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ABSTRACT

University license contracts are more complex than the fixed fees and royalties typically examined by economists. We provide theoretical and empirical evidence that suggests milestones, annual payments, and consulting 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. Royalties are optimal only when the licensee is risk averse. 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 requires milestones if the firm licenses an invention with the intention to shelve it. Whether annual fees or milestones prevent shelving depends on the university credibly threatening to take the license back from a shelving firm. When such a threat is not credible an upfront fee is needed. 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

License contracts for university inventions tend to be complex. A typical contract includes royalties based on sales and a mixture of fees, including those paid upfront, annually, and when technical milestones are met. In a survey of 62 US university technology transfer offices, 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 (Jerry Thursby *et al.* 2001). The same survey showed that 88% of the inventions licensed require further development and 71% require inventor cooperation in development (Richard Jensen and Marie Thursby 2001). This paper is motivated by these results along with those of a survey we conducted of 112 businesses that license-in university inventions which shows that, in addition to complex fees, consulting contracts are often combined with licenses when inventor cooperation is needed. Existing theories of licensing, which focus on simple fixed fees and royalties, cannot explain these complex contracts.

In this paper we argue that complex payment terms are common because moral hazard, risk, and adverse selection all play a role when embryonic inventions are licensed. The need for inventor cooperation presents a moral hazard problem since inventors may "shirk" if they prefer research to development. Risk almost surely plays a role as respondents to the business survey report that 50% of the inventions licensed from universities fail, many for purely technical reasons. There is also an adverse selection problem because firms may "shelve" an invention either because their intent in licensing is simply to prevent development by their rivals or, more innocently, because by the time development is completed expected profits are less than originally anticipated. While moral hazard and risk have been studied extensively, shelving has not. We show that this is an important oversight since it is the combination of distortions that necessitates complex contracts. While payments based on commercial success, such as royalties, work to reduce risk and moral hazard, they exacerbate problems with shelving. The analysis of contracts with shelving is also important for current policy debates over "march-in" rights of the Bayh-Dole Act, which governs the licensing of most university inventions. The Act gives universities the right to own and exclusively license results from federally funded research, but this right is contingent on "reasonable" efforts toward commercialization.[1] The fact that the federal government has never exercised these rights has contributed to the view that the law should be strengthened (Arti Rai and Rebecca Eisenberg 2003).

We construct a series of theoretical models in the context of the contingent ownership scheme specified by Bayh-Dole and examine the role of contracts in solving the moral hazard, risk-sharing, and adverse selection problems that arise when inventions need further development for commercial use. While earlier work showed that royalties can address inventor moral hazard, in our models state-

[1]The Act allows the funding agency to take back ownership of the invention and license it to another firm if the licensee does not "take effective steps to achieve practical application of the subject invention (35 USC 1a)."

contingent fixed fees or milestones serve this function without the inefficiency of royalties (Jensen and Thursby 2001, Ines Macho-Stadler *et al.* 1996 and Jay Pil Choi 2001). When milestones are feasible, it is optimal to include royalties only when the licensee is risk averse. We show that consulting contracts complement milestones in solving the moral hazard problem and we provide conditions under which they increase the expected payoff of all parties involved.

When the inventor can observe the firm's effort and all parties are risk neutral, there are instances in which the same milestone contract that solves the problem of inventor moral hazard can prevent intentional shelvers (firms which never intend to develop an invention) from licensing. This result depends on the ability of the university to credibly threaten to take the license back from a shelver and license the technology to a different firm. However, when licensee effort is neither contractible nor observable, a high upfront fee is more effective at separating shelvers from non-shelvers than is the threat to take the license back. Milestones alone are not sufficient to solve the shelving problem that arises when firms expect to commercialize an invention *ex ante*, but face different incentives once development is completed. In this case, we show that annual payments in addition to a milestone are needed to provide the firm with the incentive to return the invention to the university. Here again, the ability of contracts to separate shelving from non-shelving firms depends on a credible commitment on the part of the university to terminate the license. Thus, while our analysis supports the *rationale* for the Bayh-Dole "march-in" provision, it also suggests that the need for the federal government *to exercise* these rights may be obviated by the types of contracts that are executed.

When inventions require licensee *and* inventor development it is unlikely that license contracts will be simple. With the exception of milestone payments, no single payment type can address moral hazard, risk-sharing, and shelving. Moreover, milestones alone are sufficient to prevent shelving only when the original intent is to prevent rivals from development and the inventor can observe licensee commercialization efforts; otherwise annual payments and upfront fees are called for. Milestones are also likely to be inferior to royalties for risk-sharing since they serve to share only the risk associated with the milestone (rather than market risk).

