two contracts, it is an equilibrium strategy to report its type truthfully.

For the single contract case (either separating or pooling), A offers a contract that consist of a payment S and a probability of completion p. S is the expected net present value of transfers from A to B. Note that since all types of B have the same discount factor and the same arrival rate of innovation, the timing of payments cannot be used to separate the different types. Further, since A also has the same discounting and arrival rate, only the expected net present value S matters. For the single separating contract, A's profit maximization problem is

$$\begin{aligned} \max_{S,p} \quad & \alpha_C(pW_C + (1-p)W_A^C - S) + \alpha_F(W_A^F - k_A) \\ \text{s.t.} \quad & S + pV_C - k_C \geq 0 \\ & S + pV_F - k_F \leq 0 \end{aligned}$$

where the first constraint makes sure that C participates and the second that F does not.

For a single pooling contract, A's profit maximization problem is

$$\begin{aligned}\max_{S,p} \quad & \alpha_C(pW_C + (1-p)W_A^C) + \alpha_F(pW_F + (1-p)W_A^F) - S \\ \text{s.t.} \quad & S + pV_C - k_C \geq 0 \\ & S + pV_F - k_F \geq 0\end{aligned}$$

where the constraints make sure that both types participate.

For the menu of separating contracts, A offers a contract (S_C, p_C) and (S_F, p_F) for each type of agent. We will discuss this case after we study the optimal single separating and pooling contracts. Finally, if the principal does not cooperate with the agent at all, its profits are $\alpha_C W_A^C + \alpha_F W_A^F - k_A$.

A general principle in contract theory is that first-best can be implemented if there is no misalignment of incentives of the principal and the agent. The following proposition shows that this also holds in our setup.

Proposition 1 *If incentives are aligned, i.e. $V_C - k_C \geq V_F - k_F$, then the principal will choose a contract that implements first best with probability of completion $p^{**} = 1$ (corresponding to no breakup date, i.e. $T^* = \infty$) and payment $S^{**} = k_C - V_C$. The committed type participates, the free-rider does not.*

Proof. An agent's utility when accepting the contract is $S^{**} + p^{**}V_i - k_i$. The committed type is willing to participate since $S^{**} + p^{**}V_C - k_C = k_C - V_C + V_C - k_C = 0$. The free-rider is not willing to participate since $S^{**} + p^{**}V_F - k_F = (V_F - k_F) - (V_C - k_C) \leq 0$. ■

For $V_C - k_C \geq V_F - k_F$, incentives are aligned, since participation by the committed type rather than the free-rider is better both in terms of joint profits and in terms of the agent's private benefits. Therefore, it is costless to induce the agent to reveal his type, there is no principal agent problem, and a costly breakup clause is not necessary.

In the remainder of the paper we will focus on the case for which incentives are misaligned, so that a costly contract has to be used to screen the agent. This is expressed by the following condition.

Condition 1 *(Misalignment of Incentives) $V_C - k_C < V_F - k_F$.*

Appendix B shows how results extend to a multidimensional problem in which incentives are neither perfectly aligned nor perfectly misaligned.

We will first show that breakup always occurs with a single separating and never occurs with a pooling contract.

Proposition 2 *(i) For a single separating contract, breakup always occurs. The probability of completion is* $p^*_{single} = (k_F - k_C)/(V_F - V_C)$ *and the payment* $S^*_{single} = k_C - p^*_{single} V_C$*.* p^*_{single} *corresponds to a breakup date* $T^*_{single} = -[\ln(1 - (k_F - k_C)/(V_F - V_C))]/[r + \lambda_T]$*.*

(ii) For a pooling contract, breakup never occurs ($T^*_{pool} = \infty$*). The probability of completion is* $p^*_{pool} = 1$ *and the payment* $S^*_{pool} = k_C - V_C$*.*

(iii) A prefers a single separating contract to a single pooling contract if and only if

$$\alpha_C \left(1 - p^*_{single}\right)(V_C - W^{\Delta}_C) < \alpha_F (W^{\Delta}_F + k_C - V_C - k_A). \tag{1}$$

Proof. (i) Note that the incentive compatibility constraint for C must be binding, otherwise the principal can reduce S, which still makes sure that F does not participate, and hence increase the principal's profit. Solving C's incentive compatibility constraint yields $S = k_C - V_C p$, substituting this into $F's$ incentive compatibility constraint $S + V_F p - k_F \leq 0$ and rearranging gives

$$p \leq \frac{k_F - k_C}{V_F - V_C}.$$

The principal's problem can hence be rewritten as

$$\max_S \alpha_C (W_C + W^{\Delta}_C - k_C + (V_C - W^{\Delta}_C)p) + \alpha_F (W^F_A - k_A)$$
$$\text{s.t. } p \leq \frac{k_F - k_C}{V_F - V_C}.$$

Assumption 1 implies that $V_C - W^{\Delta}_C$ is positive and hence the upper bound for p is binding, which completes the proof of part (i).

(ii) Since the maximand and the constraints are linear and the left-hand side of both constraints is increasing in p, the problem has a bang-bang solution, i.e. p is either 0 or 1.

If it is 0, the principal lets the agent start up the project, breaks up immediately, and continues the project alone. To satisfy the individual rationality constraints of both types, $S - k_C \geq 0$ and $S - k_F \geq 0$, the principal has to pay $S^* = k_F$. However, in this case, the principal is better off by excluding the free-rider by reducing the payment to $S^* = k_C$. This results in a single separating contract that clearly dominates a pooling contract with $p^* = 0$.

If $p^* = 1$, the constraints become

$$\begin{aligned} S + V_C - k_C &\geq 0 \\ S + V_F - k_F &\geq 0. \end{aligned}$$

By Condition 1, if the constraint for C is satisfied, it also has to be satisfied for F. Hence, the principal will set the first constraint binding which yields

$$S^* = k_C - V_C.$$

(iii) Profits with a single separating contract are

$$\Pi_{\text{single}} = \alpha_C(W_A^C - k_C + (V_C - W_C^\Delta)\frac{k_F - k_C}{V_F - V_C}) + \alpha_F(W_A^F - k_A)$$

and for the single pooling contract

$$\Pi_{\text{pool}} = \alpha_C W_C + \alpha_F W_F + V_C - k_{C.}$$

The difference of profits can be rearranged to

$$\Pi_{\text{single}} - \Pi_{\text{pool}} = -\alpha_C \left(1 - p^*_{\text{single}}\right)(V_C - W_C^\Delta) + \alpha_F(W_F^\Delta + k_C - V_C - k_A).$$

This implies the part (iii) of the proposition. ■

Figure 1 provides an intuition for statements (i) and (ii) in the Proposition, which illustrates type i's utility $U_i = S + pV_i - k_i$. Note that type F's utility (the solid line) has a larger slope in p than type C (the dashed line). A would like to collaborate with type C as long as possible but the latest breakup date is at the intersection of the two lines in Figure 1 if A wants to separate the two types. In other words, a single crossing condition holds. Alternatively, A may pool both types and make sure that the dashed line, type $C's$ expected utility at the breakup date is equal to 0, so that type C's individual rationality constraint is binding. This leads to setting $p = 1$. Note that for $(k_F - k_C)/(V_F - V_C) < 0$ (i.e. $k_F - k_C$ and $V_F - V_C$ have different signs) and for $(k_F - k_C)/(V_F - V_C) > 1$ (i.e. no misalignment of incentives, a violation of Condition 1), no breakup clause can be found that separates the two types of agents (i.e. there is no $p^*_{\text{single}} \in [0, 1]$). In these cases there will be no breakup date in the contract, since either first-best can be implemented, the principal is willing to bear the cost of cooperating with a free-rider with probability α_F, or a consortium is never started in the first place.

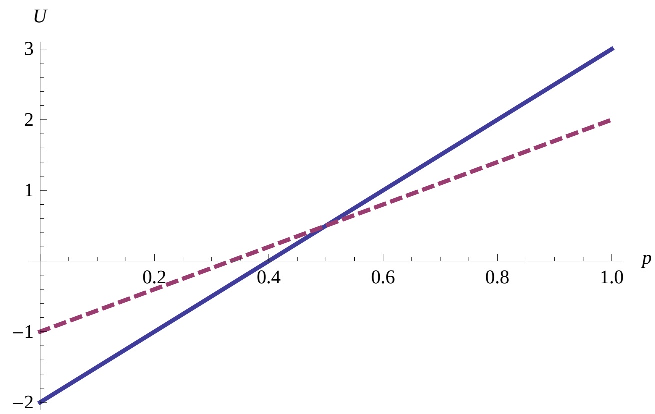

Figure 1: Utility of type C and type F agent as a function of the probability of completing p, $S + pV_C - k_C$ (dashed) and $S + pV_F - k_F$ (solid).

Inequality (1) in part (*iii*) of the Proposition can be interpreted the following way. The left-hand side is the opportunity cost of breaking up with the committed type rather than pooling: $V_C - W_C^{\Delta}$ is the value of cooperating with the committed type and $1 - p^*$ the probability of breaking up. The right-hand side is the cost of pooling. W_F^{Δ} is the efficiency loss due to cooperating with the free-rider rather than conducting the project alone. $k_C - V_C$ is the payment of the principal to the free-rider. k_A is the setup cost if principal conducts the R&D by itself. Therefore, the difference between $W_F^{\Delta} + k_C - V_C$ and k_A is the net efficiency loss due to pooling. A single separating contract is preferable to the principal if the cost of breaking up with the good type is less than the net cost of pooling. Furthermore, if the fraction of free-riders α_F is large, the principal will choose the single separating contract.

Note that the probability of completion p^*_{single} is larger the larger setup costs of the free-rider k_F and the private benefit of the committed type V_C, and the smaller the setup costs of the committed type k_C and the private benefit of the free-rider V_F. Since $T^*_{\text{single}} = -(\ln(1 - p^*_{\text{single}}))/(r + \lambda_T)$, the same comparative statics applies to the optimal breakup date T^*_{single}, with the additional effects that the breakup date decreases with the discount factor r and the discovery rate λ_T.

