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ABSTRACT

In this paper, we develop a theoretical model of university licensing to explain why university license contracts often include payment types that differ from the fixed fees and royalties typically examined by economists. Our findings suggest that milestone payments and annual payments are common because moral hazard, risk sharing, and adverse selection all play a role when embryonic inventions are licensed. Milestones address inventor moral hazard without the inefficiency inherent in royalties. The potential for a licensee to shelve inventions is an adverse selection problem which can be addressed by annual fees if shelving is unintentional, but may require an upfront fee if the firm licenses an invention with the intention to shelve it. Whether the licensing contract prevents shelving depends in part on the university credibly threatening to take the license back from a shelving firm. This supports the rationale for Bayh-Dole march-in rights but also shows the need for the exercise of these rights can be obviated by contracts.

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1 Introduction

In this paper we address the disparity between theories of licensing which focus on simple upfront fees and royalties and recent empirical evidence on contracts. Several surveys show that additional fees, such as those paid annually as well as fees paid when technical or business milestones are reached, are common [Edwards *et al.* 2003, Thursby *et al.* 2001, and Agrawal and Cockburn 2006]. Existing theories cannot explain either the prevalence of annual fees and milestone payments or the fact that they are typically combined with upfront fees and royalties.

We construct a model of university patent licensing in order to examine when, if ever, it is optimal to include annual fees and/or milestone payments in a license contract. This is an ideal setting in which to examine these contract terms, as commercialization of university inventions often requires inventor and licensee effort in development, neither of which is observable. The need for inventor effort presents a moral hazard problem because inventors may "shirk" if they prefer research to development. The need for licensee effort suggests a problem with adverse selection since firms may "shelve" inventions either because their intent in licensing is simply to block other firms from developing them or, more innocently, because by the time development is completed expected profits are less than originally anticipated. While inventor moral hazard has been studied, albeit in the context of royalties or equity [Jensen and Thursby 2001], shelving by licensing firms has not.[1] Since the intent of laws allowing university ownership of inventions, such the US Bayh-Dole Act and Bayh-Dole-inspired legislation in Europe [Verspagen 2006], is to promote commercialization, this is an important oversight.

We consider the problem of a Technology Licensing Office (TLO) with the responsibility for designing and offering an exclusive license contract to a firm that has expressed interest in developing an invention owned by the university. The invention requires further inventor and licensee collaboration in technical development, as well as licensee investment in commercialization. Importantly, we allow for the possibility of contracts with payments based on events or quantities the TLO can observe (contract acceptance, technical and commercial success, and output). In this context, we analyze the role that different payment types play in extracting rents as well as providing appropriate incentives to the inventor and the firm.

Assuming risk neutrality, if incentive provision is not an issue, a simple upfront fee is optimal. On the other hand, if inventor effort is not observable (but absent of any concern with shelving) the TLO's optimal offer includes payments contingent on technical success and possibly an upfront fee. However, the optimal contract does

[1] Macho-Stadler *et al.* [2007] examine shelving by the TLO as a device to improve the quality of inventions licensed.

not include a royalty because it would distort the firm's output. Hence, when the licensee is genuinely interested in developing the invention, risk aversion on the part of the TLO and the firm are necessary for optimal contracts to include an upfront fee and a royalty, although it is not sufficient. With licensee risk aversion, an optimal contract may include an upfront fee, payments contingent on technical success (such as milestone payments), and an output royalty.

We then examine the problem when, in the course of development, the licensee may learn that although the invention works, the opportunity cost of investing in its commercialization is higher than anticipated. In equilibrium, contracts include annual fees to induce such licensees to return the license so that it can be offered to a firm with lower expected costs of commercialization. We also introduce the possibility of a firm licensing the invention with the intent to shelve rather than develop it. We show that upfront fees may serve a different purpose here than they do in an environment in which shelving is not considered a problem (where they merely extract rents or spread risk). Finally, we show that payments that depend on technical success can address the shelving problem when used in conjunction with a credible threat to license to another firm if the licensee fails to meet technical milestones defined in the contract.

These results contribute to the extensive theoretical literature on licensing which has focused primarily on simple contracts involving fixed fees and royalties, with little attention paid to milestones (see Kamien [1992] for a review). Exceptions are Arora [1995] and Bousquet *et al.* [1998] who discuss the role of state-contingent fees in the transfer of tacit knowledge and risk sharing, respectively. By largely ignoring issues related to licensing of inventions that require further development, this literature is unable to explain the complications that arise in university licensing. For example, in Bousquet *et al.* [1998] milestones are impractical for risk sharing since there are no development milestones in their model. In Macho-Stadler *et al.* [1996], Jensen and Thursby [2001], and Choi [2001], development is a single stage process. The only evidence of success is the firm's output, so that output royalties arise naturally as a success-contingent form of payment. By contrast, when early stage inventions are licensed, milestones are not only feasible but also may be easier to define than royalties.[2] Furthermore, although, as these studies show, royalties can address inventor moral hazard, we show that milestone payments are preferable since they don't distort output.

Our most novel results pertain to the adverse selection problem that arises from shelvers having private information about their intent. Prior studies find that licensor and/or licensee private information can be used to justify royalties [see Gallini and Wright 1990, and Beggs 1992]. With shelving, however, royalties are ineffective. We show that, depending on the type of shelving and the credibility of the threat of

[2]See Thursby *et al.* 2005.

licensing to an alternative firm, fees paid upfront, annually, or with achievement of milestones can be used.

Our work is also related to the literature on the organization of R&D with incomplete contracts. We contribute to this literature by showing that, when shelving is a possibility, contingent ownership combined with appropriate contract terms is important. The work closest to ours is that of Aghion and Tirole [1994a, b] which examines conditions under which an invention should be owned by the research unit, final customer, or some combination. They derive conditions under which ownership is irrelevant for efficiency. One of the conditions is whether the invention could be developed independently by the research unit or the customer. The types of inventions that we model are those which cannot be independently developed by either the university inventor or the firm. Moreover, in their model the final customer has no incentive to prevent development of the invention.

Finally, we contribute to the literature on university licensing and associated public policy concerns (see Agrawal [2001] and Thursby and Thursby [2003] for reviews). In particular, our results on shelving contribute to the US debates on the importance of government rights to take ownership of federally funded inventions in the absence of reasonable commercialization efforts. These "march-in" rights, granted by the Bayh-Dole Act, have never been exercised, leading to the view that the law needs to be strengthened [Rai and Eisenberg 2003]. We contribute to the debate by showing that contract terms and a willingness of universities to terminate licenses may well provide a market mechanism to minimize shelving, thus obviating the need to exercise the "march-in rights."

Section 2 provides survey results that motivate our consideration of multiple development stages as well as shelving concerns. Section 3 presents the basic problem. In Section 4, we focus on the moral hazard problem when shelving by the licensee is not a concern. In Section 5, we consider the adverse selection problem that arises when the firm's opportunity cost of commercializing the invention is not observable by the TLO. Section 6 concludes. The Appendix contains all proofs.

2 University license environment

The types of inventions and licenses we consider are motivated by two university licensing surveys, one of 62 US university TLOs and one of 112 firms that license-in university inventions [Thursby et al. 2001 and Thursby and Thursby 2002]. Respondents to both surveys characterize the majority of inventions licensed as embryonic, estimating that three fourths or more of these inventions are no more than a lab scale prototype at the time of license [Jensen and Thursby 2001]. As a result, their commercial use requires further development by the licensee, making shelving a potential issue for most inventions licensed. TLO and business respondents claimed that 71% and 40%, respectively, of the inventions require inventor cooperation in development. Further, since most inventions must go through substantial development and testing, and in many cases clinical trials, this development is risky. Respondents to the business survey reported 46% of the university inventions they license fail. Forty-seven percent of those failed for purely technical reasons [Thursby and Thursby 2002].

Respondents to the university survey reported that three-fourths of the inventions they license are licensed either exclusively or exclusively in a field of use.[3] We therefore focus on exclusive contracts. This is without loss of generality because shelving would not be an issue with non-exclusive licenses since multiple licenses would be feasible for the same use. Moreover, much of the Bayh-Dole policy debate pertains to exclusivity. Proponents argue that without exclusivity, firms would not have the incentive to risk investing in commercializing the embryonic inventions which typically result from federally funded research. Critics, however, worry that the monopoly power associated with exclusivity may actually stand in the way of commercialization, as in the case of shelving.

Both surveys show that contracts typically include multiple payment types. For example, in the university survey, 97% of the respondents reported that royalties were included in license contracts either "almost always" or "often," 92% reported the same for upfront fees, 89% for annual payments, and 72% for milestone payments. Only 8% of the respondents reported often including equity, and when equity was included the majority of contracts also included other fees [Thursby *et al.* 2001].

The responses to open-ended questions in the university survey suggest that fees are often motivated by due diligence. With regard to annual payments, 19% of the respondents volunteered that they include annual payments as due diligence to ensure the licensee makes "reasonable efforts to commercialize." Interestingly, one respondent mentioned using, not annual fees, but an upfront payment when the "feasibility of march-in to recover the license was low." Whether or not these payments indeed deter such actions is an open question, but an additional 18% said they had problems with firms shelving despite their best attempts at due diligence. In general, due diligence to ensure licensee development appears to be a thorny issue for TLO personnel. Indeed, 78% of the respondents noted that when they had to terminate licenses, the reason was failure to meet due diligence requirements or payments.

Both surveys include information on milestone payments. Examples of milestones include reaching animal or clinical trials, development of a business plan or prototype, and the level of earnings [Rector and Thursby 2008]. In response to a question on the importance of various payment terms when inventor cooperation is critical for

[3]The Association of University Technology Managers *Survey* reports that roughly half of the licenses executed by its members are exclusive.

development of the technology, respondents to the business survey noted that milestone payments are by far the most important payment term. Although the university survey did not contain information linking milestones with inventor cooperation, respondents emphasized that one of their most difficult issues is maintaining the needed inventor involvement [Thursby and Thursby 2004].