The empirical relevance of these arguments depends on the extent to which parties are concerned about moral hazard, risk, and shelving as well as factors such as the feasibility of defining milestones, as well as royalties, for embryonic inventions. With the prevalence of milestones and royalties reported in our university and business surveys, all of the fees and royalties we discuss are clearly feasible for the majority of inventions licensed. To examine licensee attitudes toward inventor moral hazard and risk we use data from the business survey. The survey included a series of questions on the use of different payment types for early and late stage inventions, as well as when inventor cooperation is and is not critical. Analysis of these responses shows that milestones are perceived to be most important for assuring inventor cooperation, while also playing a secondary role in risk sharing. Royalties are not used to address moral hazard and their risk sharing role is mitigated by difficulties in defining them for early stage inventions. The survey also includes data on consulting contracts in relation to the need for inventor cooperation. Our analysis of these data support the complementarity of milestones and consulting suggested by the theory. Finally, evidence from the university survey suggests that university licensing professionals perceive shelving as a realistic threat and are willing to terminate licenses as a measure of due diligence.

This paper contributes 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 Morton L. Kamien [1992] for a review). Exceptions are Ashish Arora (1995) and Alain Bousquet *et al.* (1998) which 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, Bousquet *et al.* (1998) consider milestones impractical for risk sharing since there are no development milestones in their model. By contrast, we find that milestones are not only feasible but may be easier to define than royalties for early stage inventions.[2] Our most novel results pertain to the adverse selection problem presented because shelvers have private information about their intent. Prior studies find that licensor and/or licensee private information can be used to justify royalties (see Nancy T. Gallini and Brian D.Wright 1990 and W. Beggs 1992). We show that with shelving, fees paid upfront, annually, or when milestones are achieved address the problem while royalties exaggerate it.

Our work is also related to the literature on the organization of R&D with incomplete contracts. The work closest to ours is that of Philippe Aghion and Jean 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 possibly 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. We contribute to this literature by showing that contingent ownership combined with appropriate contract terms is important when shelving is a possibility.

We also contribute to the empirical licensing literature which has, like the theoretical literature, focused primarily on fixed fees and royalties (C. T. Taylor and Z. A. Silberston 1973, Richard Caves *et al.* 1983, M. D. Rostoker 1983, Macho-Stadler *et al.* 1996, and Bousquet *et al.* 1998). An exception is Mark G. Edwards *et al.* (2003) which provides evidence on the frequency of milestones and other fees in biotechnology licenses. With the exception of Arora (2001), Bhurat Anand and Tarun Khanna (2000), and Daniel Elfenbein (2004), few studies provide econometric models.[3] The study closest to ours is Elfenbein's which examines the likelihood

[2] Milestones are often as simple as the licensee having a business plan. Other milestones include development benchmarks such as clinical trials.

[3] Arora examines the complementarity of know-how transferred and patent rights for import

of termination of licenses for Harvard inventions as a function of royalties and milestone payments. His analysis differs substantially from ours as it is purely empirical and abstracts from the role of different distortions in explaining the use of royalties and milestones.

Finally, we contribute to the literature on university licensing and associated public policy concerns (see Ajay Agrawal 2001 and Thursby and Thursby 2003 for reviews). The crux of the Bayh-Dole "march-in" debate is whether the Act has sufficient safeguards since shelving by exclusive licensees deters rather than enhances commercialization. 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 for exercise of federal march-in.

Section 2 provides a benchmark model of university licensing in which inventor effort and firm investment are both contractible. Sections 3 and 4 examine contract terms when inventor effort and firm investment are not contractible, respectively. Section 5 presents empirical evidence on contract design and Section 6 concludes.

2 A model of university licensing

Consider the problem faced by a university technology transfer office (TTO) that has the responsibility for licensing an invention requiring further development before commercialization. There are two stages of development. In the first, inventor effort and firm investment are needed to determine technical success, and in the second, the firm invests in commercialization. The probability of technical success 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 $p(e, X) \in [0, 1)$. $p(e, X)$ is increasing in both arguments and strictly concave in e. If the invention is a technical success, the firm then invests in commercialization with probability of success $q \leq 1$.

The university owns and can exclusively license the invention but, in accordance with Bayh-Dole, this property right is contingent on the licensee making "reasonable" efforts to commercialize it. The TTO acts on behalf of the university and maximizes utility given by $E\mathbf{U}_A(\tilde{R}; L)$, where $\tilde{R}$ is random total revenue from licensing equal to R_s in case of commercial success and R_f in case of commercial failure. The majority of respondents to the university survey reported that they view their job as implementing Bayh Dole with successful commercialization as an important objective in addition to revenue generation (Thursby *et al.* 2001).[4]

agreements in India from 1950-75, but does not examine license payment terms. Anand and Khanna examine license contracts from a data base of strategic alliances with at least one US participant from 1990-93. The characteristics they examine include exclusivity, cross-licensing, *ex ante* versus *ex post* transfer, and prior relationships of licensors and licensees.

[4]We abstract from any agency problems between the TTO and administration. See Jensen *et al.*(2003) regarding the alignment of TTO and administration objectives.