A third type of arrangement that firm A can offer is a menu of contracts, in which case, the principal's problem is as follows.

$$\max_{S_C, p_C, S_F, p_F} \quad \alpha_C(p_C W_C + (1-p_C)W_A^C - S_C) + \alpha_F(p_F W_F + (1-p_F)W_A^F - S_F) \quad (2)$$

$$\text{s.t.} \quad S_C + p_C V_C - k_C \geq 0 \quad (3)$$

$$S_F + p_F V_F - k_F \geq 0 \quad (4)$$

$$S_C + p_C V_C - k_C \geq S_F + p_F V_C - k_C \quad (5)$$

$$S_F + p_F V_F - k_F \geq S_C + p_C V_F - k_F \quad (6)$$

$$1 \geq p_C, \; p_F \geq 0 \quad (7)$$

where the first and second constraints stem from individual rationality and the third and fourth from incentive compatibility.

Lemma 1 *For a menu of strictly separating contracts, we must have*

$$\begin{aligned} p_F &> p_C \\ S_C &> S_F. \end{aligned}$$

Proof. The two incentive compatibility constraints, (5) and (6) imply

$$(V_F - V_C)(p_F - p_C) \geq 0.$$

By Assumption 1 and Condition 1, we must have $V_F > V_C$, which implies

$$p_F \geq p_C.$$

Observe that $p_F = p_C \Leftrightarrow S_C = S_F$. Hence, we must have $p_F > p_C$ if the contract is strictly separating. Similarly, we can prove $S_C > S_F$. ■

This lemma illustrates an unpleasant feature of the menu of separating contracts. The principal is not willing to collaborate with type F. However, in order to separate type C from type F, the principal has to offer a contract that contains a later breakup date for the free-rider type it does not want to collaborate with. Fortunately, the following proposition shows that the principal prefers not to offer a menu of separating contracts because the payoff from a menu of separating contracts is dominated by a single separating contract.

Proposition 3 *A menu of separating contracts is dominated by the optimal single sepa-*

rating contract.

The proof is rather technical and therefore relegated to Appendix A. Intuitively, the reason is that costly breakup is necessary both in a single separating contract and in a menu of separating contracts. If the principal has to incur the cost of a breakup anyway, he can just as well exclude the inefficient free rider.

4 Renegotiation Proofness

We have so far assumed that the principal can commit to terminating the R&D consortium at the breakup date set in the contract. In some situations this is a reasonable assumption. For example, the principal forms research consortia repeatedly and fears to lose its reputation if it announces to break up the consortium in advance, but extends it once the breakup date is due. In other situations, commitment is difficult or even impossible. For example, the principal may not be playing a repeated game, because it is unlikely to form a new research consortium, or at least a consortium at which as much is at stakes. Furthermore, if details of the cooperation do not become publicly known, the principal does not have to fear for its reputation when dealing with other research partners in the future.

The difficulty in commitment is an issue especially for the single separating contract: the breakup date, induces the free-rider not to participate in R&D cooperation; therefore, the principal knows that an agent that cooperates has to be the committed type and breakup is inefficient. When the breakup date is due, it is tempting to renegotiate the contract and continue cooperation, since it is *ex post* efficient. However, if the free-rider expects this, it will not be deterred from entry by a non-credible breakup date. The following proposition formalizes this idea.

Proposition 4 *If the principal offers a single separating contract with probability of completion $p^* = (k_F - k_C)/(V_F - V_C)$ and payment $S^* = k_C - p^* V_C$, the committed agent joins the consortium and the free-rider does not join the consortium, then*

(i) breakup is not a credible threat and

(ii) a free-rider has the incentive to join the consortium at the beginning.

Proof. Consider the situation at period T^*, when breakup is due. The utility of an agent that has already joined the consortium is the same as in our original setup, except that the costs of starting the consortium k_i are sunk. Utility is hence $\tilde{U}_i(S, p) = S + pV_i$ for

$i = F, C$. Other than that, the problem is the same because of the exponential distribution of the discovery rate.

Assume that only the committed type joined the consortium. The principal considers renegotiating the contract with the agent and offering a new contract with (remaining) probability of completion $p = 1 - e^{-(r+\lambda_T)(T-T^*)}$, where T and T^* are the new and old breakup date respectively, and S is the transfer. The principal's maximization problem is

$$\max_{S,p} pW_C + (1-p)W_A^C - S$$
$$\text{s.t. } S + pV_C \geq 0$$

By the same reasoning as before, it can be shown that the constraint is binding, hence $S = -pV_C$. Therefore, the principal's maximization problem becomes $\max_p W_A^C + p(V_C - W_C^{\Delta})$. Since the expression in parentheses is positive by assumption, the principal will want to set $p^* = 1$ and $S^* = V_C$, which results in profits $W_A^C + V_C - W_C^{\Delta}$. Since the costs of starting up the consortium are already sunk, continuing the project alone would generate profits W_A^C for the principal, which is less than $W_A^C + V_C - W_C^{\Delta}$. Therefore, the principal has the incentive to renege on his threat of breakup and extend the consortium. This proves part (i). Part (ii) holds because a free-rider essentially faces a contract without a breakup clause in the beginning. If C's utility $S + V_C - k_C$ is non-negative, where S is the expected net present value of total payments (initial and at renegotiation), then so is F's utility $S + V_F - k_F$ by Condition 1. ■

Proposition 4 implies that if firm A cannot commit to breakup at the date stipulated in the single separating contract, the contract is no longer renegotiation proof. More generally, the revelation principle fails if there is imperfect commitment: once an agent reveals its type, the principle is tempted to use this information to renege on *ex post* inefficient threats. Hence, it is not sufficient to restrict one's attention to contracts that induce each type of agent to reveal its type truthfully. However, as Bester and Strausz (2001) show, a slightly modified version of the revelation principle holds in a one-agent-setup even without commitment. For any optimal contract, there exists a contract with the following properties. The message space is equal to the agent's type space. The agent sends with *positive probability* a message which is equal to its type. The crucial difference is that the probability may be less than one, in which case the agent randomizes. Randomization has to be such that the principal has to have the incentive to do the required action ex post. We will apply this approach in the remainder of this section to derive renegotiation proof contracts.

According to Proposition 2 of Bester and Strausz (2001), we can restrict ourselves to direct revelation mechanisms in which an agent reports his true type with positive probability. An additional constraint is that the principal has to have an incentive ex post to do what he had promised (or threatened) to do ex ante. For a single separating contract this means that free-riders randomize between accepting the contract and not. The probability of randomization has to be such that the principal does not have an incentive to continue the consortium at the breakup date. Note that the concepts of contract (or mechanism) and equilibrium are somewhat blurred when considering contracting under imperfect commitment: an optimal renegotiation proof mechanism is such that the strategies played by all players are part of a Weak Perfect Bayesian Equilibrium, see Bester and Strausz (2001) for more details.

Proposition 5 *A single separating contract is renegotiation proof iff free-riders play a mixed strategy consisting of participating in the consortium with probability q and not participating with probability $1-q$, where q satisfies the condition*

$$q \geq q^* := \frac{\alpha_C (V_C - W_C^{\Delta})}{\alpha_F (W_F^{\Delta} - V_C)}.$$

If $q^* \leq 1$ (which is equivalent to $\alpha_C(V_C - W_C^{\Delta}) \leq \alpha_F(W_F^{\Delta} - V_C)$), a renegotiation proof single separating contract is feasible, otherwise it is not.

Proof. Denote by q the probability that a free-rider accepts the contract. Note that in the single separating contract specified previously made sure that free-riders are indifferent between participating and not, hence randomization is an equilibrium strategy for a free-rider.

At the breakup date, it is not possible for the principal to offer a new contract which is a single separating contract. This is because $\tilde{U}_F(S,p) > \tilde{U}_C(S,p)$ for all S and $p \in (0,1]$. A menu of separating contracts is dominated by a single separating contract for the same reasoning as in Proposition 2 above. Note that the only difference to Proposition 2 is that the setup costs are sunk, which can be seen as $k_C = k_F = k_A = 0$, but the proof is otherwise the same as for Proposition 2.

Therefore, we only need to consider a single pooling contract. The principal's maximization problem when renegotiating a new contract is

$$\begin{aligned} \max_{p,S} \quad & \alpha_C(pW_C + (1-p)W_A^C) + \alpha_F q(pW_F + (1-p)W_A^F) - (\alpha_C + \alpha_F q)S \\ \text{s.t.} \quad & S + pV_F \geq 0 \\ & S + pV_C \geq 0. \end{aligned}$$

Since $V_F > V_C$, constraints for type C are binding and we can set $S = -pV_C$. Substituting S into A's profit function yields

$$\alpha_C W_C + \alpha_F q W_F + p[\alpha_C(V_C - W_C^{\Delta}) + \alpha_F q(V_C - W_F^{\Delta})]$$

To make sure that A does not have an incentive to extend the breakup date (i.e. increase p), the expression in square brackets has to be weakly negative. Since $V_C < W_F^{\Delta}$ by Assumption 1, the expression is weakly negative iff $q \geq q^*$, where q^* satisfies $\alpha_C(V_C - W_C^{\Delta}) + \alpha_F q^*(V_C - W_F^{\Delta}) = 0$, which implies the proposition. ■

The intuition for the condition $\alpha_C(V_C - W_C^{\Delta}) \leq \alpha_F(W_F^{\Delta} - V_C)$ is that if all free-riders were to join, it would be unprofitable for the principal to renegotiate the contract and continue the consortium. If the condition does not hold, the principal always has an incentive to renegotiate, which renders the contract non-renegotiation proof.

Having the condition for the contract being renegotiation proof, we can derive the optimal single separating contract.