When, if ever, the use of annual and milestone payments is optimal is not clear *a priori*, nor is it clear that the complex contracts in university licensing are optimal. For these reasons, in the following sections, we set up a stylized model of university licensing in which a TLO must design and offer an exclusive license contract to a firm that has expressed interest in developing a university invention. The invention requires further technical development, completion of which is impossible without the inventor's cooperation. Commercialization of the technology also requires further investments by the firm, but the TLO has no information on the firm's true intent.[4]

Also drawing on the university survey, we specify the TLO objective as a function, not only of revenue, but also commercialization. All survey respondents reported having multiple objectives including earning revenue and sponsored research, as well as simply executing licenses and encouraging commercialization. The most important of these objectives was earning revenue, with 98% of the respondents noting that revenue was either moderately or extremely important to them. Next in importance was the number of inventions commercialized, with 92% noting that commercialization was either moderately or extremely important [Thursby et al. 2001]. Specifying the TLO objective as a function of commercialization also has the benefit of linking the analysis to the incentives provided by the "march-in" rights of Bayh-Dole.

Finally, it is worth noting that Bayh-Dole also requires universities to share a portion of the revenue from licensing with the inventor. Revenue sharing rules vary widely across universities, but except when the university returns all invention rights to the inventor, the inventor share rarely approaches 100%. In our survey the inventor share was 40% on average. From the standpoint of modeling optimal license practices, this is interesting since a well known way to solve moral hazard problems is the so-called "sell out" contract in which a principal sells the project to the agent and extracts all rent with a fixed fee [Laffont 1989]. It is also interesting that the inventor share is specified at the university level rather than as one of the variables in an individual licensing decision (Jensen *et al.* 2003).

[4]This is in contrast to recent work in which the TLO serves an intermediary purpose by being better informed than other players in the technology transfer process (Hoppe and Ozdenoren [2005], Hellmann [2007], and Macho-Stadler *et al.* [2007]).

3 A model of university licensing

Consider the problem faced by a university TLO with the responsibility for licensing an invention that requires further development before it can be successfully commercialized. Our baseline model is in the spirit of Jensen and Thursby [2001]. However, we exploit the fact that many inventions must go through multiple stages of development before they can successfully be commercialized. In Section 5 below, we also take into account the fact that not all of the firms willing to buy the license are interested in developing a product based on the invention.

The timing of the game is shown in Figure 1. At the beginning of the first period, the TLO draws a firm from a pool of candidates and offers a license contract to that firm. The firm may accept or reject the contract. If it accepts, a development stage begins, in which inventor effort and firm investment are required for technical success. The probability of technical success at the technical development stage is given by $p(e, X)$ where e is inventor effort and X is the firm's investment. We assume $p(0, X) = p(e, 0) = 0$ and $p(e, X) \in [0, 1)$. The probability $p(e, X)$ is strictly increasing in both arguments; it is strictly concave and e and X are complements, with $\frac{\partial^2 p(e,X)}{\partial e \partial X} \geq 0$ for all $e \geq 0$ and $X \geq 0$. If the invention is a technical success, the game proceeds to the commercial development stage. Conditional on technical success, the probability of commercialization is equal to z_u. However, the firm may invest a fixed amount C in order to increase the likelihood that the invention is commercialized to z. We assume that z_u is in $[0, z)$. Finally, all players are risk neutral.

The TLO acts on behalf of the university which owns and can exclusively license the invention.[5] In accordance with Bayh-Dole, this property right is contingent on the licensee making "reasonable" efforts to commercialize it and a portion, α, of the revenue earned from the license must accrue to the inventor. Accordingly, the TLO maximizes utility from expected licensing revenue $\tilde{R}$, $\mathbf{U}_A(\tilde{R}; L)$ given by

$$\mathbf{U}_A(\tilde{R}; L) = \begin{cases} (1-\alpha)\tilde{R}_s & \text{if commercial success,} \\ (1-\alpha)\tilde{R}_f - L & \text{if commercial failure,} \end{cases}$$

where $\tilde{R}_s$ is expected revenue in case of commercial success, $\tilde{R}_f$ is expected revenue in case of commercial failure. In $\mathbf{U}_A$, $(1 - \alpha)$ is the TLO's share of revenue, and L is a loss associated with commercial failure. Thus even if licensing revenue is certain, the TLO strictly prefers an outcome in which the firm invests in commercialization.[6]

[5] We abstract from any agency problems between the TLO and administration. See Jensen *et al.* [2003] regarding the alignment of TLO and administration objectives.

[6] For the TLO, holding revenue constant, the presence of L induces a preference for commercialization. Because of the Bayh-Dole march-in provisions, universities face the possibility of losing property rights to the invention in the absence of commercialization. We believe this can lead to an important loss of reputation for the university (and thus, revenue from future licenses). This loss is accounted

The inventor's utility from license revenue is given by $U_I(\tilde{R}) = \alpha\tilde{R}$. She incurs strictly positive and increasing disutility of effort represented by the continuous function $V(e)$, with $V(0) = 0$. We also assume increasing marginal disutility ($V''(e) > 0$). Hence, the inventor's payoff function is given by $\alpha\tilde{R} - V(e)$.

The TLO offers the firm an exclusive license contract that specifies all payment terms. We restrict attention to payment types that are contingent on observable events and quantities. We denote a contract by $O = (F, M, A, r, t)$. Payment term F is an upfront fee paid when the firm accepts the contract. Payment term M, which we refer to as a milestone payment, is a lump sum fee paid if and only if technical development is successful. Payment term A, which we refer to as an annual payment, is paid along with the commercialization investment, that is, after technical success, but before commercial success. Finally, r is an output royalty, and t is a profit tax or alternatively, a share of the firm's equity.[7] Hereafter, we refer to M, A, r and t as *continuation* payments, since the firm would have to return the license if it failed to make either of these payments.

The firm's full expected utility is given by its (random) profit net of license payments. The firm's profit from selling a product based on the invention is equal to $\pi(x)$ with x denoting output. Where there is no ambiguity, we write π for $\max_x\{\pi(x)\}$. Clearly, in the absence of distortionary payments based on output, if the firm commercializes the invention, it chooses the optimal level of output and earns π. We assume $z\pi - C > z_u\pi$, so that the firm finds it worthwhile to invest C when it obtains π from commercializing the invention. Thus, immediately after technical success, the firm's expected profit is given by $\Pi[x^*(r,t), r, t] = \max\{z[(1-t)\pi[x^*(r,t)] - rx^*(r,t)] - C, z_u[(1-t)\pi[x^*(r,t)] - rx^*(r,t)], 0\}$, where $x^*(r,t)$ is the firm's optimal output level when the royalty rate is $r > 0$ and the equity share is equal to t.

If the firm invests X at the technical development stage, and behaves optimally at the commercialization stage, its expected payoff is given by

$$p(e, X)[\Pi[x^*, r, t] - A - M] - X - F.$$

In general, inventor effort and firm investment (e, X or C) are neither observable nor contractible, and the inventor's share of revenue α is not chosen by the TLO. However, as a benchmark we consider the TLO's problem if investment and effort are observable and contractible and α is a choice variable. With full information and a

for by L in our model.

[7]Note that Jensen and Thursby [2001] also consider F, r, and t. Bousquet et al. [1998] consider upfront fees and royalties only. However, they allow for two different types of royalties. One is an output royalty, and the other is a tax on the firm's revenue. We focus on output royalties, which is without loss of generality in our model. Either type of royalty implies a distortion of the licensee's output, which is what matters for our results. Because of the way we model uncertainty at the commercialization stage, the distinction between the two different types of royalties is inconsequential.

flexible α, the TLO maximizes its expected payoff by choosing payment terms, required effort and investment, and the inventor's share of revenue subject to the inventor's and the firm's participation constraints. Since the required effort and investment levels can be written in a contract independently of payment terms, as in Choi [2001], a contract with a simple upfront fee is sufficient.[8] At an interior solution with $e > 0$ and $X > 0$, the optimal values of α and of the upfront fee are such that the firm's and the inventor's participation constraints are binding.[9]

4 Non-contractible effort and investment

Our university survey revealed that TLO personnel view obtaining faculty participation as one of the more challenging parts of their jobs [Thursby *et al.* 2001 and Jensen *et al.* 2003]. Jensen and Thursby [2001] show that obtaining inventor effort requires some type of payment tied to commercial success, such as royalties or equity. In their model, there is a single development stage so there is no role for milestone payments. In this section, we show that when development milestones are feasible, a payment tied to their achievement can solve the problem of inventor moral hazard.

As in Jensen and Thursby's [2001] model with sponsored research, we assume that after the firm accepts the contract, the inventor and the firm choose their effort and investment levels simultaneously and non-cooperatively. Thus, effort and investment are determined in the Nash equilibrium of this simultaneous move game. In this section, we abstract from shelving and assume the firm has a natural incentive to invest because its only source of revenue is the profit from commercialization. However, the inventor solves:

$$\text{Maximize } \alpha\tilde{R} - V(e) \text{ with respect to } e.$$

It is clear that the expected utility term will not depend on e if the reward $\alpha\tilde{R}$ is the same whether or not the invention works because, under Bayh-Dole, αF must be paid to the inventor whether or not the invention works.[10] However, in our set-up, there

[8] With risk neutrality, any single non-distortionary payment type or combination of payment types may be used to extract the optimal amount of revenue from the firm, because the required effort and investment levels are specified in the contract. Hence, to implement the *first-best* levels of effort and investment, the only payment type that is ruled out is an output royalty because it implies a dead-weight loss.

[9] Under certain conditions, the solution to the TLO's maximization problem described in the text coincides with the solution that is obtained if the TLO sets $\alpha = 1$ and sells the project to the inventor for a fixed price (a sell-out contract). We examine this possibility in the Appendix. The solutions will coincide if, (i) with the sell-out contract, the inventor, not the TLO, bears the loss L in case the invention is not commercialized and (ii) the inventor is willing to accept the sell-out contract without subsidization by the TLO.

[10] As an anonymous referee pointed out, if the TLO could make α contingent on technical success, then it could offer an upfront fee contract, and set $\alpha = 0$ in case of technical failure and $\alpha > 0$ in case

are a wide variety of payment terms that are received by the university (and thus, the inventor) only if the invention is either technically or commercially successful. We show that an optimal contract will contain at least one such payment type when feasible. As in other licensing models, the optimal contract may also include an upfront fee to extract any residual rent from the firm.