Accordingly we assume:

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

where $(1-\alpha)$ is the share of revenue that accrues to the TTO and L is the loss associated with failure to commercialize. Thus even if $R_s = R_f$, the TTO strictly prefers the outcome where the invention is commercialized.

The inventor has utility $U_I(\alpha\tilde{R})$, where α is her share of license revenue and she incurs disutility of effort $V(e)$. She is either risk neutral or risk averse, so that $U_I'' \leq 0$, and her marginal disutility of effort is strictly positive and strictly increasing ($V' > 0$ and $V'' > 0$).

The firm's full expected payoff is $EU_F(P)$ where P is the firm's (random) profit net of license payments. The firm may be risk neutral or averse. In most of the analysis, we focus on risk neutral firms, in which case, a firm investing X in Stage 1 and C in Stage 2 has expected profits gross of payments to the TTO of

$$p(e, X)(q\pi(x) - C) - X.$$

where $\pi(x)$ denotes operating profits as a function of output. Throughout, we assume that the functions U_A, U_I and U_F are continuous and differentiable twice as a function of income. We also assume that U_A is strictly concave as a function of income.

The timing is as follows. The TTO offers the firm an exclusive license contract that specifies all payment terms. If the firm rejects the offer, the game ends. If it accepts, the inventor and the firm choose effort and investment, respectively, to determine technical success of the invention. If the firm reports that the invention doesn't work, the game may or may not end depending on the circumstances. If the invention is technically successful, the firm decides whether or not to invest in commercialization.

In general, inventor effort and firm investment (e, X or C) are neither observable nor contractible. However, as a benchmark we consider the TTO's problem if they are observable and contractible. In this case, the TTO can offer an enforceable contract specifying the amount of effort expected from the inventor and the optimal payment by the licensee is a fixed fee, f^*, that extracts all of the firm's profits (Kamien 1972). The TTO's problem is to choose effort to maximize its utility subject to the firm's and the inventor's participation constraints.

$$\begin{array}{cl} \text{Maximize} & \mathbf{U}_A(f; L) \\ \text{with respect to} & e \geq 0 \\ \text{subject to} & EU_I - V(e) \geq 0 \\ \text{and} & f = f^* \geq 0. \end{array} \tag{1}$$

Since f^* and $\mathbf{U}_A(f^*; L) = U_A(f^*) - (1 - p(e, X))L$ are strictly increasing in e, the TTO will pick the maximum level of effort consistent with the inventor's participation. That is, if effort is contractible, the TTO will set $e = e^*$ where e^* is given by:

$$e^* = \max\{e \geq 0 | U_I(\alpha f^*) - V(e) = 0\}.$$

Under our concavity assumptions, e^* exists and is unique. Moreover, we assume that e^* is strictly positive. Note that if for effort level e^*, f^* is negative, then the firm will not accept any contract offered by the TTO because the expected profit from developing and commercializing is less than the cost of technical development at the maximum level of effort consistent with the inventor's participation. Thus, we assume that $f^* \geq 0$ when $e = e^*$.

3 Non-contractible inventor effort

Now suppose there is no problem with firm shelving, but that inventor effort is subject to moral hazard since her effort is unobservable. Our university survey revealed that TTO personnel view obtaining faculty participation as one of the more challenging parts of their jobs (Thursby *et al.* 2001, 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.

3.1 The role of milestones: Shirking

In general, the inventor solves:

$$\text{Maximize } E[U_I(\alpha \tilde{R})|e] - V(e) \text{ with respect to } e. \tag{2}$$

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. We therefore consider a contract which includes a payment contingent on technical success, m, in addition to the fixed fee.

For simplicity, we assume a fixed investment, $X > 0$, by the firm is necessary if technical success is to be determined (for example the cost of equipment necessary for the inventor's development experiments). Since $p(e, 0) = 0$, we can write $p(e) = p(e, X)$ for $X > 0$. The firm's expected profit is then:

$$EU_F = p(e)(q\pi(x) - m - C) - X - f. \tag{3}$$

The TTO maximizes $E\mathbf{U}_A(\tilde{R}; L)$ with respect to m and f, subject to the firm's and the inventor's participation constraints and assuming that inventor effort $e^{**}(m, f)$ is optimal.[5] Our assumptions on the marginal disutility of effort

[5]The optimal effort level at an interior solution $e^{**}(m, f)$ is implicitly given by the first order condition to the inventor's problem $p'(e^{**}, X)\{U_I[\alpha(m + f)] - U_I(\alpha f)\} - V'(e^{**}) = 0$

imply that $e^{**}(m, f) > 0$ only if the milestone payment is positive.[6] The contract that induces positive inventor effort is then an $m > 0$ and $f \geq 0$ such that the firm's participation constraint is satisfied when effort is given by $e^{**} > 0$, which we denote as $\{m^{**}, f^{**}\}$.