Proposition 6 *Suppose $V_C \leq \alpha_C W_C^{\Delta} + \alpha_F W_F^{\Delta}$. In the optimal single separating renegotiation proof contract (partially separating contract), the probability of completion is $p^* = (k_F - k_C)/(V_F - V_C)$ and the payment $S^* = k_C - p^* V_C$. Type C participates for sure and type F participates with probability $q^* = \alpha_C(V_C - W_C^{\Delta})/[\alpha_F(W_F^{\Delta} - V_C)]$. The probability of completion p^* corresponds to a breakup date $T^* = -[\ln(1-(k_F - k_C)/(V_F - V_C))]/[r + \lambda_T]$.*

Proof. The assumption $V_C \leq \alpha_C W_C^{\Delta} + \alpha_F W_F^{\Delta}$ makes sure q^* is well defined and the single separating renegotiation proof contract is feasible. Since p^* makes sure that both type C and type F agents are indifferent between participating and not, it is an optimal strategy for C to participate for sure and for F to randomize with probability q^*. By the reasoning of the previous proposition, it is (also ex post) optimal for the principal not to renegotiate the contract at the breakup date. While the contract is renegotiation proof for all values $q \geq q^*$, the participation of free-riders is inefficient. Therefore, it is optimal for

the principal if the lower bound is reached and free-riders randomize with probability q^*.
■

We can also compare profits to the pooling contract. Note that a single pooling contract is obviously renegotiation proof, since no information is revealed to the principal and the principal is hence not tempted to use information to change ex post inefficient outcomes.

Proposition 7 *Suppose $V_C \leq \alpha_C W_C^{\Delta} + \alpha_F W_F^{\Delta}$. A's profits in this partially separating contract are*

$$\Pi_{psep} = \alpha_C(W_C - k_C) - \alpha_F q^*(W_F^{\Delta} + k_C - k_A) + \alpha_F(W_A^F - k_A) > \Pi_{pool}.$$

That is, firm A prefers a single separating contract to a pooling contract.

Proof. Profits for the single separating contract can be derived the following way. By the reasoning put forward previously, $S = k_C - pV_C$. Therefore, the principal's profit can be rewritten as

$$\begin{aligned} \Pi_{\text{psep}} &= \alpha_C(pW_C + (1-p)W_A^C - S) + \alpha_F q^*(pW_F + (1-p)W_A^F - S) + \alpha_F(1-q^*)(W_A^F - k_A) \\ &= \alpha_C\left(W_C - k_C + V_C\right) - \alpha_F q^*\left(W_F^{\Delta} + k_C - k_A - V_C\right) + \alpha_F\left(W_A^F - k_A\right) \end{aligned}$$

Profits for the pooling contract are unchanged by the requirement that contracts should be renegotiation proof, therefore $\Pi_{\text{pool}} = \alpha_C W_C + \alpha_F W_F + V_C - k_C$ as before. $\Pi_{\text{psep}} - \Pi_{\text{pool}}$ can be rearranged to

$$\begin{aligned} \Pi_{\text{psep}} - \Pi_{\text{pool}} &= \alpha_C\left(W_C - k_C + V_C\right) - \alpha_F q^*\left(W_F^{\Delta} + k_C - k_A - V_C\right) + \alpha_F\left(W_A^F - k_A\right) \\ &\quad - \left(\alpha_C W_C + \alpha_F W_F + V_C - k_C\right) \\ &= \alpha_F\left(1 - q^*\right)\left(W_F^{\Delta} + k_C - k_A - V_C\right) > 0 \qquad (8) \end{aligned}$$

The inequality follows from Assumption 1. ■

Recall that when firm A can commit to break up, it compares the cost of breaking up with the good type C with the cost of pooling with bad type F. Inequality (8) appears to imply that firm A only cares whether the cost of pooling with the bad type is positive as it is similar to the right hand side of condition (1) in Proposition 1. In other words, it appears firm A no longer cares about the cost of breaking up with type C if it cannot commit to break up. This surprising result turns out not to be counter-intuitive. When firm A cannot commit to breaking up, it offers a single separating contract that is renegotiation proof, which only partially separates committed agents and free-riders. Firm A knows with probability $\alpha_C(1-p^*)$ it will break up with the good type, resulting in an efficiency loss of $V_C - W_C^\Delta$. However, with probability $\alpha_F q^*$, it will break up with the bad type, resulting an efficiency gain of $W_F^\Delta + k_C - V_C - k_A$. The net cost of break up turns out to be negative

$$
\begin{aligned}
& \alpha_C\left(1-p^*_{\text{single}}\right)(V_C - W_C^\Delta) - \alpha_F q^*(W_F^\Delta + k_C - V_C - k_A) \\
= \quad & \alpha_C\left(V_C - W_C^\Delta\right)\left[-\frac{k_F - k_C}{V_F - V_C} + \frac{k_A - k_C}{W_F^\Delta - V_C}\right] \\
< \quad & \alpha_C\left(V_C - W_C^\Delta\right)\frac{k_A - k_F}{V_F - V_C} \\
< \quad & 0,
\end{aligned}
$$

which explains why the principal always prefers the single (partially) separating contract.

Note that the principal prefers the partially separating contract to a pooling contract *whenever it is feasible*. However, for some parameter values, a partially separating contract is not feasible: even if all free-riders were to join the consortium ($q = 1$), the principal would prefer to renegotiate the contract, i.e. $q^* > 1$. The condition for the partially separating contract being feasible without commitment is stricter than the condition for the fully separating being optimal under commitment. In other words, for some parameters, the principal would prefer a fully separating contract if it could commit, however, it has to offer a pooling contract because of lack of commitment possibilities.

An empirically testable implication of this is that less commitment power by the principal makes a breakup clause less likely, since the set of parameters for which breakup occurs under no commitment is a strict subset of the set of parameters for which breakup occurs with the possibility of commitment. This also means that with less commitment power, the project is more likely to be completed.[12] The principal's commitment power may be due to its market power or a past reputation of committing.

A comparison worthwhile making is the one between a partial separating contract and doing the project alone, the latter generating profits $\Pi_{\text{alone}} = \alpha_C W_A^C + \alpha_F W_A^F - k_A$. Note that with some algebra the partial separating profits can be transformed to $\Pi_{\text{psep}} =$

[12]Of course, this is under the assumption that commitment power is not correlated with the parameters of the model. If commitment power is correlated with a parameter and this parameter cannot be controlled for, this correlation will additionally affect the correlation between commitment power and the probability of completion.

$\alpha_C(W_A^C - k_C) + \alpha_F(W_A^F - k_A) + \alpha_F q^*(k_A - k_C)$. The profit difference is hence

$$\Pi_{\text{psep}} - \Pi_{\text{alone}} = (k_A - k_C)(\alpha_F q^* + \alpha_C),$$

which is positive by Assumption 1. Therefore, whenever the renegotiation proof single separating contract is feasible, the principal will prefer it to conducting research alone.

While the comparison with the menu of separating contracts is somewhat more cumbersome, it should be clear that there are parameter values for which the partially separating contract is preferable to the menu of contracts, the pooling contract, and not forming a consortium. The reason is that the profits in the menu of contracts typically depend on k_F, for the three other setups they do not. Hence, for k_F sufficiently large, the menu of separating contracts is worse than the other setups. Therefore, if a renegotiation proof single separating contract is feasible, it is preferred to all other setups for k_F sufficiently large.

Note that the usual justification can be given for players playing mixed strategies. One justification is that we should think of a free-rider playing a mixed strategy as the principal *believing* that the free-rider chooses to participate with probability q^*. Another justification is a standard purification argument (see e.g. Harsanyi (1973) and Fudenberg and Tirole (1991, pp. 233-234)).[13]

5 Empirical Implications: The Role of Termination Date

As discussed at the beginning of this paper, many R&D contracts contain termination dates and there is empirical evidence that terminations indeed happen frequently in R&D collaboration. In this paper, we have presented an explanation of termination dates based on adverse selection. There are two alternative theories that could explain breakup of R&D

[13] Assume e.g. that a free-rider has an additional privately observed random variable ν which is uniformly distributed on $[-\bar{\nu}, \bar{\nu}]$. ν affects the free-rider's payoff, for example, its setup cost is $k_F + \nu$ rather than k_F. As $\bar{\nu}$ goes to 0, this model converges to our basic model. However, in this modified model, the free-rider plays a pure, rather than a mixed strategy. A free-rider with $\nu \leq \nu^*$ participates, a free-rider with $\nu > \nu^*$ does not, where the indifferent type ν^* is given by $pV_F - k_F + \nu^* = pV_C - k_C$, where p is the completion probability. Ratio $q = (\bar{\nu} - \nu^*)/(2\bar{\nu})$ of free-riders participate, $1 - q$ do not. The principal can make sure that ratio q^* of free-riders participate by choosing p^{**} such that it satisfies $p^{**}V_F - k_F + \nu^{**} = p^{**}V_C - k_C$, where ν^{**} is the solution of $q^* = (\bar{\nu} - \nu^{**})/(2\bar{\nu})$. As $\bar{\nu}$ goes to 0, the principal's strategy converges to the strategy of our basic model ($p^{**} \rightarrow p^*$), so does the agent's strategy, i.e. a free-rider participates with probability q^*. In other words, the mixed strategy equilibrium described above can be seen as the limiting case of a slightly perturbed model with a pure strategy equilibrium.

consortia. First, breakup may occur because the involved parties find out that the project is non-viable. Second, a breakup date may be the solution of a moral hazard problem: the principal is worried that the agent may exert insufficient effort and uses a breakup date to incentivize him to work harder.

Whether the termination date is the result of adverse selection, moral hazard, or non-viability of the project is an empirically challenging question. It is well known in the empirical literature that the identification of the different types of informational asymmetries is difficult, since information unobservable to one party is typically also unobservable to the econometrician. Empirical strategies to disentangle adverse selection from moral hazard typically rely on natural experiments or field experiments, see Lazear (2000) and Karlan and Zinman (2009).[14] There has been recent work that uses additional instruments to identify different types of informational asymmetries without natural or field experiments (Perrigne and Vuong, 2011). A full-fledged empirical analysis is beyond the scope of the current paper, but we will describe identification strategies in the spirit of existing empirically work in other areas of economics.

To make the empirical predictions of the different models as clear as possible, we will describe results in terms of extremes, as if the models were mutually exclusive and only one model explained the data. In reality, one would assume that a combination of these models is the explanation. Then, an empirical goal would be to quantify the importance of the different effects, rather than test the hypothesis which of the models is the correct one. This approach has been taken by most of the empirical literature on adverse selection and moral hazard in other areas. Lazear (2000) finds for the labor contracts he investigates, e.g. that roughly half of the effect of incentive contracts is due to a selection effect (adverse selection) and half due to a treatment effect (moral hazard).

To simplify our exposition, we assume that firm and R&D project heterogeneity has been controlled for. Controlling for heterogeneity is a well-known – but often challenging – problem in empirical studies and has to be considered along with the specific data set that is available to the econometrician when applying our suggested identification strategies.