Proposition 1 *Suppose that all parties are risk neutral and that neither inventor effort, nor firm investment are contractible. Then, if an optimal licensing contract that leads to positive inventor effort and firm investment exists, it contains at least one continuation payment type tied to technical success. Furthermore, the optimal contract is not unique regarding payment types. However, in all optimal contracts, the output royalty rate r is set equal to zero and the upfront fee is set so that the firm's participation constraint is binding.*

Given the complementarity of the inventor's effort and the firm's investment, there is another equilibrium in the technical development subgame in which the firm does not invest and the inventor spends no effort so that the project fails with probability one. As in Jensen and Thursby's [2001] analysis of moral hazard with royalties and sponsored research, it is straightforward to show that this equilibrium is unstable with standard assumptions on the firm's and inventor's problems. We therefore restrict our attention to the equilibrium with positive effort.[11]

As shown in Proposition 1, in our simple model, if an equilibrium with non-zero probability of development exists, the specific payment terms do not matter as long as a sufficient portion of the total payments to the TLO is contingent on technical success and the output royalty rate is set equal to zero.[12] There are several ways, not

of technical success to provide incentives to the inventor.

[11]We do not examine the case $p(0, X) > 0$ for $X > 0$ and the possibility to obtain additional effort from the inventor in this paper. If the firm earns a profit of zero when it does not commercialize (that is, it does not have an incentive to shelve) and inventor effort is not necessary, then the TLO always has the option of offering a contract with a simple upfront fee and foregoing the inventor's participation. Note that the TLO would still be required to transfer a share α of revenue to the inventor even if the inventor spends no effort. The TLO's other option is to provide an incentive for the inventor to work, via continuation payments like in our model. The optimal contract is thus determined by a comparison between the contract that maximizes the TLO's expected payoff conditional on zero inventor effort and the best contract that induces positive inventor effort. Hence, if the probability of success is non-zero even when the inventor does not participate, the TLO faces a trade-off between, on the one hand, letting the firm develop the invention on its own and on the other hand, introducing payment terms that distort its investment in order to motivate the inventor. This trade-off depends on the degree of complementarity between inventor effort and firm investment. In Section 5, we examine a game between the TLO and the firm and focus on the moral hazard problem that arises when some firms have an incentive to shelve the invention.

[12]The conditions on the inventor's and the firm's best-replies that are required for the existence and uniqueness of an equilibrium in which inventor effort and firm investment are strictly positive are similar to equation (15) in Jensen and Thursby [2001] after adjusting for notational differences.

modeled here, to explain why milestone payments are prevalent. One such explanation is discounting of future payoffs by the inventor and the TLO. Since we assume that the TLO makes a take-it-or-leave it offer to the firm, even a small preference for current payoffs would make it optimal for the TLO to set $A = 0$ and $t = 0$ and charge all continuation fees in the form of a technical milestone. A similar argument can be made if either the TLO or the inventor, or both, are risk averse, while the firm is risk neutral.

An important result is that, when all players are risk neutral, the milestone payment dominates a royalty. Why then do we observe contracts that include royalties and upfront fees in addition to milestones and annual fees? With uncertainty related to commercialization, Bousquet *el al.* [1998] show risk aversion on the part of the firm explains the presence of output-distorting royalties. If, as they do, we assume that equity contracts are not feasible, then risk aversion is a natural explanation given the embryonic nature of university inventions. In our model, once the firm invests C, it obtains $\Pi[x^*(r,t), r, t]$ either with probability $z < 1$ or with probability $z_u < 1$, so that the worst state of nature for the firm is one in which the invention is a technical success but commercial success is not realized. In this case, the firm anticipates having to pay the milestone payment and the annual fee, while earning no revenue from the invention. A positive royalty rate will reduce the variance in the distribution of profits and result in more equal payments across states. With a risk neutral TLO and inventor, this leaves open the possibility that the optimal contract will include an output royalty when z is sufficiently low.[13]

5 Shelving

In this section, we examine the problems that arise because the firm's commercialization effort is not contractible. We consider situations in which the firm may be better off shelving the invention than commercializing it. We allow for two types of shelving, one in which a firm licenses with the intent to prevent commercialization of the invention and another in which a firm licenses intending to commercialize the invention, but decides not to commercialize it after spending time on development. For simplicity, we refer to the first type of shelving as *intentional* and to the second as *unintentional.*

The motivation for intentional shelving is similar to that of "sleeping patents" examined by Gilbert and Newbery [1982] in which a monopolist patents substitutes for

[13] If the firm's investment can take only two values, 0 or X and the probability of technical success is given by $p(e, X) = p(e)$ and $p(e, 0) = 0$, it is possible to show the following. If there exists a contract with $M > 0$ and $r = 0$ that leads to positive inventor effort and is accepted by the firm, then a small increase in r compensated by an equivalent reduction in M will increase the expected payoff of the firm without affecting the probability of success. Hence, increasing r allows the TLO to increase the upfront fee and thus, its expected payoff.

its product to keep others from producing it. Well known examples include DuPont's patenting of 200 substitutes for Nylon. More recently, Cohen *et al.* [2000] find that when firms in their survey patent inventions, 82% (64%) patent them in order to block rivals in the case of product (process) inventions.

The most publicized example of unintentional shelving was involved in the CellPro-Johns Hopkins march-in dispute. In 1997 CellPro petitioned the National Institutes of Health to take back the Johns Hopkins license for the My-10 antibody originally licensed to Becton Dickinson. While the company had invested in development, over time it decided to withdraw from the therapeutic business, so that developing the antibody had no economic value to the company.

5.1 The Shelving Game

In order to keep the model as simple as possible, but rich enough that it generates insight into the shelving problem, we assume that the probability of success depends only on the firm's investment. That is, we assume the probability of technical success is equal to p if the firm invests a fixed amount $X > 0$ and zero if the firm does not invest. Without loss of generality, we set $\alpha = 0$ and $z = 1$. Finally, to keep the notation simple, we rule out output royalties since we assume that the players are risk neutral (and equity contracts are feasible). It will also become clear that payments which depend on commercialization are ineffective at solving the shelving problem since they are not paid by shelving firms.

We introduce the possibility of shelving in the following way. At the time the TLO offers a license contract, there are two types of firms in the pool. With probability s the firm is interested in licensing the invention to prevent development (either by itself or a rival). It is natural to think of this firm either producing or trying to develop a substitute for the invention. The firm, which we call an *intentional shelver,* earns profit π^m when it obtains the license for the invention but does not commercialize it, and $\pi^c \leq \pi^m$, if it obtains the license and commercializes it. The shelver earns $\pi^d \leq \pi^m$ if another firm, holding the exclusive license, commercializes the invention. Therefore, a shelver would never attempt to commercialize the invention since $\max\{z_u\pi^c, \pi^c - C\} < \pi^m$ by assumption. Moreover, a shelver saves an amount $D \equiv \pi^m - \pi^d$ when it obtains and shelves the license, preventing commercialization of the invention.

At the time the TLO offers the contract, the probability that the firm is interested in developing and commercializing the invention is $1 - s$. However, we assume that after technical success is determined but before the decision to incur C is made, new information becomes available which reveals whether the commercial potential for the invention is good or bad. With probability q, commercial potential is good and the firm's profit from commercializing is equal to π. With probability $1 - q$, the firm is an *unintentional shelver* whose investment in commercialization has to be increased to $C_u > C$ to ensure that the probability of commercialization is equal to 1. This could be because technical success has revealed that this invention is not as profitable as other development projects the licensee is working on concurrently.[14] Moreover, we assume that $z_u\pi > \pi - C_u$ holds, so that an unintentional shelver finds it too costly to invest in commercial development and thus faces a lower probability of commercialization z_u. If a firm is not an intentional shelver, following technical success but before it learns its type, its expected profit is equal to $\hat{z}\pi - qC$, where $\hat{z} \equiv q + (1-q)z_u$.

The timeline for this game is given in Figure 2. The TLO first offers a contract to a firm that was randomly selected from the pool. If it rejects, the TLO must decide whether or not to search for a second firm at a cost $K > 0$. The second firm may accept or reject the contract. If it rejects the contract, we assume that the project is abandoned. Thus, we assume that the TLO can search only once. If the first firm accepts, it pays an upfront fee and decides whether or not to invest X. If the observed outcome of the technical development stage is a failure, the TLO can take the license back from the firm. Note that failure will be observed when either the firm does not invest or the invention does not work. If the TLO takes the license back, it decides whether or not to search for a second firm at cost K. The outcome of the search process is as described above. On the other hand, if technical development is successful, the licensee must pay the milestone payment. If the firm is not an intentional shelver, it also learns its type (its commercial development cost). Upon learning the cost of commercial development, if the firm decides to keep the license, it must pay the annual fee. Otherwise, it returns the license to the TLO which can search for another firm at the cost K. If the firm decides to keep the license, it then decides whether or not to invest.

There are three critical dates at which the TLO may want to search for a different firm: immediately after the initial contract offer is made if it is rejected, immediately after observed failure in the technical development stage, and, finally, after technical success if the TLO determines that the firm is an unintentional shelver. The information available to a potential second firm about the first firm's investment plays an important role in this context. To abstract from potential agency problems between the TLO and the second firm, we assume that the second firm has the same information as the TLO.

Throughout the analysis, we focus on contracts that can be supported as pure strategy Perfect Bayesian equilibria within the class of contracts that, first, are accepted by firms that are not intentional shelvers, and second, lead to positive investment in

[14] For instance, suppose that the licensee learned that another one of its innovations would surely be commercially successful and yield a profit net of development costs equal to π_u. If the licensee has limited resources, and can only work on one of the two projects, then the opportunity cost of investing C in the university invention is $C + \pi_u = C_u$.

technical development by such firms. A contract can be supported as an equilibrium if there is no other contract that satisfies all participation and incentive compatibility constraints and gives the TLO a strictly higher expected payoff. Hence, an equilibrium contract is optimal for the TLO, subject to participation and incentive compatibility constraints. For the problem to be interesting, we assume

A0: $p(\hat{z}\pi - qC) - X > 0$

If **A0** is not satisfied, firms that are not intentional shelvers are unwilling to accept any contract which generates strictly positive revenue.