Comparative statics allow us to show that inventor effort is increasing in the inventor's share of revenue α if she is risk neutral or not too risk averse, a result consistent with empirical studies of inventor response to economic incentives (Goldfarb and Colyvas 2003, Lach and Schankerman 2003). Optimal effort, given α is increasing in the milestone payment regardless of the inventor attitude toward risk. Finally, as in Jensen and Thursby (2001), effort is independent of the fixed fee f if the inventor is risk neutral and decreasing in the fee if the inventor is risk averse.

These results have three important implications when one or more parties is risk neutral. First, if the inventor and firm are risk neutral, the TTO's payoff is strictly increasing in the fixed fee since inventor effort does not depend on f. In this case, regardless of its attitude toward risk, the TTO will extract all of the firm's rent. Second, if the TTO is also risk neutral, its payoff is strictly increasing in m (substituting the firm's rent for f). Thus, if all parties are risk neutral, the TTO optimally sets the milestone payment equal to the maximum amount consistent with the firm's participation, i.e.:

$$m^{rn} = \max\{m \geq 0 | p(e^{**}(m))[q\pi(x) - C - m] - X = 0\}.$$

and the fixed fee is set equal to zero, $f^{rn} = 0$. Finally, if the firm is risk neutral, there are parameter values for which the TTO could enforce the first best level of effort by choosing m and f such that $e^{**}(m, f) = e^{*}$. As long as the firm's participation constraint is satisfied, this level of effort is feasible. If, however, the TTO is risk averse, this level of effort may be suboptimal so that, in general, we refer to $\{m^{**}, f^{**}\}$ as a second best contract.

3.2 The role of royalties: Shirking or sharing risk?

How does a milestone payment compare with a royalty? Consider first the case where the firm is risk neutral and the TTO and inventor are either risk neutral or not too risk averse, so that the only use of a royalty is to induce inventor effort. Jensen and Thursby (2001) show that inventor effort is increasing in the royalty rate if royalty revenue is increasing in the rate. One could find a royalty that induces the same effort as the milestone, but the royalty introduces an output distortion. Thus, for the same reason that equity dominates royalties in Jensen and Thursby, the milestone dominates a royalty when the royalty reduces the firm's

[6] 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 and inventor's problems. We therefore restrict our attention to the equilibrium with positive effort.

equilibrium profits. To see this, recall that when the inventor is risk neutral (or not too risk averse), other things equal, the TTO will set a fixed fee f that extracts all rents from the firm. Let $x(r)$ denote the firm's profit maximizing level of output when the royalty rate is r. We assume that $x(r)$ is unique and $x'(r) < 0$ and that royalty revenue $rx(r)$ is strictly concave so that its maximum is also unique. Then the firm's expected profit is $p(e)[q(\pi(x(r)) - rx(r)) - m - C] - X - f$. By setting a milestone payment equal to $m' \equiv qrx((r)) + m$, all else equal, the TTO weakly increases its payoff (strictly, if it is risk averse). Since this raises the firm's profit maximizing output, it can also raise the fixed fee.

Why then do we observe contracts that include both royalties and milestone payments? A natural explanation is risk aversion on the part of the firm. In our model, 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 has to pay the fixed fee plus the milestone payment but earns no revenue from the invention. A positive royalty rate will reduce the variance in the distribution of profits across states and so may be optimal.

The TTO's problem when fees, milestones, and royalties are allowed is to maximize $E\mathbf{U}_A(\tilde{R}(r, m, f); L)$ with respect to r, m and f subject to the firm's and the inventor's participation constraints and assuming that the inventor behaves optimally. We continue to assume the inventor is not too risk averse, so that the TTO uses the fixed fee to extract all rents from the firm. We are then left with a problem similar to that in Bousquet *et a*l. (1998) with the exception that we allow milestone payments. Suppose that the TTO sets a zero royalty (i.e., $\{0, m, f\}$) and consider a simultaneous marginal increase in r and a marginal decrease in m that keeps the inventor's incentives (and hence effort) constant (i.e., $x(0)qdr = -dm$.) For sufficiently low values of q, this will increase the firm's expected payoff (i.e., $p(e)[(1-q)U_F'(-m - X - C - f) - qU_F'(\pi[x(0)] - m - X - C - f)] > 0$, since U_F is concave), so that the TTO can increase the fixed fee, thereby increasing its own payoff. In this case, a positive royalty rate, milestone and fixed fee may coexist.[7] For sufficiently high values of q, the milestone alone provides for risk-sharing. Proposition 1 summarizes the optimal contract when the only incentive problems arise from uncertainty and the need for inventor effort.