Identification is easiest if one has a natural or a field experiment as in Lazear (2000) and Karlan and Zinman (2009). The basic idea of such experiments adapted to our setup is that initially only contracts without a breakup date are offered. Then contracts with a breakup date are introduced in two phases. In the first phase, it is voluntary to opt-in to

[14] Lazear (2000) and Karlan and Zinman (2009) use field experiments to distinguish moral hazard and adverse selection in labor relations and consumer credit markets, respectively.

a contract with a breakup date. In the second phase, contracts with a breakup date are mandatory. Depending on whether breakup dates are used to deal with adverse selection or moral hazard or whether breakup is the result of the partners finding out that the project is non-viable, one will observe different outcomes in the different phases, e.g. in terms of the realized value of the project. Since natural or field experiments can be expected to be rare for R&D contracts, we do not describe them here, but refer the reader to Appendix C. For a more detailed description of the theory of breakup dates which serve to mitigate moral hazard, see Appendix D. Appendix E describes a model in which break up occurs because the research partners find out that the project is non-viable.

Next, we show that identification is still possible using our theory without natural or field experiments. We will describe three such identification strategies in the following. The first distinguishes between adverse selection and moral hazard on one hand and non-viability on the other hand by using data on the time until discovery. The second relies on proxies for setup costs to distinguish the effects of adverse selection, moral hazard, and non-viability. The third uses a proxy for effort to distinguish the three effects.

Hazard Rate of Discovery Given observations of the time until discovery, it is well known in the econometric literature how to estimate the hazard rate of discovery as a function of duration (see e.g. van den Berg (2001)). Given such an estimate of how the discovery rate changes over time, we can distinguish a model of a non-viable project and adverse selection.

Appendix E describes a model in which the two firms find out that the project is non-viable after some time. If break up is due to non-viability, the empirically observed discovery rate should be decreasing over time if there is a breakup date. This is because the more time passes without discovery, the more likely it is that the project is not viable (lower discovery rate). The discovery rate should be constant if there is no breakup date. The reason is that the R&D partners do not need to specify a breakup date if they are sure that the project is viable. Hence, as time passes without discovery, the posterior probability of the project being viable does not change and the discovery rate does not change either. See Appendix E for formal results.

If break up is due to adverse selection (or moral hazard), the hazard rate of discovery should be constant both for contracts with and without a breakup date. As shown in a previous version of this paper with an alternative specification of adverse selection in which screening occurs also with respect to the discovery rate, one should observe the opposite of what is observed with non-viability: for contracts with a breakup date (separating contracts) one should observe a constant discovery rate, whereas for contracts without a breakup date (pooling contracts) one should observe a decreasing discovery rate. The reason is that with a separating contract only one type of agent participates and only the constant hazard rate of this type is empirically observed. For a pooling contract, there are several types of agents; the more time passes without discovery, the more likely that the agent has a low discovery rate.

The above reasoning is based on the assumption of an exponential distribution of discoveries. While this is a widely used assumption in the applied theory literature on R&D, one can also think of setups with non-exponential distributions. In this case, the argument is slightly more involved, but similar. Instead of a constant versus decreasing discovery rate, one has to consider an approach similar to the differences in differences technique.[15]

Setup Cost Assume that a proxy for the agent's setup cost k is observable *ex post*, but it is not possible to contract on this proxy. One possible proxy for setup costs is the liquidity of a firm (or deep pockets): a low liquidity does not allow for high initial setup costs.

In the following we will argue that in the setup without commitment the following identification strategy can be used to distinguish adverse selection from moral hazard if free-riders are sufficiently rare ($\alpha_F < 1/2$). If one observes the setup costs k *ex post*, one should see that for contracts without a breakup date (pooling contracts) the variance of k is larger than for contracts with a breakup date (partially separating contracts) if adverse selection is the explanation. If moral hazard rather than adverse selection is the explanation, it should be the other way around: the variance should be larger for contracts with a breakup date.

First, observe that in the adverse selection with no commitment case (Section 4), the choice of a pooling versus a partially separating contract is independent of k_F and k_C, since the principal will always choose a partially separating contract over a pooling contract as long as it is feasible. A partially pooling contract is feasible if

$$\frac{\alpha_C(V_C - W_C^{\Delta})}{\alpha_F(W_F^{\Delta} - V_C)} =: q^* \leq 1,$$

[15]In case of non-viability, the derivative of the discovery rate with respect to time should be smaller with rather than without a breakup date. In case of adverse selection, the derivative should be smaller *without* rather than with a breakup date. For the special case of exponential distributions considered here, the larger derivative is zero and the smaller derivative is negative.

which is independent of k_F and k_C. Therefore, there is no selection effect for k_F and k_C for *potential* research partners in submarkets in which pooling contracts are preferred versus submarkets in which partially separating contracts are preferred.[16] However, there is a selection effect for k when considering *actual* (rather than potential) research partners with a partially separating contract,[17] since free-riders are less likely to be in the sample for this type of contract. There is no selection effect when considering actual research partners with a pooling contract.

Therefore, for a pooling contract (i.e. no breakup date) the agent has the setup cost k_C with probability α_C and the cost k_F with probability α_F. By the definition of the variance of a binary distribution, the variance of k is

$$\mathrm{Var}^{\text{adverse selection}}_{\text{no breakup}}[k] = \alpha_F \alpha_C (k_F - k_C)^2.$$

For a partially separating contract (i.e. with a breakup date), the probability of k_F is $q^* \alpha_F / (q^* \alpha_F + \alpha_C)$ and of k_C it is $\alpha_C / (q^* \alpha_F + \alpha_C)$ due to the selection effect, where q^* is the free-rider's probability of participating as defined in Proposition 5. Therefore, the variance is

$$\mathrm{Var}^{\text{adverse selection}}_{\text{breakup}}[k] = \frac{q^* \alpha_F \alpha_C}{(q^* \alpha_F + \alpha_C)^2} (k_F - k_C)^2$$

Denote the ratio of variances as a function of q^* as

$$X(q^*) := \frac{\mathrm{Var}^{\text{adverse selection}}_{\text{no breakup}}[k]}{\mathrm{Var}^{\text{adverse selection}}_{\text{breakup}}[k]} = \frac{(\alpha_F q^* + \alpha_C)^2}{q^*}.$$

The derivative of X is

$$X'(q^*) = \frac{\alpha_F q^* + \alpha_C}{q^{*2}} \alpha_F \left[q^* - \frac{1 - \alpha_F}{\alpha_F} \right].$$

Free-riders being sufficiently rare ($\alpha_F < 1/2$) implies $(1 - \alpha_F)/\alpha_F > 1$, which in turn implies $q^* - (1 - \alpha_F)/\alpha_F < 0$ and hence $X'(q^*) < 0$ for all q^*. Since $X(1) = 1$ and

[16] This is under the assumption that these parameters are either uncorrelated with the parameters for which there is a selection effect or that the correlated parameters can be controlled for.

[17] Comparing contracts with and without breakup dates (that is partially separating and pooling contracts) is a simplified version of a comparison of contracts with short versus long times until a breakup.

$X'(q^*) < 0$, $X(q^*) > 1$ for all q^*, which means

$$\text{Var}^{\text{adverse selection}}_{\text{no breakup}}[k] > \text{Var}^{\text{adverse selection}}_{\text{breakup}}[k],$$

for all q^*.[18]

For moral hazard a similar reasoning about the selection effect of k for potential research partners can be made as for adverse selection. A high effort inducing mixed strategy contract is feasible if

$$\frac{V_C - W_C^{\Delta}}{W_F^{\Delta} - W_C^{\Delta}} =: q_m^* \leq 1,$$

which is independent of k_F and k_C (see Appendix D for the derivation of q_m^*). Hence, there is no selection effect for k_F and k_C for potential research partners in submarkets in which low effort contracts (no breakup date) are preferred versus submarkets in which high effort contracts (breakup date) are preferred.

Since for moral hazard, all agents are ex ante identical, a contract without a breakup date will induce all agents to incur the same low effort. Therefore, all agents will have the same setup costs k_F and variance is $\text{Var}^{\text{moral hazard}}_{\text{no breakup}}[k] = 0$ in our simple binary distribution setup. A renegotiation proof contract with a breakup date will cause the agents to randomize between exerting effort and not, hence the variance of k is $\text{Var}^{\text{moral hazard}}_{\text{breakup}}[k] = q_m^*(1 - q_m^*)(k_F - k_C)^2 > 0$, where $q_m^* \in (0, 1)$ is the probability of the agent exerting low effort in the agent's mixed strategy. Therefore, for moral hazard, we have

$$\text{Var}^{\text{moral hazard}}_{\text{no breakup}}[k] < \text{Var}^{\text{moral hazard}}_{\text{breakup}}[k],$$

i.e. the opposite ordering as for adverse selection.

In case of non-viability the variance in setup costs should be the same for contracts with and without a breakup date. In our simple setup, the variance is 0, if all sources of heterogeneity are controlled for.

Note that for the sake of notational simplicity, we stated our results under the assumption that our model is the sole reason of the variance of k. However, it is straight-forward to extend these results to a setup in which there is an additional error term. For an additive error term ϵ, observed setup costs would be $k + \epsilon$ and variance $\text{Var}[k] + \text{Var}[\epsilon]$ and the above reasoning would go through with minor modifications.

[18] This inequality can also hold if $\alpha_F > 1/2$ provided that q^* is sufficiently small, since $\lim_{q^* \to 0} X(q^*) = \infty$.

Proxy of Effort Observable Assume that a proxy for effort is observable ex post, but not contractible. An example in the labor literature is Malmendier and Tate (2009), who show that after a CEO achieves superstar status, the performance of his firms becomes worse, but the ranking of the CEO in golf tournaments and the probability of him writing an autobiography increase, these being interpreted as a proxy for (the lack of) effort. Here, a similar reasoning holds as with setup costs.