To characterize equilibrium contracts, it is necessary to analyze the TLO's behavior if the first firm rejects the original contract offer. In this case, the TLO may try to license the invention to a second firm. If the TLO searches for a second firm, then it will optimally extract all rents from this firm by offering, for instance, an upfront fee contract. If the firm accepts the contract and is not an intentional shelver, its expected payoff gross of payments to the TLO is

$$p(\hat{z}\pi - qC) - X.$$

Hence, a contract offer of $O = (F)$ to this firm, where $F = p(\hat{z}\pi - qC) - X$, maximizes the TLO's expected payoff. A simple calculation shows that the TLO will search for a second firm if and only if

$$(1 - s)[p(\hat{z}\pi - qC) - X] + (1 - s)p\hat{z}L \geq K. \quad (1)$$

Since our premise is that the TLO views shelving as a problem we make the following assumption:

A1: The TLO's utility loss from failing to commercialize the invention and the cost of search satisfy $(1 - s)[p(\hat{z}\pi - qC) - X - p\hat{z}D] + (1 - s)p\hat{z}L \geq K$.

Since $D > 0$, **A1** is stronger than (1). This assumption rules out the TLO finding it profitable to offer an upfront fee contract to an intentional shelver. To see this, suppose the TLO knows the firm's type and is faced with an intentional shelver. The assumption implies that the TLO prefers to turn that firm down and search for another firm rather than extract all rents from the shelver and commit not to take the license back after observing technical failure.

For some, but not all, of our results, we also assume

A2: $\hat{z}\pi - qC \geq (1 - s)D$.

This condition guarantees that if technical development is a success, the expected profit from commercialization for a firm that is not an intentional shelver is greater than the amount an intentional shelver expects to save by blocking commercialization.

5.2 Unintentional shelving: The role of annual fees

In this section, we assume $s = 0$ and focus on the problem presented by unintentional shelving. Consider the incentives faced by a licensee that is not an intentional shelver. Since, *ex-ante*, the firm does not know the value of the licensed invention, it expects to earn a gross expected profit equal to $\hat{z}\pi - C$ if technical development yields a success. The problem is that when $\hat{z} < 1$ the TLO may want to take the license back even if technical development is successful. The TLO's incentive to take the license back from an unintentional shelver stems from the opportunity to license to a second firm, which on average, will have a higher probability of commercialization. It is thus important to determine when it is optimal for the TLO to license to a second firm after it observes a technical success with the first firm.

Suppose technical development is successful, but the licensee learns that $z_u\pi > \pi - C_u$ so that it is not profitable to invest in commercialization. Then if (1) holds with $s = 0$, it is simple to show that the TLO will always find it worthwhile to search for a second firm. This additional search cannot be done with the first firm holding an exclusive license unless the license is terminated. To justify termination, the TLO may include another type of contract requirement before commercialization. Suppose that the TLO's contract includes an annual fee $A > 0$ to be paid after technical success, but before commercial success. If this payment is sufficiently high, specifically greater than an unintentional shelver's expected profit, $z_u\pi$, then a firm of that type will prefer to return the license to the TLO to avoid making this payment.

The tradeoff faced by the TLO is the following. Setting $A \geq z_u\pi$ brings about an obvious benefit. Indeed, if the first firm is an unintentional shelver who returns the license, the TLO gets a chance to search for a second firm, which, on average has a higher probability of commercialization. This benefit increases as z_u decreases. However, forcing unintentional shelvers to return the license is costly. First, the revenue raised from the first firm is necessarily lower than if the licensee anticipates keeping the license regardless of its type. This cost increases as z_u increases. Second, search itself is costly. The next proposition shows that if annual fees are feasible, then it is optimal for the TLO to include an annual fee if and only if q is sufficiently high and z_u is sufficiently low.

Proposition 2 *Assume $s = 0$ and suppose **A0** and (1) hold.*

(i) If $q \leq \frac{X}{p(\pi - C)} < 1$, then the firm will reject any contract with an annual fee $A \geq z_u \pi$.

(ii) If $q > \frac{X}{p(\pi - C)}$ holds, there exists a $\hat{z_u} > 0$ such that a contract that contains an annual fee A is optimal if and only if $z_u \in (0, \hat{z}_u]$. The annual fee must be no less than $z_u \pi$ and no greater than $\hat{A}$ where $\hat{A} \equiv (\pi - C) - \frac{X}{pq}$. In equilibrium, the firm accepts the TLO's contract and invests X, but returns the license to the TLO if it learns that it is an unintentional shelver.

In our model, the distinction between annual fees and technical milestone payments is somewhat artificial. Annual fees are paid along with the commercial development cost, while technical milestones are paid immediately following technical success. An interpretation of our simple timing assumption is that in order for the firm to learn about the commercial potential it must undertake commercial development, as would be the case with market testing, for example. However, the firm is committed to pay the milestone payment immediately upon technical success so that annual continuation fees to be paid at a later date are required to ensure due diligence. Clearly, whether the TLO decides to enforce due diligence by including such annual fees will depend on the revenue it has to forego as shown in Proposition 2.

In solving the problem with unintentional shelving, it is clear that annual payments dominate output royalties since royalties distort output. Furthermore, it is possible to show that annual payments dominate equity shares. Indeed, equity shares will negatively affect a non-shelver's investment in commercial development since they are paid only if commercial success occurs. Our model provides an extreme example of this effect. Consider the equity share that is sufficient to deter unintentional shelvers from maintaining the license. Here, the equity share equals 1 since unintentional shelvers face no cost from commercial development. But then, this means that a non-shelver earns a profit of zero from commercializing the invention and thus will optimally invest zero in either commercial or technical development. An annual payment does not generate any such adverse effects.

5.3 Intentional shelving: The role of upfront fees and continuation payments

In this section, we consider the case where unintentional shelving is not an issue ($q = 1$), but $s > 0$ so that some firms in the pool are intentional shelvers. The problem with intentional shelvers is that if such a firm obtains the license, it definitely will not invest in commercial development. Thus, if the licensee is an intentional shelver, the

TLO incurs the loss L with certainty if it allows the firm keep the license until the commercialization stage. Our analysis highlights the role of upfront fees and technical continuation payments along with the credibility to threaten to license to another firm if a technical failure is observed.

If types were observable, the TLO would simply select a non-shelver from the pool and offer, for instance, a simple upfront fee contract $\hat{O} = (\hat{F})$ that extracts an amount of revenue equal to

$$\hat{F} \equiv p(\pi - C) - X$$

from the firm. The probability of commercialization would be equal to p, and the TLO's expected payoff would be $p(\pi - C) - X - (1 - p)L$.

With unobservable types, we assume that the TLO can offer two types of contracts, separating or pooling, and determine when each type of contract can be supported in a Perfect Bayesian equilibrium. We call a separating contract one that is accepted by non-shelvers and rejected by shelvers, while a pooling contract is one that is accepted by both types of firms. An equilibrium contract is a contract, either separating or pooling, that maximizes the TLO's expected payoff and satisfies all participation and incentive compatibility constraints. For a wide range of parameter values, an equilibrium contract is straightforward to characterize and consists of an upfront fee (Propositions 3 and 4). However, in the most interesting case, where the TLO can credibly threaten to license the invention to a second firm after observing a technical failure, if the benefit from blocking commercialization is high enough for intentional shelvers, the TLO will offer a pooling contract that consists of success-contingent fees only (Proposition 5). In every equilibrium, expected licensing revenue to the TLO is less than or equal to $\hat{F}$, and the probability of commercialization is strictly less than p.

Since **A1** implies that (1) holds (after setting $\hat{z} = 1$), it is clear that if the first firm rejects the contract, the TLO will search for a second firm. This has an important implication for equilibrium behavior as summarized in Lemma 1.

Lemma 1 *An equilibrium in which both shelvers and non-shelvers accept the TLO's contract and invest X in technical development does not exist.*

Proof. Suppose that an equilibrium exists in which both types of firms invest X. We show that shelvers have an incentive to deviate, contradicting equilibrium behavior. Indeed, upon observing a technical failure, both the TLO and a potential second firm's beliefs should assign probability one to the event that the invention does not work. Hence, a second firm will not be willing to invest, so that it cannot be worthwhile for the TLO to search for a second firm. But, anticipating this behavior by the TLO, shelvers will shirk so as to strictly increase their payoff, contradicting equilibrium behavior. □

Hence, if an equilibrium exists, it must either be the case that shelvers reject the TLO's contract or that they accept it, but shirk at the technical stage. In the case shelvers accept the contract, there are two possibilities if the TLO observes a technical failure: Either the TLO finds it profitable to search for a second firm or it does not and the game ends.

As shown in Proposition 3, a contract that shelvers reject in equilibrium exists if and only if $\hat{F}$ exceeds the expected saving to the firm from shelving. If $\hat{F}$ is lower than the expected saving from shelving, then a separating contract cannot be an equilibrium contract since shelvers would find it profitable to deviate, accept the contract, and pay any fees that non-shelvers are willing to pay. Note that the separating contract under asymmetric information leads to a lower probability of commercialization than under complete information.

Proposition 3 *Assume $q = 1$ and suppose that **A0** and **A1** hold. An equilibrium contract is a separating contract if and only if $\hat{F} \geq (1-s)pD$. The equilibrium contract is not unique, but one such contract consists of a simple upfront fee equal to $\hat{F}$.*

In equilibrium, non-shelvers accept the TLO's contract and invest X in technical development. Shelvers turn down the TLO's contract offer. Furthermore, the probability of successful commercialization is equal to $(1-s)p + s(1-s)p$.