Proposition 1 *Assume that the TTO's payoff increases with the fixed fee. Under the assumptions of the model, the optimal licensing contract with unobservable inventor effort includes a royalty only if the firm is risk averse. If the firm is risk neutral, then the optimal contract contains only a positive milestone payment tied to technical success.*

3.3 The role of consulting

The remaining puzzle with regard to inventor effort is why consulting is prevalent if milestones or royalties address inventor moral hazard. In this section, we analyze

[7] If the TTO's payoff is not increasing in the fixed fee, one cannot simply argue that the TTO will try to increase the firm's payoff to extract higher rents by increasing the fixed fee.

incentives for the firm and inventor to agree on a consulting contract after the firm has accepted the TTO's contract but before they start technical development. We do not model the offer process by which the inventor and the firm determine the terms of the consulting contract, but rather, we study the conditions under which both parties have an incentive to engage in consulting. We assume that consulting makes inventor effort observable to the firm and that the consulting contract is enforceable.[8]

To analyze the incentives for consulting, note that after the firm has accepted the contract and paid the fixed fee, its continuation expected payoff before the inventor spends any effort is given by:

$$p(e^{**})[q\pi(x) - m^{**} - C] - X \geq 0.$$

This expression is strictly increasing in the effort level (unless $X = 0$ and $p(e^{**})[q\pi(x) - m^{**} - C] = 0$), so that a firm's expected profit increases if it can increase inventor effort above e^{**}. For any $e > e^{**}$, we define $c(e)$ as this increase in expected profit

$$c(e) = (p(e) - p(e^{**}))[q\pi(x) - m^{**} - C] \tag{4}$$

and consider the conditions under which the inventor would accept a contract offering a share of $c(e)$ if she exerts additional effort. The inventor will accept a share of $c(e)$ only if:

$$\begin{aligned} p(e)U_I(\alpha(m^{**} + f^{**}) + c(e)) + (1 - p(e))U_I(\alpha f^{**} + c(e)) - V(e) \quad > \\ p(e)U_I(\alpha(m^{**} + f^{**})) + (1 - p(e^{**}))U_I(\alpha f^{**}) - V(e^{**}) \end{aligned} \tag{5}$$

which, if the inventor is risk neutral, is equivalent to

$$c(e) = (p(e) - p(e^{**}))[q\pi(x) - m^{**} - C] > V(e) - V(e^{**}). \tag{6}$$

That is, the increase in the firm's expected profit must more than compensate for the extra effort.

In general, given $\{m^{**}, f^{**}\}$, the maximum increase in surplus or "gains from trade" from a consulting contract is achieved by maximizing $c(e)$ (indeed, $p(e)$) with respect to e subject to (5). If a consulting contract is feasible given $\{m^{**}, f^{**}\}$, the TTO maximizes its profit by letting the firm and the inventor agree on such a contract since it increases the probability of success above $p(e^{**})$ without affecting the TTO's contract terms. Thus, if consulting is allowed and there exists $e > e^{**}$ satisfying (5), it must be part of the equilibrium since it increases all three players' payoff.

Equation (6), which is the relevant feasibility constraint when the inventor is risk neutral, provides insight into how consulting relates to the characteristics of the license. Since $p(e)$ is concave and $V(e)$ is strictly convex, (6) is more likely to be satisfied when e^{**} is low. The same qualitative observation holds when the inventor is risk averse (by considering (5))

[8] Note that in reality, the contract may not be enforceable in court. However most consulting relationships between a licensing firm and an inventor are not one-shot as in our model. In this case, enforceability may still occur through the potential loss in reputation from shirking.

4 Non-contractible firm effort

In this section, we examine the problems that arise because the firm's commercialization effort is not contractible. We examine two cases, 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. In either case, the licensee may shelve the invention. For simplicity, we refer to the first type of shelving as "intentional" and the second as "unintentional."

In order to focus on the ability of contingent ownership and contracts to prevent shelving, we assume all parties are risk neutral.[9] In the first case, we show that the second best contract $\{m^{**}, f^{**}\}$ can separate shelving from non-shelving firms as long as the inventor can observe firm development efforts and the university threatens to take back the invention without firm effort. If the inventor cannot observe these efforts, the threat is not credible and the existence of a separating equilibrium requires a higher upfront fee and lower milestone payment. In the second case of unintentional shelving, a milestone payment and fixed fee alone are not sufficient. Additional payments such as annual fees are needed to deter shelving. Importantly, this equilibrium also depends on the ability of the TTO to credibly threaten to take the invention back in the absence of firm effort.

4.1 The role of upfront fees: Intentional shelving

In this section, we incorporate the possibility that firms might license the invention simply to block rivals from developing it. This is similar to the situation of "sleeping patents" examined by Gilbert and Newbery (1982) in which a monopolist patents substitutes for 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. While the licensing literature has ignored this possibility, our interviews with TTO personnel reveal that they think shelving is a realistic possibility.