Consider the case in which commitment to breakup is possible. If adverse selection is the explanation, there should be variance in effort for contracts without a breakup date (pooling contracts) and no variance in effort for contracts with a breakup date (separating contract). The reason is that in a separating contract, only committed types participate, hence there is no heterogeneity and no variance. In a pooling contract, both types participate, hence heterogeneity and variance. If moral hazard is the explanation, there should be no variance in effort for both contracts without (low effort inducing contracts) and with (high effort inducing contracts) a breakup date. The reason is that with moral hazard, agents are ex ante identical. For a contract with a breakup date, all agents exert the same level of (high) effort. For a contract without a breakup date, all exert the same low level of effort.

Both adverse selection and moral hazard imply that average effort should be higher with the contract with a breakup date. If non-viability is the explanation, then effort should be the same irrespective of whether there is a breakup date.

6 Discussion and Conclusions

In contrast to the previous literature on R&D contracts that focuses on payment schemes, our paper is the first to model an essential clause in R&D collaboration agreements — the breakup date — as a screening device. We identify the conditions under which a breakup rule becomes necessary. In essence, breakup is unavoidable if the potential partners' incentives are misaligned — the agent who has high value of the project is also less attractive for the principal. In our setup this also means that a high value of the project is linked to a high setup cost. This turns out to be particularly relevant in the biotech-pharmaceutical industry, which not only shows high popularity of R&D collaboration through contractual arrangements, but also has high occurrence of breakups. In contrast to the conventional wisdom that breakup is a loss control measure, we show that firms can use a breakup clause to screen potential partners. Breakup clauses may be attractive for the principal even if commitment to an (ex post inefficient) breakup date is not possible.

Compared with the large literature on optimal contracts under asymmetric information,[19] the theoretical analyses on the role of asymmetric information in R&D contracts are rather sparse, most of them focusing on the moral hazard problem within research joint ventures or under cross licensing agreements. A number of papers, however, have shown that first-best can still be implemented in the presence of moral hazard, see e.g. Choi (1992), Morasch (1995), and Pastor and Sandonis (2002).[20] Only a few papers focus on the adverse selection problem. Bhattacharya, Glazer, and Sappington (1992) and Gandal and Scotchmer (1993) consider adverse selection in R&D research joint ventures and show how payment schemes can be used to implement first-best in their setups. Our paper differs from theirs by providing insights on using breakup dates to screen R&D partners, an outcome that cannot be achieved through payment schemes alone.

There is very little research focusing on breakup in R&D collaborations. In fact, the theoretical literature has largely ignored the breakup clause in R&D contracts until recently.[21] Two notable exceptions are Lerner and Malmendier (2010) and Bonatti and Hörner (2011). Lerner and Malmendier (2010) argue that the right of termination when coupled with claims on a broader intellectual property right can help reduce or eliminate the moral hazard problem among the agents' research when using the principal's funding. Unlike our paper, they do not allow for endogenous breakup timing. Bonatti and Hörner's (2011) work on team collaboration touches breakup time in a wider sense, but they deal with a very different question. They provide an explanation for breakup under the assumption that there is uncertainty about the feasibility of the project and members of a collaborating team can commit ex ante to an ex post inefficient deadline. Our analysis is complementary to Bonatti and Hörner's by showing the optimality of deadlines even when there is no belief updating and even if commitment to a deadline (or breakup date) is not possible.

Nevertheless, our paper is just a first step towards a better understanding of breakup clauses in R&D contracts. In reality, the reasons for breakup could vary under different conditions, so our theory by no means is an all-inclusive explanation. Given adverse selection, moral hazard, and non-viability being the three major reasons for including a breakup

[19] See e.g. the seminal paper by Mussa and Rosen (1978) and Bolton and Dewatripont (2005) for a recent overview of the literature.

[20] An exception is Brocas (2004), who focuses on the second best contract and shows the optimal effort level may be distorted both upward and downward.

[21] Cabral (2000) shows the R&D collaboration breakup can facilitate tacit collusion among firms facing product market competition.

date, we propose several identification strategies in Section 5. Finally, because each side is very serious about negotiating a termination clause, an alternative approach is to model breakup as a signaling device by a privately informed principal. The principal may want to use a short breakup date to signal that he is committed to the project, that the project is feasible in a relatively short period of time, or that the principal is experienced in the area of research. A model of a contract that serves both to screen the agent and to signal the principal's type is a technically challenging, yet potentially rewarding, avenue for further research.[22]

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Appendix

A Proof of Proposition 3

Proof. We can rewrite the objective function (2) as

$$\alpha_C W_A + \alpha_F W_A^F - \left\{ \min_{S_C, p_C, S_F, p_F} \alpha_C W_C^{\Delta} p_C + \alpha_C S_C + \alpha_F W_F^{\Delta} p_F + \alpha_F S_F \right\}$$

Because $\alpha_C W_A + \alpha_F W_A^F$ is a constant, we focus on the following linear programming problem

$$\begin{aligned} \gamma_P \quad = \quad & \min_{S_C, p_C, S_F, p_F} \alpha_C W_C^{\Delta} p_C + \alpha_C S_C + \alpha_F W_F^{\Delta} p_F + \alpha_F S_F \\ & \text{s.t. } (3) - (7) \end{aligned}$$

The dual of this problem is

$$\begin{aligned} \gamma_D \quad = \quad & \max k_C y_1 + k_F y_2 - y_5 - y_6 \\ & \text{s.t.} y_1 + y_3 - y_4 = \alpha_C & (9) \\ & y_2 - y_3 + y_4 = \alpha_F & (10) \\ & V_C y_1 + V_C y_3 - V_F y_4 - y_5 \leq \alpha_C W_C^{\Delta} & (11) \\ & V_F y_2 - V_C y_3 + V_F y_4 - y_6 \leq \alpha_F W_F^{\Delta} & (12) \\ & y_1, y_2, y_3, y_4, y_5, y_6 \geq 0 \end{aligned}$$

(9) and (10) imply

$$y_1 + y_2 = \alpha_C + \alpha_F = 1 \Rightarrow y_2 = 1 - y_1$$

Furthermore, we must have $y_5 = 0$, otherwise, by the complementary slackness theorem (see Theorem 4.10 in Vohra (2005)), we must have $p_C = 1$, which leads to a contradiction because we then have $p_F > p_C = 1$.

Substituting $y_2 = 1 - y_1$, $y_4 = y_1 + y_3 - \alpha_C$ and $y_5 = 0$ into (11) and (12) and simplifying the expressions, we have

$$
\begin{aligned}
y_1 &\geq \alpha_C \frac{V_F - W_C^{\Delta}}{V_F - V_C} - y_3 \\
y_6 &\geq \alpha_F \left(V_F - W_F^{\Delta}\right) + \left(V_F - V_C\right) y_3.
\end{aligned}
$$

Note that the objective function in the dual becomes

$$
\begin{aligned}
\gamma_D &= k_F - \left(k_F - k_C\right) y_1 - y_6 \\
&\leq k_F - \left(k_F - k_C\right) \left(\alpha_C \frac{V_F - W_C^{\Delta}}{V_F - V_C} - y_3\right) - \left[\alpha_F \left(V_F - W_F^{\Delta}\right) + \left(V_F - V_C\right) y_3\right] \\
&\leq k_F - \left(k_F - k_C\right) \alpha_C \frac{V_F - W_C^{\Delta}}{V_F - V_C} - \alpha_F \left(V_F - W_F^{\Delta}\right).
\end{aligned}
$$

The last inequality follows from $V_F - V_C > k_F - k_C$ as implied by Condition 1. By the Weak Duality Theorem (see Vohra (2005)), we must have $\gamma_D \leq \gamma_P$, which implies the principal's optimal profit, Π_{sep}, must satisfy

$$
\Pi_{\text{sep}} \leq \alpha_C W_A^C + \alpha_F W_A^F - \left[k_F - \left(k_F - k_C\right) \alpha_C \frac{V_F - W_C^{\Delta}}{V_F - V_C} - \alpha_F \left(V_F - W_F^{\Delta}\right)\right].
$$

From Proposition 1, we have

$$
\Pi_{\text{single}} = \alpha_C (W_C + W_C^{\Delta} - k_C + (V_C - W_C^{\Delta}) \frac{k_F - k_C}{V_F - V_C}) + \alpha_F (W_A^F - k_A).
$$

Hence

$$
\Pi_{\text{single}} - \Pi_{\text{sep}} \geq \alpha_F \left(k_F - k_A\right) - \alpha_F \left(V_F - W_F^{\Delta}\right) > 0,
$$

where the last inequality follows from Assumption 1. This completes the proof. ■

B Multidimensional Analysis

Our analysis reflects the general notion in contract theory that clauses in contracts are used to solve a problem stemming from a misalignment of incentives between the principal and the agent. Here the misalignment is due to the fact that cooperation with a committed agent is more attractive for the principal (Assumption 1), but a free rider is more inclined to cooperate than a committed agent (Condition 1). An implication of Assumption 1 and Condition 1 is that a single-crossing condition holds: for a probability of completion $p \geq p^*_{\text{single}}$, the private benefits of the free-rider are larger than those of the committed agent; for $p \leq p^*_{\text{single}}$, the opposite holds. This also means that the committed agent has a lower value of participating in the project ($V_C < V_F$) and a lower opportunity cost ($k_C < k_F$). This may be seen as a special case of the following two-dimensional setup: the agent may have high or low opportunity costs $k_H > k_L$, and may be a free-rider or a committed agent with $V_C < V_F$. Our one dimensional setup can be viewed as considering two extremes: when Condition 1 does not hold (as analyzed in Proposition 1) V and k are perfectly negatively correlated (the two possible types are (V_C, k_H) and (V_F, k_L)); when Condition 1 does hold (as analyzed in the rest of the paper) V and k are perfectly positively correlated (the two possible types are (V_C, k_L) and (V_F, k_H)). One may wonder how results carry over to a setup beyond the extremes, when correlation is neither -1 nor $+1$. This requires us to consider a multidimensional screening setup. Given that multidimensional screening is known to be a very difficult and tedious problem, we provide numerical results that show that breakup may be necessary even if V and k are negatively, but not perfectly, correlated.