In the remainder of this section, we assume that $\hat{F} < (1-s)pD$ holds. That is, a non-shelver's expected payoff gross of licensing fees is less than a shelver's expected saving from blocking commercialization. This implies the following relationship between the parameters

$$(1-s)pD > p(\pi - C) - X. \tag{2}$$

In this case, Proposition 3 implies that a separating contract equilibrium does not exist. Thus, given the result in Lemma 1, we may now focus on equilibrium contracts that both types of firms accept. We maintain assumption **A1** and focus on equilibria in which non-shelvers invest X, while shelvers do not invest in technical development. Suppose such an equilibrium pooling contract exists. Recall that the TLO has the option to search for a second firm upon observing technical failure with the first firm. If the TLO searches for a second firm, then, using Bayes rule, that firm's posterior belief that the invention failed because the first firm did not invest is given by

$$\mu = \Pr(\text{Investment} = 0|\text{Failure}) = \frac{s}{s + (1-s)(1-p)}.$$

Hence, the second firm's gross expected payoff from investing X in technical development is equal to $\mu p(\pi - C) - X$. A second firm that is a non-shelver will be willing to invest in development at this stage if and only if

$$\mu p(\pi - C) - X \geq 0. \tag{3}$$

The maximum amount the second firm will be willing to pay for the license is equal to the left-hand side of (3), which we denote by $\hat{F}_2$. It follows that the TLO will search for a second firm if and only if

$$\hat{F}_2 \geq 0 \text{ and } (1-s)[\hat{F}_2 + \mu pL] \geq K. \tag{4}$$

We can now show that if (4) does not hold, then there exists a unique pooling contract supported by an equilibrium in pure strategies.

Proposition 4 *Assume $q = 1$. Suppose that **A0**, **A1** and $\hat{F} < (1-s)pD$ hold, but that the threat to license to a second firm after observing a technical failure is not credible, that is, (4) does not hold. Then, in the unique equilibrium, the TLO offers a pooling contract with a simple upfront fee $\hat{F}$.*

In equilibrium, both non-shelvers and shelvers accept the TLO's contract, non-shelvers invest X in technical development, while shelvers shirk. Furthermore, the probability of successful commercialization is equal to $(1-s)p$.

Now suppose instead that (4) holds and that the TLO offers a contract consisting of a simple upfront fee F_1 to the first firm. Using Lemma 1, if an equilibrium pooling contract exists, then, in equilibrium, a shelver that accepts the contract shirks at the technical stage. In such an equilibrium, the TLO will search for a second firm upon observing a technical failure. Thus a shelver recognizes *ex ante* that its gross expected payoff from accepting the contract, but shirking at the technical stage, is equal to

$$(1-s)p\pi^d + [1-(1-s)p]\pi^m,$$

which is also equal to its payoff from rejecting the contract. On the other hand, if the shelver accepts the contract and invests X in development, its gross expected payoff is equal to

$$\pi^m - X.$$

It follows that, for the TLO's belief that shelvers accept the contract and shirk to be correct ex-post, two conditions must hold. First, the upfront fee must be such that a shelver is no worse off accepting the contract and shirking than rejecting the contract. That is, the upfront fee must satisfy

$$F_1 \leq (1-s)[p-p]D = 0. \tag{5}$$

Second, it must be the case that a shelver that accepted the contract does not find it profitable to deviate and invest X in technical development. Hence,

$$\pi^m - X \leq (1-s)p\pi^d + [1-(1-s)p]\pi^m$$

must hold as well, which implies

$$(1-s)pD \leq X.$$

Constraint (5) immediately implies that a contract with a positive upfront fee cannot be part of an equilibrium. Given that the TLO cannot commit not to license to a second firm upon technical failure if it is profitable to do so, (5) implies that shelvers will not be willing to pay a positive upfront fee and shirk since this is worse than rejecting the contract. Further, by Lemma 1, an equilibrium cannot involve shelvers accepting the contract and investing X.

We now show that in equilibrium the TLO will offer a contract containing technical continuation payments such as a technical milestone or annual fees, but no upfront fee. The continuation payments are set so that non-shelvers are indifferent between accepting and rejecting the contract, a level that turns out to be sufficiently high to deter shelvers from investing X. By shirking, shelvers avoid these payments. Finally, if a technical failure is observed, the TLO takes the license back from the first firm and searches for a second firm.

Proposition 5 *Assume $q = 1$. Suppose that* ***A0****,* ***A1****,* ***A2****, $\hat{F} < (1-s)pD$ and (4) hold. Then, an equilibrium contract is a pooling contract that consists of technical continuation payments only and does not include an upfront fee. The expected value of the sum of continuation payments is equal to $\hat{S}$, where $\hat{S} \equiv (\pi - C) - \frac{X}{p}$. Furthermore, technical milestone payments and annual fees combined must add up to no less than $\max\{(1-s)D - \frac{p}{X}, 0\} < \hat{S}$ and the equity share must be less than $\hat{t} \equiv 1 - \frac{C}{(z-z_u)\pi}$.*

In equilibrium, both non-shelvers and shelvers accept the TLO's contract. Non-shelvers invest X in technical development, while shelvers shirk. Upon observing a technical failure, the TLO searches for a second firm. Finally, the probability of successful commercialization is equal to $(1-s)p + s(1-s)p$.

Proposition 5 can be interpreted as a signaling result. If the TLO offered a contract with an upfront fee, then the threat of licensing to a second firm upon technical failure would not be credible because shelvers would reject the TLO's contract. However, by offering a contract without an upfront fee but a set of high continuation payments, the TLO can guarantee that all types of firms will accept the contract. The TLO is then in a position to credibly argue to a second firm that a technical failure may well have resulted from lack of investment rather than a bad invention.

If assumption **A2** is relaxed, then a pure strategy equilibrium fails to exist. Indeed, in this case, the pooling contracts in Proposition 5 are not immune to deviations by a shelver. If **A2** does not hold and the continuation payments are set sufficiently high to deter shelvers, then the contract is too costly for non-shelvers to accept.

5.4 Both types of shelving

So far, our analysis has considered intentional shelving and unintentional shelving separately. When both types of shelving are possible, overall, most of the results are qualitatively similar. However, there is a difference that is worth emphasizing. It arises when the inequality $\underline{F} \equiv pq(\pi - C - z_u\pi) - X \geq (1-s)p\hat{z}D$ as well as conditions similar to those in Proposition 2(ii) hold. Proposition 6 below shows that annual and upfront fees may be included together in an optimal contract when both intentional and unintentional shelving are possible.

Proposition 6 *Suppose that **A0**, **A1**, $\underline{F} \geq (1-s)p\hat{z}D$. Then, there exists a $\hat{z}'_u > 0$ such that if $z_u \in (0, \hat{z}'_u]$, the separating contract, $\underline{O} = (\underline{F}, \underline{A}) = (\underline{F}, z_u\pi)$, is an equilibrium contract. Furthermore, for such values of z_u, $F \geq \underline{F} > 0$ and $A \geq z_u\pi > 0$ in all equilibrium separating contracts. In equilibrium, non-shelvers accept the TLO's contract, invest X in technical development, but return the license to the TLO if they learn that they are unintentional shelvers. Intentional shelvers turn down the TLO's contract offer. Finally, the probability of successful commercialization is equal to $(1-s)p[q + (1-q)(1-s)\hat{z}] + s(1-s)p\hat{z}$.*

The intuition behind Proposition 6 is simple. The TLO has to deal with two issues related to shelving. On the one hand, keeping intentional shelvers out requires a sufficiently high upfront fee, while on the other hand, making sure that unintentional shelvers return the license in time requires an annual fee no lower than $\underline{A} = z_u\pi$. Hence, a contract that includes the minimal annual fee $z_u\pi$ and an upfront fee that extracts a non-shelver's expected rent is optimal. The contract $\underline{O}$ is not the unique equilibrium contract. In fact there are other separating contracts that can be supported as equilibria. However, it is important to note that all such contracts must include a strictly positive upfront fee as well as an annual fee no lower than $z_u\pi$. Furthermore, when comparing Proposition 6 to Proposition 2, note that in Proposition 6, the condition $\underline{F} \geq (1-s)p\hat{z}D > 0$ is substituted for the assumption $q > \frac{X}{p(\pi - C)}$ in Proposition 2.

5.5 Shelving with inventor effort

We have abstracted from inventor moral hazard in this section to highlight the effect of shelving on optimal contracts. A previous version of this paper contains propositions similar to Propositions 2-5 if inventor effort and shelving are both issues (see Thursby *et al.*, 2005). It is clear that whenever continuation payments are invoked to solve the shelving problem, they also help provide incentives for inventor effort. Thus, a result similar to that of Proposition 2 in the presence of unintentional shelvers holds when inventor participation is required.

Importantly, we show that a contract similar to the signaling contract of Proposition 5 is also optimal when the incentive to shelve is sufficiently pronounced. The intuition is simple. The TLO can use continuation payments both to motivate the inventor and to prevent shelvers from investing but shelving in the commercialization stage. However, for values of the parameters similar to those described by the assumptions in Propositions 3 and 4, the critical difference between situations in which inventor effort is required and the analysis in this paper is that to motivate the inventor, the TLO is forced to offer continuation payments that are contingent on success. This implies a loss of revenue whenever the contract is a pooling contract because shelvers fail to make these payments.

5.6 Shelving without inventor effort, but continuous investment

Another important assumption in our simple shelving game is the firm's discrete investment choice. Relaxing this assumption will affect the results in Propositions 2 and 5. Indeed, continuation payments provide a disincentive for investment in technical development and thus lead to lower probabilities of technical success with the first licensee. This implies that with continuous firm investment, forcing unintentional shelvers to give back the license is more costly than under discrete investment. The annual fee necessary to separate unintentional shelvers from non-shelvers reduces the optimal value of X with the first licensee. Thus the range of parameter values under which it is optimal to include an annual fee is not as wide as that investment is discrete.

Relaxing the discrete investment assumption also affect the result in Proposition 5 for the following reasons. First, contrary to Proposition 5, when the incentive to shelve is sufficiently pronounced and the threat to license to a second firm in case of technical failure may be credible, the TLO's contract may still include a positive upfront fee in addition to continuation payments. A constraint similar to equation (5) arises, but the critical value of the upfront fee is not zero with continuous investment because the expected payoff to a shelver from accepting the TLO's contract and shirking is strictly higher than its expected payoff from turning down the offer. This follows because a second firm that obtains the license after observing a technical failure will invest less than a second firm that obtains the license after the first firm turns down the TLO's offer. Second, an existence problem arises because the level of continuation payments needed to deter shelvers may be too high for a non-shelver to be willing to invest.