Suppose that a firm has expressed interest in the invention. 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 a *shelver*, S, earns profit π^m when it obtains the license for the invention but does not commercialize it, and $\pi^c < \pi^m$, if it obtains the license and commercializes it. The shelver earns π^d if another firm, holding the exclusive license, commercializes the invention. A

[9] The results extend directly to low levels of inventor risk aversion as long as the TTO's payoff increases with the fixed fee. If the inventor is sufficiently risk averse that the TTO's payoff decreases with the fixed fee, we postulate that the main insights derived in this section regarding the role of the milestone payment, the annual fee and the fixed fee should carry through since the results rely mostly on the effect of these instruments on the firms' payoffs. For this reason, the case of risk averse firms is more difficult to analyze as risk-sharing concerns arise.

shelver therefore saves an amount $D \equiv \pi^m - \pi^d$ when it obtains and shelves the license, preventing commercialization of the innovation. With probability $1 - s$, the firm is a *non-shelver*, NS. Non-shelvers earn profits equal to $\pi(x)$ by optimally producing x units of the new product if they commercialize it; they gain nothing from licensing and shelving. For simplicity, we write π for $\pi(x)$.

The timing of this game is as follows. Nature picks a firm to which the TTO offers a contract. The firm accepts or rejects the contract. If it rejects, the TTO must decide whether or not to search for a second firm at a cost K. We assume a second firm that is a non-shelver exists with probability z. If the first firm accepts, the firm and the inventor play the simultaneous development game. If the outcome of the development game is a failure, the TTO takes the license back from the firm. Note that failure can occur because the firm did not invest or the inventor spent no effort, or simply because the invention does not work. We consider two cases depending on whether or not the inventor can observe the firm's investment. It is reasonable to assume the inventor can observe whether or not the firm invests when there is a consulting contract between the inventor and the firm, or in general when inventor and firm cooperation is required for success. We assume that the inventor can then decide whether or not to report to the TTO about the firm's investment, after which the TTO decides whether or not to search for a second firm at cost K. If it cannot find another firm that will accept the contract, the project is abandoned. With probability z the TTO finds a second firm, in which case the TTO offers a contract and the new firm accepts or rejects it. We assume the TTO can only search once after taking a license back and that successful search cannot occur after the commercialization stage. Therefore, a shelver that keeps a license until the commercialization stage obtains π^m.

4.1.1 Firm effort observable by the inventor

When the inventor can observe whether or not the firm invests X (but not the firm's type), we show that the second best contract $\{m^{**}, f^{**}\}$ can be supported in a Perfect Bayesian Equilibrium if D, the difference between monopoly and duopoly profit for a shelver, is less than the net monopoly profit from successful commercialization.

Proposition 2 *Let* $\tilde{D}_1 \equiv \frac{q\pi(x)-C}{zq}$. *For sufficiently low* K, *if* $D = \pi^m - \pi^d < \tilde{D}_1$ *then the second best contract* $\{m^{**}, f^{**}\}$ *can be supported in a Perfect Bayesian equilibrium in which shelvers do not accept the TTO's contract, but non-shelvers do.*

Proof. See Appendix.

Critical for the result in Proposition 2 is the TTO's ability to credibly commit to take the license back and search for a second firm As shown in Appendix A, the conditions that ensure the TTO's ability to credibly commit are more likely to hold the lower is the cost of search K, the higher is the probabilty of successful search z, and the greater the utility loss from a failure to commercialize, $-L$. Finally, note that there is no role for royalties in driving intentional shelvers out since shelvers prefer contracts with all payments in royalties, which of course they never pay.

As we show in the next section, the result also depends crucially on the assumption that the inventor can observe whether or not the firm invests in development. If this were not the case, the TTO may not be able to prevent shelvers from accepting the contract by offering the second best contract.

4.1.2 Non-observable firm effort

In many situations, the inventor cannot observe the firm's effort, in which case the contract $\{m^{**}, f^{**}\}$ cannot be supported in a separating equilibrium. In this case, we provide qualitatively similar conditions on K, D, and z under which the TTO resorts to a higher fixed fee upfront that shelvers will not accept, but non-shelvers are willing to accept. In this case, the fixed fee is a mechanism to sort firms.

If D is sufficiently high, the TTO is not able to prevent shelvers from accepting the contract. This is most evident by considering the extreme case in which $D \geq q\pi - C$, where the return to a shelver from blocking commercialization is greater than the return to a non-shelver from commercializing. In this case, any individually rational fixed fee for a non-shelver can also be paid by a shelver. For high D, if an equilibrium (in pure strategies) exists, then, in equilibrium, shelvers accept the contract and shirk at the development stage. The TTO may or may not find it optimal to search for a second firm after observing a failure at the development stage depending on the cost of search K and the probability of finding another firm z.

Proposition 3 *For sufficiently low K, there exist $\tilde{D}_2$ and $\tilde{z}$ such that if $D \leq \tilde{D}_2$ and $z \geq \tilde{z}$, there is a unique equilibrium in pure strategies. In equilibrium, $m < m^{**}$ and $f > f^{**}$. Moreover, shelvers do not accept the TTO's contract.*

Proof. See Appendix.