We spell out the details of the two-dimensional setup in the following. One dimension is whether the agent is a free-rider or a committed type (F/C) and the other whether he has a high or a low outside option (H/L). If the agent's type is $(i, j) \in \{F, C\} \times \{H, L\}$, the agent's net present value of completing the project is $V_i = (\lambda_T v_i - \varepsilon_i)/(r + \lambda_T)$ and its outside option k_j. The principal's payoff is $W_i = (\lambda_T w_i - 1)/(r + \lambda_T)$ when cooperating and $W^j_A = (\lambda w^j_A - 1)/(r + \lambda)$ when conducting the research alone. Note that firm A's payoff from R&D collaboration depends on whether B is of type C or type F, because a committed type contributes to the project and increases its value. On the other hand, firm A's payoff from carrying out the research alone depends on firm B's outside option: a free-rider has a competing product, making the development alone may lead to a product which faces tough competition, such as it is the case of Airbus's superjumbo jet competing with Boeing's 747 or dreamliner.

Denote the probability of type ij as α_{ij}. Let p_{ij} and S_{ij} be the probability of completion and the transfer designed for type ij. The principal's profit is $W_A^j - k_A$ when conducting the research alone, and $p_{ij}W_i + (1-p_{ij})W_A^j - S_{ij}$ when cooperating with type ij.

Firm A can offer a menu of contracts which induces types $(i,j) \in P \subset \{F,C\} \times \{H,L\}$ to participate. Type ij gets the up-front payment S_{ij} and the probability of completion p_{ij}. The four individual rationality constraints are $U_{ij}^* \geq 0$ for all $(i,j) \in \{F,C\} \times \{H,L\}$, where $U_{ij}^* = U_{ij}(S_{ij}, p_{ij})$ if $(i,j) \in P$ and $U_{ij}^* = 0$ else. The twelve incentive compatibility constraints are $U_{ij}^* \geq U_{ij}(S_{i'j'}, p_{i'j'})$ for all $(i,j) \in \{F,C\} \times \{H,L\}$ and $(i',j') \in P$, $(i',j') \neq (i,j)$.

A naive direct approach would be to check all combinations of the twelve constraints being binding or not (i.e. 2^{16} combinations) and do this procedure for all 15 non-empty subsets P of the type space. While the computational burden could be somewhat reduced by a more sophisticated approach, it would still be too much. We therefore solve the problem numerically for different parameter values.

We take as initial values $W_C = 16$, $V_C = 10$, $W_A^L = 17$, $k_L = 8$, $W_F = 8$, $V_F = 16$, $k_H = 12$, $W_A^H = 32$, $k_A = 0$. We compute the optimal contract for different values of the probability of the agent being committed α_C and the affiliation parameter ϕ, which determines the probabilities of types $\alpha_{LC} = \alpha_C\phi$, $\alpha_{HF} = (1-\alpha_C)\phi$, $\alpha_{HC} = \alpha_C(1-\phi)$, and $\alpha_{LF} = (1-\alpha_C)(1-\phi)$. The random variables V and k are affiliated if

$$\alpha_{FH}\alpha_{CL} \geq \alpha_{CH}\alpha_{FL}$$

see e.g. Krishna (2009, Appendix D). For our specification, this condition is equivalent to $\phi \geq \frac{1}{2}$. For $\phi < \frac{1}{2}$, they are anti-affiliated. Affiliation implies correlation, since

$$\rho = \text{Corr}(V,k) = 2\left(\phi - \frac{1}{2}\right)\sqrt{\frac{\alpha_C(1-\alpha_C)}{\alpha_H(1-\alpha_H)}},$$

where $\alpha_H = \alpha_C(1-\phi) + (1-\alpha_C)\phi$ is the unconditional probability of k_H. V and k are positively correlated ($\rho > 0$) if $\phi > \frac{1}{2}$ and negatively correlated if $\phi < \frac{1}{2}$. The two cases analyzed in the main text are perfect positive correlation ($\phi = 1$ which implies $\rho = 1$) and perfect negative correlation ($\phi = 0$ which implies $\rho = -1$).

We solve the linear programming problem numerically for each of the possible subsets P, compute the optimal contract, and check whether the optimal contract includes a breakup date. We repeat this procedure for each value of (α_C, ϕ) on a 100×100 grid on $[0,1] \times [0,1]$. This procedure in turn we repeat for different initial parameter values. Results are reported in Figures 2 and 3. Figure 2 presents the optimal contract for different parameter values. The case with initial parameters is represented in the lower right of Figure 2, where area (i) indicates the optimal contract induces types $\{CL, FL\}$ to participate while area (ii) indicates the optimal contract induces types $\{CL, FL, HF\}$. Figure 2 shows that for the majority of values of $\alpha_C \in [0,1]$ and $\phi \in [0,1]$, the principal collaborates with firms having low outside option only unless the principal's payoff from collaboration or from conducting research alone are high enough, which are illustrated in cases (d) and (g). Figure 3 shows in which regions breakup is necessary. As shown in panels (d), (g), and (i) of Figure 3, breakup is more likely to occur in general if α_C and ϕ are large. However, for α_C sufficiently close to one, the principal prefers to let type FH enter and to drop the breakup clause.

Figure 3 also shows that perfect positive correlation between V and k is not necessary to have a breakup date. Breakup may even occur if correlation is (imperfectly) negative ($\phi \in (0, \frac{1}{2})$), i.e. incentives are imperfectly aligned.

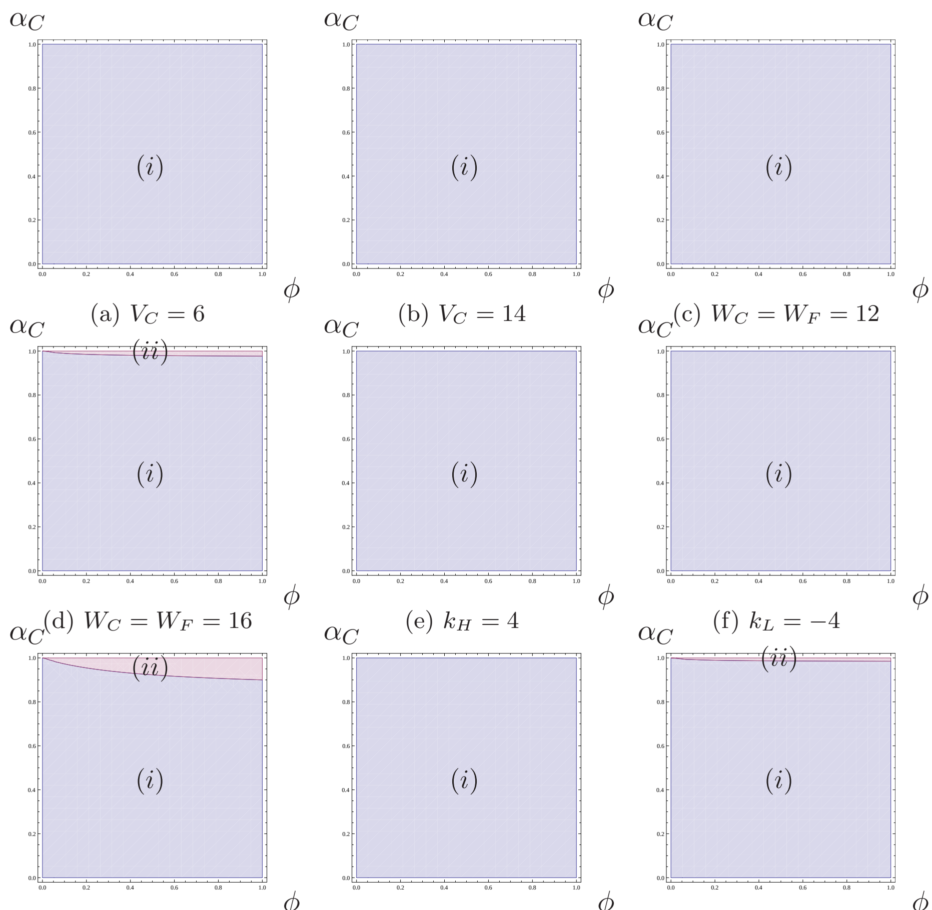
C Identification with Natural or Field Experiment

First, we explain how a natural experiment (similar to the one described by Lazear (2000) for labor contracts) would distinguish the role of termination date as the result of adverse selection or moral hazard. Suppose the principal is a firm that conducts many R&D collaborations with different firms. Assume that initially, only contracts without breakup dates are offered. This may be because a firm (that can be seen as the principal) has a general policy of not including breakup dates in contracts.[23] As Lazear (2000) suggests, this initial contract may not be optimal.[24]

The experiment is divided into two stages. At the first stage, cooperation partners are

[23]Lacetera (2009) observes that when an R&D collaboration involves partnering with academic institutions, the contract offered by the industry firm often does not include a termination date, although this lack of termination date may be endogenous. For the experiment we described below, we assume the lack of breakup dates is exogenous. Alternatively, there may be legal restrictions, such as the termination clause that specifies the breakup dates is deemed unenforceable by courts. For example, an Ontario court in Canada recently ruled that the termination clause in an employment contract in *Wright v. The Young and Rubicam Group of Companies* is unenforceable.

[24]It may be that the initial contract was optimal at some point in the past, but circumstances changed and the principal has not adapted to the change yet.