6 Conclusion

University-industry technology transfer is an important part of national innovation systems and one fraught with incentive problems, largely because of the informational asymmetries and investment needed for industrial application of many university inventions. In this paper, we focus on the role of contracts, and in particular the form of payments in overcoming these distortions. We show that in the presence of moral hazard and adverse selection, simple contracts are unlikely to be optimal. Interestingly, continuation payments such as milestones or annual fees, which have largely been ignored in the literature, may be used not only to solve moral hazard problems with the inventor, but also to deal with licensee shelving.

By assuming that several stages of development must be completed before an invention can be commercialized, our model accounts for an important characteristic of university licensing, namely the embryonic nature of university inventions. We show that when development requires both firm investment and inventor participation, but these inputs are not observable, payments tied to the achievement of technical milestones, or continuation payments, are necessary to obtain inventor cooperation. When inventor participation is not required, but shelving is a concern, continuation payments may also be optimal.

In our model of firm shelving, the TLO offers a contract to a firm that is either one of two unobservable types, an intentional shelver or a non-shelver. Moreover, *ex ante* non-shelvers may learn over the course of development that they are unintentional shelvers, facing higher than expected commercialization costs. Licensing to an intentional shelver leads to a sure commercial failure, an outcome the TLO seeks to avoid, while licensing to an unintentional shelver simply results in a lower probability of commercialization. In this context, our analysis highlights the role played by upfront fees, continuation payments, and the TLO's option to search for and license to a second firm when the original licensee fails. An upfront fee matters because any firm that accepts the contract must pay it, whether or not the firm plans to shelve. Continuation payments matter when intentional shelving is a problem because, if the original licensee fails to develop the invention, the TLO can use them to send a credible signal to a potential second firm regarding the expected quality of the invention. Finally, annual fees are optimal when unintentional shelving significantly reduces the probability of commercialization. They are included in contracts to induce unintentional shelvers to voluntarily return the license to the TLO.

Notice that the contracting problems we examine are predicated on the split ownership implicit in Bayh-Dole, that is, the university owns the invention but the government reserves the right to take it back in the absence of reasonable commercialization effort. We argue that this march-in provision provides the incentive for the university to execute separating contracts, so that in equilibrium actual march-in would not occur.

The university ownership of the invention makes our contracting problems fundamentally different from those of Aghion and Tirole [1994a]. In our model the researcher (inventor) has a moral hazard problem that does not exist in their framework where either the researcher or the customer (licensee in our case) owns the invention. However, it is well understood from principal-agent theory that if the agent is risk neutral and faces no limited liability constraints, the principal can usually fully solve the moral hazard problem by "selling" the project to the agent and extracting rent with a fixed fee (see, for instance, Laffont [1989]). This solution is reminiscent of a commonly observed practice in university licensing, which consists of letting the inventor start her own firm to develop and commercialize the invention. An interesting question for further research, particularly given increasing commercialization through inventor startup companies, is when it would be optimal for the university to transfer ownership to the inventor. This question has also been the topic of debate among a number of European countries where traditionally ownership has resided with the inventor [OECD 2003]. Another question, currently a point of contention between some firms and universities, is when the firm funds the research, whether firm ownership is optimal.

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Appendix

The full information solution

Below we show that the optimal contract the TLO would offer if it could choose α, e and X as well as the payment terms (the *full information* contract) does not always yield the same outcome as a contract whereby the TLO sells the invention to the inventor, who then offers a contract to the firm.

We focus on cases in which (i) the optimal *full information* contract leads to positive effort and firm investment and (ii) given the effort and investment level that result from implementing this contract, expected profit from commercialization is sufficient to cover the investment cost and the inventor's effort disutility. This is guaranteed by the following assumption:

A3: There exists a unique solution (e^*, X^*), $e^* > 0$, $X^* > 0$, to the following problem

$$\text{Maximize } p(e, X)(z\pi - C) - V(e) - X - (1 - p(e, X)z)L$$

with respect to $e \geq 0$ and $X \geq 0$. Furthermore, $p(e^*, X^*)(z\pi - C) - X^* - V(e^*) > 0$.

Note that the effort and investment levels that solve the problem in **A3** are the *first-best* levels in this three-player game. Indeed (e^*, X^*) maximizes the sum of expected payoffs, which is equal to the expected profit from the invention, minus the investment and effort cost and the expected loss from not commercializing. Hence, **A3** is equivalent to assuming that first-best effort and investment levels are positive, and that expected profit from the invention covers the sum of their cost.

<u>Full information contract</u>

Suppose that the TLO offers a contract $O = (F, M, A, t, r; X)$ to the firm and requires effort e from the inventor in exchange for a share α of licensing revenue. The TLO chooses O, e and α to maximize its expected payoff subject to non-negativity constraints and participation constraints. Without loss of generality, we may assume $M = A = t = r = 0$. Since $r = t = 0$, if the firm accepts the contract, it will invest C upon commercial success. Then the TLO chooses $(F; X)$, e and α to maximize

$$(1 - \alpha)F - [1 - p(e, X)z]L$$

subject to

$$\alpha F - V(e) \geq 0,$$

$$p(e, X)(z\pi - C) - X - F \geq 0,$$

and $F \geq 0$, $\alpha \in [0, 1]$, $X \geq 0$ and $e \geq 0$.

We now show that under **A3**, setting $e = e^*$ and $X = X^*$ is a solution to the above problem and $\alpha^* \in (0, 1)$. Indeed, consider a problem similar to the above but ignoring the constraints $F \geq 0$, $\alpha \in [0, 1]$, $X \geq 0$ and $e \geq 0$. In this case, to maximize expected utility, the TLO will clearly set $F = p(e, X)(z\pi - C) - X$ since its expected payoff is increasing in F. Furthermore, for every (e, X), the TLO's expected payoff is strictly decreasing in α. Hence, the TLO will set α so that $\alpha F - V(e) = 0$ or $\alpha = \frac{V(e)}{F}$. Substituting for $\frac{V(e)}{F}$ in place of α in the TLO's objective function yields $F - V(e) - [1 - p(e, X)z]L$. Substituting for $F = p(e, X)(z\pi - C) - X$ in this last equation yields $p(e, X)(z\pi - C) - V(e) - X - (1 - p(e, X)z)L$. Hence, this unconstrained problem is equivalent to maximizing $p(e, X)(z\pi - C) - V(e) - X - (1 - p(e, X)z)L$ with respect to e and X. By assumption **A3**, the solution to the unconstrained problem is (e^*, X^*). We also have $p(e^*, X^*)(z\pi - C) - X^* > 0$ so that $F^* > 0$ and $\alpha^* = \frac{V(e^*)}{p(e^*, X^*)(z\pi - C) - X^*}$. That $\alpha^* \in (0, 1)$ follows from the assumption $p(e^*, X^*)(z\pi - C) - X^* - V(e^*) > 0$ and $e^* > 0$, which implies $0 < \frac{V(e^*)}{p(e^*, X^*)(z\pi - C) - X^*} = \alpha^* < 1$.

It follows that under assumption **A3**, the expected payoff to the TLO from offering the optimal *full information* contract is $p(e^*, X^*)(z\pi - C) - V(e^*) - X - (1 - p(e^*, X^*)z)L$, while both the firm and the inventor obtain an expected payoff of 0.

<u>Selling the project to the inventor</u>

Assume **A3** holds and suppose now that the TLO offers a contract to the inventor with $\alpha = 1$ and a fixed price F_T to be paid by the inventor. That is, the inventor gets to keep the entire licensing revenue but must pay an upfront fee to the TLO. The inventor accepts or rejects the contract. If the inventor rejects the contract, the optimal *full information* contract is implemented and the inventor obtains an expected payoff of zero. If the inventor accepts the contract, she then offers a contract to the firm. Importantly, we assume that the inventor's expected payoff is given by

$$\mathbf{U}_I(\tilde{R}; e, L) = \begin{cases} \tilde{R}_s - V(e) & \text{if commercial success,} \\ \tilde{R}_f - L - V(e) & \text{if commercial failure.} \end{cases}$$

Without loss of generality, assume that the inventor offers a contract $O = (F_I, X)$ to the firm. The firm's expected payoff from accepting the contract is $p(e, X)(z\pi - C) - X - F_I$, while the inventor's expected payoff is equal to $F_I - V(e) - F_T - (1 - p(e, X)z)L$. It is clear that the inventor will set $F_I^* = p(e, X)(z\pi - C) - X$, so that its expected payoff can be written as

$$p(e,X)(z\pi - C) - X - V(e) - F_T - (1 - p(e,X)z)L. \qquad (1')$$

Since F_T is a lump-sum fee, it will not affect the inventor's optimal choice of e and X. The optimal values of e and X maximize $p(e,X)(z\pi - C) - X - V(e) - (1 - p(e,X)z)L - F_T$, where F_T is a constant. It is clear that under assumption **A3**, the solution is given by (e^*, X^*). The inventor's expected payoff from offering an optimal contract to the firm is equal to $p(e^*,X^*)(z\pi - C) - V(e^*) - X^* - (1 - p(e^*,X^*)z)L - F_T$. Hence, the inventor will be willing to buy the project from the TLO at a positive price, $F_T \geq 0$, if and only if $p(e^*,X^*)(z\pi - C) - V(e^*) - X - (1 - p(e^*,X^*)z)L \geq 0$. If this last inequality is satisfied, then the TLO sets $F_T^* = p(e^*,X^*)(z\pi - C) - V(e^*) - X - (1 - p(e^*,X^*)z)L$ and earns its expected payoff from the *full information* contract. Again, the inventor and the firm earn an expected payoff of zero.

Now it is clear that if $p(e^*,X^*)(z\pi - C) - V(e^*) - X - (1 - p(e^*,X^*)z)L < 0$, the inventor will not accept the TLO's sell-out contract unless the TLO offers a subsidy $F_T^* < 0$. If the TLO does not offer a subsidy to the inventor, then the sell-out contract is not feasible.

Furthermore, if the inventor does not suffer the loss from failing to commercialize, but instead the TLO does, then the inventor's choice of e and X under the sell-out contract will generally differ from (e^*, X^*). This is simply because in this case, the inventor's objective function does not take the term $-(1 - p(e,X)z)L$ into account as it does in (1').