Thus, up-front fees may play a critical role in sorting shelvers from non-shelvers. In contrast to the previous section, the threat of taking the license back and searching for another firm is not used to deter shelvers from accepting the contract. This is a consequence of the fact that, absent the inventor's signal that the firm did not invest, the TTO cannot credibly commit to licensing to a second firm, because in any equilibrium in which shelvers do not enter, the potential second firm interprets a failure as sure evidence that the invention does not work. Thus, the second firm is unwilling to invest. On the other hand, in an equilibrium in which shelvers accept the first contract and shirk, a second firm may be willing to take on the license after observing a failure since there is a chance that the invention failed because the first firm shirked.

The $\tilde{D}_2$ threshold in Proposition 3 is always below the threshold $\tilde{D}_1$ in Proposition 2. Thus the range of returns to shelving for which a separating contract is feasible is smaller than if the inventor can report to the TTO. Moreover, separation always entails a distortion of the contract terms away from second best.

4.2 The role of annual payments: Unintentional shelving

The other case we examine is one in which the firm expects to commercialize the invention *ex ante*, but faces different incentives once development is completed.[10] In this case, the second best contract $\{m^{**}, f^{**}\}$ is no longer optimal. We consider when annual fees, which are common in contracts, can induce the return of an invention that has low commercial potential for a licensee *ex post.*

We consider the situation where new information becomes available to the firm after technical success is determined but before the decision to incur C is made. This information reveals whether the commercial potential for the invention is good or bad, in which case the firm's type is G or B. The probability that the firm is of type B is $s < 1$. The probability that the firm invests in commercialization is q_i, $i = G, B$, where $q_G > q_B$, and the complementary probability $1 - q_i$ is the probability a firm of type i decides not to pursue commercialization even though it knows the invention works.[11] Strict "unintentional shelving" occurs when $q_B = 0$ so that the firm abandons commercialization with probability one. Further, if $q_G = 1$, a firm with high commercial potential always commercializes the invention.[12] To highlight the conditions under which contracts can ensure commercialization of inventions that work, we focus on contracts when $q_B = 0$ and $q_G = 1$, but we have also derived similar results for $q_B > 0$ and $q_G > 0$. For simplicity, we also assume $q = 1$. A firm's type is unknown to all players until technical development occurs, at which point the firm, and only the firm, learns its type.

As before, we assume that at any point before the commercialization stage, the TTO can take the license back and search for another firm which can be found with probability z at a cost K. We assume that if a second firm exists, it is of type G. Moreover, the TTO can observe if the invention works after development, so it can define a state contingent fixed fee or milestone payment.

As a benchmark, we first consider the optimal contract in the class of contracts that do not deter either type of firm from keeping the license after technical success.

[10] The CellPro-Johns Hopkins march-in dispute involved many issues beyond those considered here, but a part of the case involved unintentional shelving. Becton Dickinson licensed the My-10 antibody, invested in development, but later decided to withdraw from the therapeutic business. The Bayh-Cutler 1997 march-in petition claimed the university should have taken the license back.

[11] To illustrate, suppose with probability $1 - q_i$, the firm can allocate the cost of commercial effort, C, to a different project yielding a certain net profit π^i, where $\pi^i > \pi$. In this case, the return to developing the invention is π, but the full opportunity cost is $-C - \pi^i$, so that the firm will abandon the project for its best alternative.

[12] This assumption is without loss of generality in our case because we assume that the opportunity to find a second firm has vanished by the time the TTO finds out the firm will not commercialize. Therefore, if $q_G < 1$, with probability $1 - q_G$ a firm of type G is not interested in commercializing, but there is no incentive for the TTO to retake the license at this point so that annual fees would not be set after the commercialization stage.

We then show that if the chances of finding another firm are sufficiently high, the TTO can increase its payoff by offering a separating contract which includes an annual payment.[13]

Consider a TTO contract for which both types of firms keep the license once technical success is determined. Conditional on firm investment in technical development, inventor effort is $e^p(m)$ which solves:

$$\text{Maximize } \alpha p(e)m + f - V(e). \tag{7}$$

If, as we assume, the inventor is risk neutral and $V'''(e) \geq 0$, then e^p is strictly concave as a function of m.

For the firm to accept the contract before it knows its type, expected profit must be nonnegative or:

$$p(e^p(m))[(1-s)(\pi - C) - m] - X - f \geq 0. \tag{8}$$

We assume the firm is obligated to pay m on technical success even if the net expected return from the invention is negative at this point. Thus m is sunk once the firms decides whether or not to commercialize.