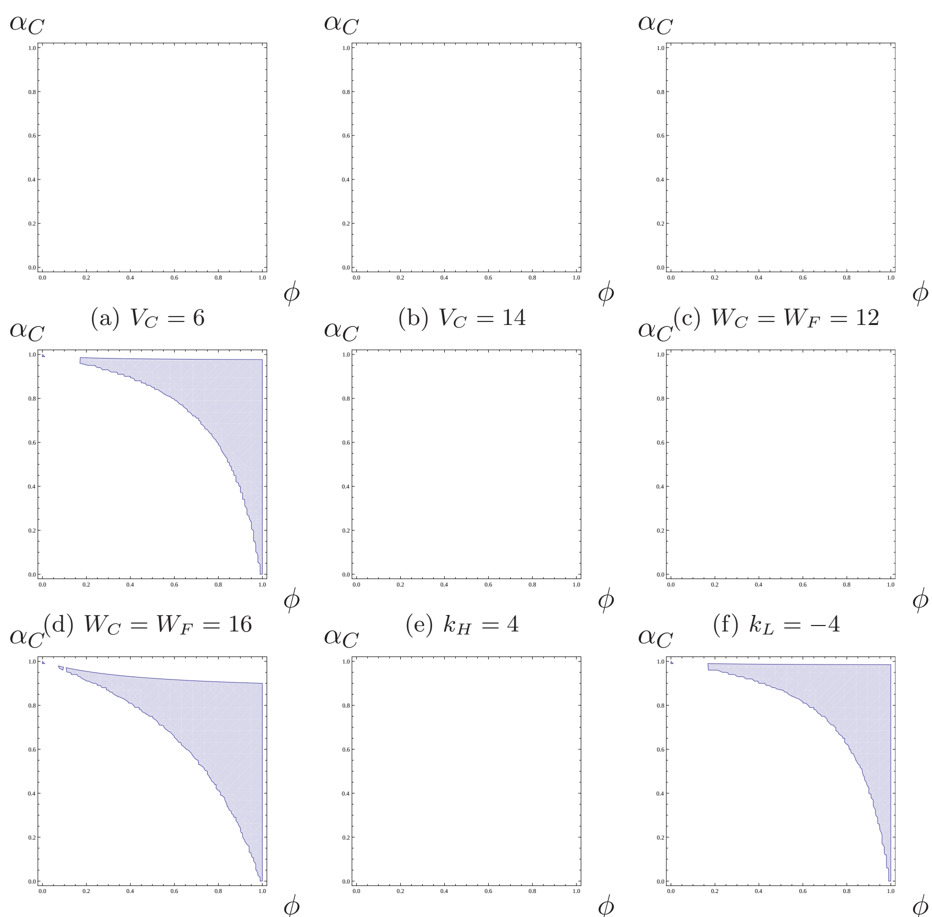


(a) $V_C = 6$ (b) $V_C = 14$ (c) $W_C = W_F = 12$

(d) $W_C = W_F = 16$ (e) $k_H = 4$ (f) $k_L = -4$

(g) $W_A^L = W_A^H = 24$ (h) $W_A^L = W_A^H = 32$ (i) Initial parameters set

Figure 2: Optimal contract for different parameter values and different values $\phi \in (0, 1)$ and $\alpha_C \in (0, 1)$. Initial parameter set $W_C = 16$, $V_C = 10$, $W_A^L = 17$, $k_L = 8$, $W_F = 8$, $V_F = 16$, $k_H = 12$, $W_A^H = 32$, $k_A = 0$. Probabilities of types $\alpha_{CL} = \alpha_C \phi$, $\alpha_{FH} = (1-\alpha_C)\phi$, $\alpha_{CH} = \alpha_C(1 - \phi)$, and $\alpha_{FL} = (1 - \alpha_C)(1 - \phi)$. In region (i) the optimal contract induces types $\{CL, FL\}$ to participate, in region (ii) types $\{FH, FL, CL\}$.



(a) $V_C = 6$ (b) $V_C = 14$ (c) $W_C = W_F = 12$

(d) $W_C = W_F = 16$ (e) $k_H = 4$ (f) $k_L = -4$

(g) $W_A^L = W_A^H = 24$ (h) $W_A^L = W_A^H = 32$ (i) Initial parameters set

Figure 3: Regions in which breakup is necessary for different parameter values and different values $\phi \in (0,1)$ and $\alpha_C \in (0,1)$. Initial parameter set $W_C = 16$, $V_C = 10$, $W_A^L = 17$, $k_L = 8$, $W_F = 8$, $V_F = 16$, $k_H = 12$, $W_A^H = 32$, $k_A = 0$. Probabilities of types $\alpha_{CL} = \alpha_C\phi$, $\alpha_{FH} = (1-\alpha_C)\phi$, $\alpha_{CH} = \alpha_C(1-\phi)$, and $\alpha_{FL} = (1-\alpha_C)(1-\phi)$.

offered the possibility to opt into a contract with a breakup date. Partners that do not wish to have a breakup date can keep their initial contract. Call partners that opt into the new contract type 1 firms and firms that stay in the initial contractual arrangement type 0 firms. Types 1 and 0 are the committed and the free-rider types when adverse selection is the underlying reason as our theory models. Alternatively, if the underlying reason is moral hazard, then type 1 and 0 are the non-shirking and shirking firms respectively.

At the second stage, the contract with a breakup date is compulsory for all partners. To keep the analogy to Lazear's experiment, assume that the firms that did not wish to opt into the new contract in the first stage are paid enough to be willing to participate. The reasoning is similar, but slightly different if they choose not to cooperate any more at the second stage.

We will describe the empirical observations that one should make given the different theories.

Adverse Selection In case of adverse selection type 1 firms are the committed types that self-select into the new contract. Type 0 firms are free-riders. One observes the outcomes of the R&D cooperations with the partners in the first stage. For type 1 firms, the value of the discovery of the project is higher on average than for type 0 firms. (Particularly in our model, collaboration with a type 1 firm increases the joint value of the project but collaboration with a type 0 firm decreases the joint value of the project.) Controlling for other factors that affect the value of the project, if the econometrician observes the values of discovery in past cooperations with the same partners, the value of discovery changes neither for types 1 nor 0, it is only a selection effect. In the second stage, when contracts with breakup dates are compulsory, the value of discovery is still unchanged for both types 1 and types 0, since in an adverse selection setup only the inherent type of the agent, which does not change in both stages, affects output.

Moral Hazard If moral hazard is the explanation and adverse selection plays no – or only a negligible role – the following should be observed. Assume that at the first stage, the new contract is such that the partners are just indifferent between the new and the old contract in case there is no heterogeneity between partners. Then partners randomize whether to accept the new contract or not. Alternatively, there might be some small (almost negligible) heterogeneity, so that partners self-select according to small type differences (purification argument). The breakup date gives type 1 firms an incentive to exert effort, whereas type

0 firms do not have an incentive to exert effort. Therefore, the value of discovery for type 1 firms is larger than at the initial stage, whereas for type 0 firms it remains the same. At the second stage, after the new contract becomes compulsory for both types, the value of discovery stays the same for type 1 firms as in the first stage, since they still have the same incentives to exert effort. For type 0 firms, however, there is a change, since now they face the same contract as type 1 firms and have the same incentives for effort. Therefore, the realized value of the project increases to the level of the value for type 1 firms. (Or slightly below their average value, if there is a small selection effect.) See Appendix D for a formal treatment of moral hazard in our context.

Non-viability An alternative explanation is that the two firms involved in the cooperation find out that the cooperation is not fruitful, either because no discovery is to be expected in general or because cooperation between the two parties does not work. For this explanation, the changes of contracts will not have an effect on the value of discovery.[25] See Appendix E for a formal treatment of a model of a potentially non-viable project.

Table 1 summarizes the identification strategy through the two-stage experiment discussed above. Alternatively, one can also think of the following natural experiment – instead of two stages, there are a control group and two treatment groups. The partners in the control group only are offered a contract without a breakup date, partners in the first treatment group (corresponds to first stage) can choose between a breakup date and no breakup date, partners in the second treatment group (corresponding to the second stage) have to accept a contract with a breakup date. Such an experiment is less informative, since in the second treatment group one cannot distinguish who would have chosen a contract with a breakup date if it were voluntary. But the theories are still empirically distinguishable: in case of adverse selection, the average value of the discovery is the same for the two treatment groups and lower for the control group. Further, in the first treatment group, the average value is higher for type 1 than 0. In case of moral hazard, the average value should be higher for the first treatment group than in the control group. The average value should be even higher for the second treatment group. Types 1 in the first treatment group should have the same average value as partners in the second treatment group. For the non-viability, there should be no difference between treatment and control

[25] A second hypothesis that would generate the same empirical predictions is that the principal uses the breakup date to signal his type. For this hypothesis, the breakup date has no effect on the value of discovery either.

hypothesis	first step type 1	0	second step type 1	0
adverse selection	+	0	+	0
moral hazard	+	0	+	+
non-viable project	0	0	0	0

Table 1: Effects on the value of the project compared to original outcome (or: compared to control group).

groups.

D Moral Hazard

It is well known in the contract theory literature that hidden action and hidden information are very similar. The same (or a similar) incentive scheme can both serve to screen out undesired types and to induce agents to exert effort.

A logic very similar to our adverse selection setup can be applied to derive results for moral hazard. In the following we describe a setup in which a breakup date in a contract is used to solve a moral hazard problem. For the sake of simplicity and comparability, we keep this setup as similar as possible to the adverse selection setup in the main text. In particular, assume the agent can decide whether to put in effort (which means he becomes committed, C) or not to put in effort (i.e. he becomes a free-rider, F). The agent makes the decision once at the beginning after the contract was signed and cannot change the decision later on. Similarly to before, denote net present values of discovery by V_C, W_C, W_C^{Δ}, W_A^C and setup costs by k_C in case the agent decided to exert effort. In case of no effort, let these values be denoted by V_C, W_C, W_C^{Δ}, W_A^C, k_F.

If the agent exerts effort $i = C, F$, the principal's profit is $pW_i + (1-p)W_A^C - S$ and the agent's utility $pV_k - k_i + S$, where p is the probability of completing the project and S the transfer to the agent. There are two types of contracts: high-effort contracts that induce the agent to exert effort and low effort contracts which induce the agent to exert low effort. Note that only one contract is needed, since there is only one (ex ante) type of agent. Further, a low effort contract may be profitable if the cost of inducing effort is too high.

For the high effort contract, the principal's maximization problem is

$$\begin{aligned} \max_{p,S} \quad & pW_C + (1-p)W_A^C - S \\ \text{s.t.} \quad & S + pV_C - k_C \geq S + pV_F - k_F \\ & S + pV_C - k_C \geq 0 \end{aligned}$$

where the first constraint makes sure that the agent exerts effort (incentive compatibility) and the second makes sure he is willing to participate (individual rationality). Solving the incentive compatibility constraint for p yields

$$p^* = \frac{k_F - k_C}{V_F - V_C}.$$

Using p^* in the individual rationality constraint yields

$$S^* = -p^* V_C + k_C.$$

For the low incentive contract, the maximization problem is

$$\begin{aligned} \max_{p,S} \quad & pW_F + (1-p)W_A^F - S \\ \text{s.t.} \quad & S + pV_F - k_F \geq 0. \end{aligned}$$

Note that there is no incentive compatibility constraint in this case, since the principal is not trying to induce the agent to exert effort. Choosing S such that the individual rationality constraint is just binding, $S = k_F - pV_F$, and plugging this into the principal's profit function yields $W_A^F - p(W_F^\Delta - V_F) - k_F$. Since profits are linear in p, the principal's maximization problem has a bang-bang solution: $p = 1$ if $W_F^\Delta > V_F$ and $p = 0$ if $W_F^\Delta < V_F$. Under Assumption 1, the latter is the case and breakup occurs immediately.