Proof of Proposition 1

Suppose that the TLO offers a contract $O = (F, M, A, t, r)$ to the firm. If the firm accepts, then the firm and the inventor play the simultaneous move investment game. The firm maximizes

$$p(e,X)(\Pi[x^*(r,t),r,t] - A - M) - X - F, \qquad (2')$$

with respect to X, while the inventor maximizes

$$p(e,X)\alpha(\tilde{B} + A + M) - V(e) + \alpha F, \qquad (3')$$

with respect to e. In (3'), $\tilde{B}$ is the expected royalty and equity revenue, which depends on the firm's decision at the commercialization stage. The TLO's expected payoff is given by

$$p(e,X)(1-\alpha)(\tilde{B} + A + M) + (1-\alpha)F - (1 - p(e,X)Z)L,$$

where the probability of commercial success Z depends on the firm's decision at the commercialization stage ($Z = z$ if the firm invests C, while $z = z_u$ if the firm does not invest).

We first show that the royalty rate will be set equal to zero in an optimal contract that leads to strictly positive effort and investment. To this effect note that for any given contract with strictly positive royalty rate $r = r' > 0$, a contract that includes no output royalty ($r = 0$), but instead a technical milestone payment M whose amount is equal to the expected revenue raised by r', provides identical incentives to the inventor than the contract with r'. This is because, from (3'), the inventor's expected payoff depends only on the total expected revenue received upon technical success, $\tilde{B}+A+M$, but not on each payment type separately. Since, by definition, milestone payment M raises the same amount of expected revenue as r', it is no more costly to the firm than the royalty payment with rate r'. Furthermore, the milestone payment does not distort the firm's output and thus, by assumption, the reduction in r will lead to higher firm profit, ie, $\Pi[x^*(0,t), r, t] > \Pi[x^*(r',t), r, t]$ for every $t < 1$ (from $\pi > \pi[x^*(r',t)]$). Finally, from (2') and (3'), note that the upfront fee has no effect on the incentives to spend effort or invest in development. Hence, by setting $r = 0$ and including a revenue equivalent milestone payment instead of the royalty r', the TLO can increase the upfront fee, while still satisfying the firm's participation constraint. It then obtains a strictly higher payoff. Hence, $r = 0$ in an optimal contract.

Setting $r = 0$, let the expected sum of continuation payments in the contract be equal to S. That is, $S \equiv M + A + \tilde{B}$, where $\tilde{B}$ depends only on t since $r = 0$ and the probability of commercialization. That $S > 0$ is necessary for strictly positive inventor effort follows naturally from equation (3'). If $M + A + \tilde{B} = 0$, then the inventor's expected payoff is equal to $-V(e) + \alpha F$, and thus, optimal effort $e^* = 0$ for every X.

Finally, an optimal contract, if one exists, is not unique regarding payment types because the three risk neutral players' payoff functions depend only on S and on the upfront fee F, but not on each continuation payment type separately.

Proof of Proposition 2

Suppose the TLO offers a contract with $A = 0$ and an upfront fee equal to the firm's expected payoff. Then it is clear that both non-shelvers and unintentional shelvers will keep the license upon technical success. Hence, the greatest amount of revenue the TLO will be able to extract from the firm is equal to

$$p(\hat{z}\pi - qC) - X.$$

An upfront fee contract in which the upfront fee is set equal to $F' = p(\hat{z}\pi - qC) - X$ is feasible and raises the greatest amount of revenue. If the TLO offers this contract, its expected payoff is then equal to

$$p(\hat{z}\pi - qC) - X - (1 - p\hat{z})L. \tag{4'}$$

Now suppose that the TLO offers a contract (F, A) where the fee A is to be paid upon technical success but before commercial success. If the firm accepted the TLO's contract and the fee A satisfies $A < z_u\pi$, then A has no effect on behavior. However, suppose $A \geq z_u\pi$. Then a firm realizes ex-ante that it will return the license if it finds out that it is an unintentional shelver. Therefore, ignoring the upfront fee, its expected payoff from accepting the TLO's contract is equal to $pq(\pi - C - A) - X$. There exists a contract with $A \geq z_u\pi$ that the firm will accept if and only if $pq(\pi - C - z_u\pi) - X \geq 0$ or $z_u \leq \frac{\pi - C}{\pi} - \frac{X}{pq\pi}$, where the right-hand side is strictly greater than zero if and only if $q > \frac{X}{p(\pi - C)}$. Thus, the conditions $q > \frac{X}{p(\pi - C)}$ and $z_u \leq \frac{\pi - C}{\pi} - \frac{X}{pq\pi}$ are necessary and sufficient for a contract with $A \geq z_u\pi$ to be accepted by the firm.

Assume that $q > \frac{X}{p(\pi - C)}$ and $z_u \leq \frac{\pi - C}{\pi} - \frac{X}{pq\pi}$ hold. If the TLO offers a contract with $A = z_u\pi$, F can be optimally set equal to $pq(\pi - C - A) - X$ to pick up any remaining slack in the firm's participation constraint. An unintentional shelver returns the license after technical success because $A \geq z_u\pi$. Given assumption **A1** with $s = 0$, the TLO finds it profitable to search and offer a contract to a second firm. Furthermore, the TLO's contract extracts all rents equal to $(\hat{z}\pi - qC) - X$ from that firm. The TLO's expected payoff from offering the contract (F, A) is thus equal to

$$pq(\pi - C) - X + p(1 - q)(\hat{z}\pi - qC - K) - [1 - pq - p(1 - q)\hat{z}]L. \tag{5'}$$

To show that $\hat{z}_u$ exists, consider the difference between (5') and (4'). Note that $\lim_{z_u \downarrow 0} \hat{z} = q$. Hence, in the limit as z_u goes to zero, this difference is equal to

$$p(1 - q)[q(\pi - C) - K] + p(1 - q)qL > 0,$$

by assumption **A1** (as z_u goes to zero). Hence, in the limit as z_u goes to zero, the contract (F, A) yields a strictly higher expected payoff than the contract (F'). Since both (5') and (4') are continuous in z_u, it follows that the strict inequality will hold for a range of values of z_u that are strictly positive and bounded above by $\frac{\pi - C}{\pi} - \frac{X}{pq\pi}$. Therefore, letting $A = z_u\pi$ and $F = pq(\pi - C - z_u\pi) - X$, we have shown that there exists a $\hat{z}_u > 0$ such that the expected payoff from the contract (F, A) is greater than the expected payoff from the contract (F') for all $z_u \in (0, \hat{z}_u]$.

Finally, it is clear that for $z_u \in (0, \hat{z}_u]$, the TLO's optimal contract must contain an annual fee $A \geq z_u\pi$, but this contract is not unique. The maximum value of the upfront fee that can be supported is the value of A that solves $pq(\pi - C - A) - X = 0$ or $A = (\pi - C) - \frac{X}{pq} = \hat{A}$. Furthermore, equity payments must be sufficiently so as to guarantee the firm invests in commercial development. That is, t must be such that $(1-t)\pi - C \geq z_u\pi$. All contracts with an annual fee $A \in [z_u\pi, \hat{A}]$, and other payments set so as to extract all rents from the firm (with the condition $t \leq 1 - \frac{C}{(1-z_u)\pi}$ on the equity share) are also optimal.

Proof of Proposition 3

We first prove the "only if" part of the statement. Note that in a separating equilibrium, upon observing a technical failure, the TLO's belief should assign probability zero to the belief that the firm did not invest. Hence, in equilibrium, the TLO will not search for a second firm upon technical failure. It follows that a shelver's payoff from deviating and accepting the contract is equal to $\pi^m - F$, where F is the upfront fee set in the contract. The deviation is profitable whenever $\pi^m - F > (1-s)p\pi^d + (1-(1-s)p)\pi^m$ or $F < (1-s)pD$. Hence, to support the equilibrium $F \geq (1-s)pD$ must hold. Since the maximum upfront fee the TLO can set is $\hat{F}$, it follows that $\hat{F} \geq (1-s)pD$ is necessary to support a separating equilibrium.

To prove the "if" part of the statement, consider the contract $\overline{O} = (\hat{F})$. We show that this contract leads to separation, raises strictly more revenue and leads to a weakly higher probability of commercialization than other separating contracts or pooling contracts.

That $\overline{O}$ leads to strictly higher revenue and the same probability of commercialization than other separating contracts follows from the fact that $\hat{F}$ maximizes the amount of expected revenue the TLO can extract from non-shelvers. Furthermore, the probability of commercialization is the same for all separating contracts and is equal to $(1-s)p + s(1-s)p$.

Consider now a pooling contract O'. If a contract that both non-shelvers and shelvers accept is to be supported in equilibrium, from Lemma 1, it must be the case that shelvers shirk. Hence, with O', the probability of commercialization is no greater than $(1-s)p+s(1-s)p$, the probability of commercialization that would be obtained if the TLO was able to license the invention to a second firm upon observing a technical failure with the first firm. We now show that with O', expected revenue cannot possibly be greater than with $\overline{O}$. To this effect, we consider two cases. First, suppose that the TLO cannot profitably license to a second firm upon observing a technical failure. In this case, the result follows from assumption **A1** with $q = 1$ and $\hat{z} = 1$. Indeed, under O', the maximum amount of expected revenue that can be raised from the first firm is no greater than $(1-s)\hat{F} + s(1-s)pD$. Therefore, the payoff the TLO can guarantee itself with O' is equal to $(1-s)\hat{F} + s(1-s)pD - [1-(1-s)p]L$. The TLO's payoff from offering $\overline{O}$ is instead equal to $(1-s)\hat{F} + s(1-s)(\hat{F} - K) - [1-(1-s)p - s(1-s)p]L$. The difference between the TLO's payoff under O' and its payoff under $\overline{O}$ is equal to $s(1-s)(pD - \hat{F} - pL + K) < 0$, where the strict inequality follows from **A1**.