The comparison of profits under high effort and low effort

$$W_A^C + p^*(V_C - W_C^\Delta) - k_C > W_A^F - k_F$$

can be rearranged to

$$(1 - p^*)(V_C - W_C^\Delta) < (W_C + V_C - k_C) - (W_A^F - k_F).$$

The left hand side is the efficiency loss due to early breakup and the right hand side is the efficiency gain because of high effort. If the latter is larger, a breakup clause is profitable.

No Commitment We can make a similar reasoning as for adverse selection when considering the additional constraint that contracts have to be renegotiation proof.

One can make a similar argument as before that the standard high effort contract is not renegotiation proof. Consider the breakup date, at which the agent's setup costs k_C are already sunk. This means that the principal's maximization problem at the breakup date is

$$\begin{aligned} \max_{p,S} \quad & pW_C + (1-p)W_A^C - S \\ \text{s.t.} \quad & S + pV_C \geq 0, \end{aligned}$$

where p is the probability of completing the project after the breakup date given by the contract and S are additional transfers. Setting the agent indifferent ($S = -pV_C$), the principal's profit is $pW_C + (1-p)W_A^C + pV_C = W_A^C + p(V_C - W_C^\Delta)$. By Assumption 1, profits are increasing in p, i.e. the principal would prefer renegotiating the contract once breakup is due. Therefore, the threat of breakup is not credible at the initial contracting stage.

As for adverse selection, the solution concept from Bester and Strausz (2001) can be used. The contract is such that the agent is indifferent between exerting high or low effort and randomizes such that the principal is indifferent between continuing after the breakup date or not. We formalize this in the following. Denote the agent's probability of exerting low effort as q. The principal's maximization problem at the breakup date is

$$\begin{aligned} \max_{p,S} \quad & (1-q)(pW_C + (1-p)W_A^C) + q(pW_F + (1-p)W_A^F) - S \\ \text{s.t.} \quad & S + pV_F \geq 0 \\ & S + pV_F \geq 0 \end{aligned}$$

By Assumption 1 and Condition 1, $V_F \geq V_C$, so that the individual rationality constraint of the agent that had exerted high effort will be made binding. Therefore, $S = -pV_C$. Plugging S into the principal's profits and rearranging yields

$$(1-q)W_A^C + qW_A^F + p\left[(1-q)(V_C - W_C^\Delta) + q(V_C - W_F^\Delta)\right].$$

The principal has no incentive to renegotiate ($p^* = 0$) if the expression in square brackets in (weakly) negative. This is the case if $q \geq q_m^*$, where

$$q_m^* = \frac{V_C - W_C^\Delta}{W_F^\Delta - W_C^\Delta}.$$

A renegotiation proof high effort contract is feasible if $q_m^* \leq 1$. Note that the minimal probability of not exerting effort q_m^* for moral hazard is similar to the minimal probability of free-riding types participating for adverse selection $q^* = [\alpha_C(V_C - W_C^\Delta)]/[\alpha_F(W_F^\Delta - V_C)]$ (see Proposition 5).

Profits with the renegotiation proof contract with a breakup date are larger than with a contract without a breakup date if

$$(1 - q_m^*)(W_A^C + p^*(V_C - W_C^\Delta) - k_C) + q_m^*(W_A^F + p^*(V_F - W_F^\Delta) - k_F) > W_A^F - k_F$$

which can be rearranged to

$$(1 - q_m^*)(W_A^C - W_A^F) + k_F - k_C > 0.$$

For $W_A^C \geq W_A^F$,[26] this condition always holds under Assumption 1, i.e. the principal always prefers a contract with a breakup date, given that a renegotiation proof breakup date is feasible.

E Viability of Project

In addition to adverse selection and moral hazard, a third explanation of breakup (and of breakup dates in contracts) is that the firms find out that the project is non-viable.[27] One possibility is that it is non-viable in general. This explanation would clearly predict different empirical observations, since we should not observe that firms conduct research on their own, after breaking up with their research partner (as it was observed for the example of Airbus and Boeing). In other words, conditional on that the project was

[26] We have not made any assumptions on the relative magnitudes of W_A^C and W_A^F. However, it appears reasonable to assume that developing the product alone after having terminated the contract with a committed (high effort) agent is more profitable than after a breakup with a (low effort) free-rider.

[27] In general, firms may never find out whether the project is viable or not unless the project is successfully developed. See Besanko and Wu (2013) for a theory of R&D cooperation when the project viability is unknown.

developed successfully, the reason of breakup is limited to either adverse selection or moral hazard. Therefore, the identification strategy for adverse selection versus moral hazard described in Section 5 can be used if the project is potentially non-viable in general.

Another model of non-viability is that the research project is viable, but not by the two firms cooperating together. It could be, for example, that the research cultures of the two firms are incompatible, so that working together is an obstacle rather than a help. The project may be viable after breakup. We will consider a model in more detail, which includes both cases: the project not being continued after breakup and only one firm continuing after breakup.

Take the simplest model of non-viability. With probability α the project is viable together and the discovery rate is λ_T. With probability $1-\alpha$ it is non-viable together and the discovery rate is 0. Denote the discovery rate in case A continues the project alone as λ. For the special case $\lambda = 0$, if the project is not viable together, it is not viable by A alone either. Assume for the sake of simplicity that there is no private information whatsoever, so that the two firms maximize joint profits. Denote the joint profit in case of discovery w and the joint effort ϵ. By a similar argument as before, if the project is viable, joint profits are

$$\begin{aligned}
&\left[\int_0^T \lambda_T e^{-\lambda_T t}\left(e^{-rt}w - \epsilon\int_0^t e^{-r\tau}\,d\tau\right)dt\right] \\
&+\left[\left(\int_T^\infty \lambda_T e^{-\lambda_T t}dt\right)\left(-\epsilon\int_0^T e^{-r\tau}\,d\tau + \max\left\{0, e^{-rT}\left(\int_0^\infty \lambda e^{-\lambda x}\left(e^{-rx}w_A - \epsilon\int_0^x e^{-r\tau}\,d\tau\right)dx\right)\right\}\right)\right] \\
&= W_V + W_V^\Delta e^{-(r+\lambda_T)T}
\end{aligned}$$

where $W_V = (\lambda_T w - \epsilon)/(r+\lambda_T)$ is the expected net present value of A and B conducting research together without a deadline, $W_A = \max\{0, (\lambda w_A - \epsilon)/(r+\lambda)\}$ is the expected net present value of A conducting the project alone, and $W_V^\Delta = W_A - W_V$ is the difference between the two. The $\max\{0,\cdot\}$ expression is due to the fact that A may choose not to continue the project alone if this were to generate a negative net present value (i.e. if $(\lambda w_A - \epsilon)/(r+\lambda) < 0$, a sufficient condition for this is $\lambda = 0$).

If the project is non-viable, the parties incur effort costs, without a discovery ever realizing from their cooperation and then A conducts the research alone (if $W_A > 0$) or completely discontinues the project (if $W_A = 0$), which means a profit

$$
\begin{aligned}
&-\epsilon \int_0^T e^{-r\tau}\,d\tau + \max\left\{0, e^{-rT}\left(\int_0^\infty \lambda e^{-\lambda x}\left(e^{-rx}w_A - \epsilon\int_0^x e^{-r\tau}\,d\tau\right)dx\right)\right\}\\
&= W_N + W_N^\Delta e^{-rT}
\end{aligned}
$$

where $W_N = -\epsilon/(r+\lambda_T)$ is the expected net present value of A and B conducting research together without a deadline and $W_N^\Delta = W_A - W_N$ is the difference between A conducting the research alone and with B in case of non-viability.

The consortium chooses the breakup date such that it maximizes profits:

$$
\max_T \alpha\left(W_V + e^{-(r+\lambda_T)T}W_V^\Delta\right) + (1-\alpha)\left(W_N + e^{-rT}W_N^\Delta\right).
$$

Solving the first order condition, one gets the optimal breakup date

$$
T^* = \frac{1}{\lambda_T}\ln\left(\frac{-W_V^\Delta\alpha(r+\lambda_T)}{W_N^\Delta(1-\alpha)r}\right)
$$

If the probability of viability is $\alpha = 1$, then breakup never occurs $T^* = \infty$. (Or, if the probability of viability is close to 1, never breaking up is close to optimal.) If $W_A > 0$, A continues the project alone after breakup. If $W_A = 0$, A does not continue. This provides an alternative explanation for breakup clauses in contracts: after having no discovery for a longer time, it is very likely that the project is not viable (together), hence continuing (together) does not pay off.

We can also make a statement about how the hazard rate of discovery evolves over time. Observe that the probability that no discovery has been made up to some time t if the project is viable (hazard rate λ_T) is $e^{-\lambda_T t}$. If the project is non-viable (hazard rate 0), the probability is 1. Given the prior belief α that the project is viable, by Bayes law the posterior belief that the project is viable if no discovery was made after time t is

$$
\tilde{\alpha}(t) = \frac{\alpha e^{-\lambda_T t}}{\alpha e^{-\lambda_T t} + (1-\alpha)1}.
$$

One can show that for $\alpha \in (0,1)$ the posterior probability is decreasing in time, i.e. $\tilde{\alpha}'(t) < 0$, and for $\alpha = 1$, the posterior probability is constant, i.e. $\tilde{\alpha}'(t) = 0$.

The observed hazard rate at time t is $\tilde{\lambda}_T(t) = \tilde{\alpha}(t)\lambda_T + (1-\tilde{\alpha}(t))0$. By the properties of $\tilde{\alpha}'$, the observed hazard rate is decreasing over time, i.e. $\tilde{\lambda}'_T(t) < 0$, if $\alpha \in (0, 1)$, and constant, i.e. $\tilde{\lambda}'_T(t) = 0$, if $\alpha = 1$. Note that this holds no matter whether $W_A = 0$ or $W_A > 0$.