Now suppose the TLO is able to license to a second firm upon observing a failure with the first firm. In this case, the probability of commercialization under O' is equal to $(1-s)p+s(1-s)p$. We now show that expected revenue cannot possibly be greater than under $\overline{O}$. To this effect, note that if a non-shelver accepts the TLO's contract and shirks in technical development, while correctly anticipating that the TLO will search for a second firm, then the upfront fee must be set equal to zero in O'. Indeed, a shelver's payoff from rejecting O' is equal to $(1-s)p\pi^d + [1-(1-s)p]\pi^m$. Its gross payoff from accepting the contract is also equal to $(1-s)p\pi^d + [1-(1-s)p]\pi^m$, since the shelver fails with probability one. Hence a shelver will accept the contract only if the upfront fee is equal to zero. Thus, the TLO earns no revenue from a shelver in this case. Furthermore, the maximum amount of expected revenue that can be extracted from a non-shelver is equal to $\hat{F}$. Because positive revenue can be obtained from a second firm only if that firm is not a shelver, it follows that the maximum amount of revenue the TLO can possibly obtain in this case is equal to $(1-s)\hat{F}+s(1-s)(\hat{F}-K)$, which is equal to expected revenue under $\overline{O}$. Hence, we have proven the result.

Proof of Proposition 4

From Proposition 4, a separating contract cannot be supported in equilibrium. Hence we focus our attention on pooling contracts that both firms accept. Since (4) does not hold, the project is abandoned following a technical failure. It follows immediately that a shelver can guarantee itself a payoff of $\pi^m - F$ by accepting the contract and shirking. Hence, a shelver will accept any contract with an upfront fee that satisfies $F \leq (1-s)pD$. From the definition of $\hat{F}$ and the assumption $\hat{F} < (1-s)pD$, it follows that if the TLO offers $\hat{O} = (\hat{F})$, both shelvers and non-shelvers will accept the contract. Non-shelvers will invest X, while shelvers will shirk. Since continuation payments are only paid by non-shelvers, including such payments would strictly lower the TLO's expected revenue without affecting the probability of commercialization. Hence, it would lower the TLO's expected payoff. Since the maximum upfront fee non-shelvers are willing to pay is equal to $\hat{F}$, offering the contract $\hat{O} = (\hat{F})$ is optimal and thus, is the unique equilibrium contract.

Proof of Proposition 5

By Lemma 1 and Proposition 4, we focus our attention on pooling equilibria in which non-shelvers accept and invest X and shelvers accept, but shirk. If such an equilibrium exists, then given that (3) is satisfied by assumption, the TLO cannot commit not to search for a second firm. We have argued in the text that this implies a constraint on the upfront fee that the TLO can set in the contract in the form of equation (5). That is, if an equilibrium exists, the upfront fee is set equal to zero. Now consider a contract $O' = (M', A', t')$ in which the upfront fee is set equal to zero and the expected value of continuation payments is equal to S'. In equilibrium S' must satisfy the following for a non-shelver to accept the contract

$$p(\pi - C - S') - X \geq 0 \iff S' \leq \pi - C - \frac{X}{p} \equiv \overline{S},$$

and t' must satisfy $(1-t')\pi - C \geq z_u\pi$ or $t' \leq \hat{t}$, otherwise a non-shelver will prefer not to invest C in commercial development. Let M' and A' denote the technical milestone payment and the annual fee included in the contract. Since shelvers will not pay equity shares, there is no loss of generality in assuming that $S' = M' + A'$. That is, the TLO sets $t' = 0$.

Under this contract, a shelver will be indifferent between rejecting and accepting, but shirking. However, for the contract to be part of an equilibrium, shelvers must prefer shirking to investing X. A shelver will prefer to shirk if and only if:

$$\pi^m - p(M' + A') \leq (1-s)p\pi^d + [1-(1-s)p]\pi^m \iff S' \geq (1-s)D - \frac{X}{p} \equiv \underline{S}.$$

Since $\overline{S} - \underline{S} > 0$ from the assumption $\pi - C > (1-s)D$ (which is **A2** with $q = 1$), it follows that any contract $\overline{O} = (M, A)$ where $M + A = \overline{S}$ satisfies all necessary conditions for an equilibrium. Furthermore, by extracting an amount of expected revenue equal to $p(\pi - C) - X$ from non-shelvers, the contract maximizes expected revenue. Since no other contract could possibly generate a greater probability of commercialization, $\overline{O}$ is an equilibrium contract.

Finally, although we ruled out equity shares for simplicity in the first part of the proof, it should be clear that any contract in which $t \leq \hat{t}$, $\underline{S} \leq M + A \leq \overline{S}$ and $p(t\pi - M - A - C) - X = 0$ is a contract that can be supported in equilibrium. Indeed, this contract is incentive compatible and generates the same expected revenue and the same probability of success as $\overline{O}$.

Proof of Proposition 6

Consider the contract $\underline{O}$ in the statement of Proposition 6. First, note that $A = z_u\pi$ implies that an unintentional shelver returns the license to the TLO. However, $F = \underline{F}$ implies that, ex-ante, a non-shelver will accept the TLO's contract since it yields an expected payoff of zero. On the other hand, a shelver's payoff from accepting the contract is equal to $\pi^m - \underline{F}$, while its payoff from rejecting is equal to $(1-s)p\hat{z}\pi^d + [1-(1-s)p\hat{z}]\pi^m$. Under the assumption $(1-s)p\hat{z}D \leq \underline{F}$, it is easy to see that the former is less than the latter. Hence a shelver rejects $\underline{O}$. It follows that the TLO's expected payoff from offering $\underline{O}$ and behaving optimally with a potential second firm is equal to

$$(1-s)\left\{pq(\pi - C) - X + p(1-q)[(1-s)(\hat{z}\pi - qC) - K]\right\}$$
$$+s(1-s)[p(\hat{z}\pi - qC) - X] - sK - [1-Q]L. \tag{6'}$$

where $Q = (1-s)p[q + (1-q)(1-s)\hat{z}] + s(1-s)p\hat{z}$ is the probability of successful commercialization.

Compare the expected payoff in (6') to the expected payoff from offering the contract $\hat{O}' = (\hat{F}')$, where $\hat{F}' = p(\hat{z}\pi - qC) - X$. This contract clearly maximizes the TLO's expected payoff in the class of separating contracts that do not induce unintentional shelvers to give back the license. The TLO's expected payoff from offering $\hat{O}'$ is equal to:

$$(1-s)p(\hat{z}\pi - qC) - X + s(1-s)[p(\hat{z}\pi - qC) - X] - sK - [1-Q']L, \tag{7'}$$

where $Q' = (1-s)p\hat{z} + s(1-s)p\hat{z}$ is the probability of commercial success.

In the limit as z_u goes to zero, the difference between (6') and (7') is equal to

$$(1-s)p(1-q)[(1-s)q(\pi - C) - K] + (1-q)(1-s)^2 qL,$$

which is strictly positive under assumption **A1** (as z_u goes to zero).

The proof that a pooling contract cannot possibly provide the TLO with a strictly higher expected payoff is similar to the second part of the proof of Proposition 3, where we compare a pooling contract to the separating contract.

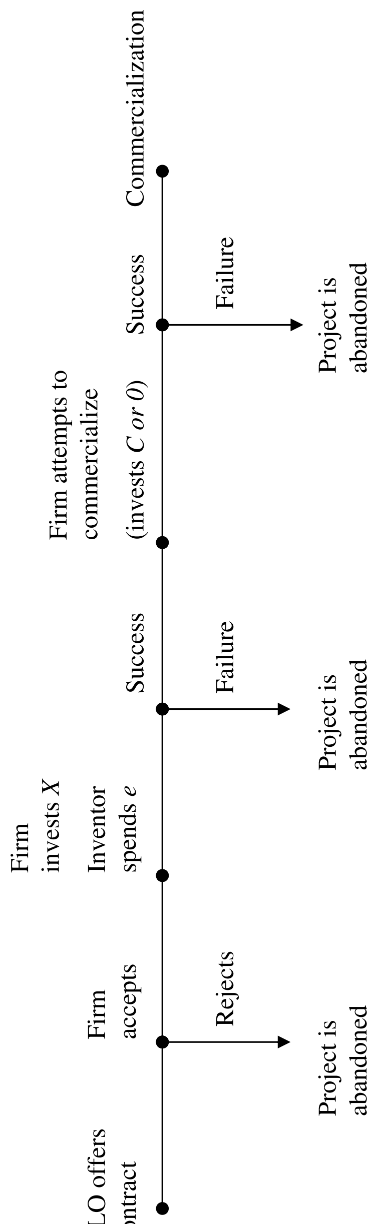

Figure 1: Timeline of decisions.

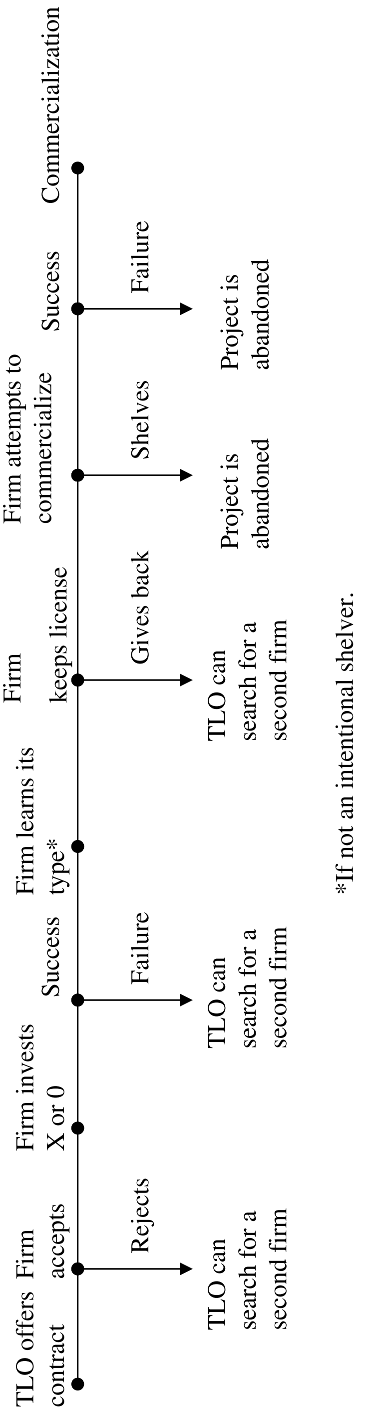

Figure 2: Timeline of decisions in the game with shelvers.