The highest milestone payment that a firm would be willing to pay when the inventor behaves optimally is then, $\hat{m}'$, or the maximum value of m that solves :

$$p(e^p(m))[(1-s)(\pi - C) - m] - X = 0. \tag{9}$$

Lemma 1 characterizes the optimal "pooling contract" $\{m^p, f^p\}$. which consists of a milestone equal to $\hat{m}'$and a fixed fee paid upfront that extracts the firm's rent. The proof is straightforward and relies on the fact that given risk neutrality, the TTO's expected payoff from a pooling contract is strictly increasing in the milestone payment.[14]

Lemma 1 *If the TTO is risk neutral, $m^p = \hat{m}'$ and $f^p = 0$.*

Now consider a *separating contract* such that only a type G firm will continue once it knows its type and has paid the milestone. Recall that conditional on a type B firm returning the license, the TTO can search for another firm. At this point, technical development has been completed so that the TTO maximizes his payoff by offering a fixed fee contract $\{f_2\}$, which in equilibrium is equal to the firm's expected profit. Therefore, the TTO sets

$$f_2 = \pi - C, \tag{10}$$

[13] In a one period model, Beggs (1992) shows that an uninformed licensor will offer a separating contract that only high-value informed licensees accept if the difference in types is sufficient. Our timing assumptions allow us to relate this type of result to the presence of annual fees (rather than high fixed fees) in most university license contracts.

[14] Note that under our assumptions, if the TTO offers the pooling contract, it may still have an incentive to take back the license after development is completed and the first milestone is paid. This is obvisouly the case when K is equal to zero and $z \geq s$. However, in our model, the TTO can only take back the license in three situations: (i) the firm does not make a payment, (ii) the firm voluntarily returns the license or (iii) the firm fails at the technical stage.

and obtains a continuation expected payoff equal to:

$$z(1-\alpha)(\pi - C) - K - (1-z)L. \tag{11}$$

The TTO will search if and only if this continuation payoff exceeds the loss associated with failure to commercialize. This occurs for a sufficiently high probability of finding a second firm, or

$$z \geq \hat{z} \equiv \frac{K}{(1-\alpha)(\pi - C) + L}.$$

The only way for the TTO to induce type B firms to terminate the license is to set a fee to be paid after the first milestone. Let this fee be m_2 and denote the usual milestone payment by m_1. Optimal inventor effort in this case is denoted by $e^s(m_1, m_2)$ and solves the inventor's problem. The inventor expects to receive m_2 only if the first firm finds that it is type G. However every type of firm pays m_1. Given such a contract, the inventor's problem is:

$$\text{Maximize } p(e)\alpha[m_1 + (1-s)m_2 + szf_2] + f - V(e). \tag{12}$$

As before, to ensure firm participation, expected profits prior to their finding out their type must be nonnegative (given that effort is e^s). However, recall that only firms of type G continue and pay m_2 after development. Thus the constraint is:

$$p(e^s)[(1-s)(\pi - C - m_2) - m_1] - X - f \geq 0. \tag{13}$$

The optimal separating contract is a fixed fee f^s such that (13) is binding and a combination of fees, $m_1 \geq 0$, and $m_2 \geq 0$. In equilibrium, the TTO searches for a second firm only if the first firm encounters technical success but decides to give the license back, thus the inventor has no incentive to deviate and shirk with the first firm, since she would obtain a payoff of zero from doing so. Comparing (7) to (12), it is clear that if $z \geq \hat{z}$ and given $m = m_1$, the solution to (12) is greater than the solution to (7). Thus effort is higher with an annual fee even if the fee is set at an arbitrarily small level. By continuity, this will continue to hold true for m_1 arbitrarily close to m. Therefore, if $z \geq \hat{z}$, there exists a separating contract acceptable to the firm, which improves upon the pooling contract characterized in Lemma 1 from the TTO's point of view. On the other hand, if $z < \hat{z}$, the TTO would not search after taking the license back from the first firm, so that the pooling contact is optimal.

Proposition 4 *If the TTO is risk neutral, then*

(i) If $z \geq \hat{z}$, a separating contract including an annual fee $m_2 > 0$ exists and is optimal.

(ii) If $z < \hat{z}$, a pooling contract without annual fee exists and is optimal.

Note that, as with intentional shelving, the existence of a separating contract depends on the incentives for the TTO to terminate a license and search for another firm. However, because the licensee does not know its type until after the technical development stage, the ability of the inventor to observe and report shelving is no longer important. Finally, we have not shown that milestone payments and annual fees coexist in the sense that both are strictly positive. m_2 is constrained to be slightly above zero. However, since the annual fee also serves to provide incentives for the inventor to exert effort, it could be the case that $m_1 = 0$.[15]

5 Empirical implications

Results of our theoretical analysis are summarized in Table 1 where the row labels give payment terms and column labels give potential incentive problems when embryonic inventions are licensed. A plus sign indicates that a payment type works to overcome the problem listed in the column, while a minus sign indicates that the payment term exacerbates the problem, and a zero indicates no effect. Where a cell is blank, the case was not explicitly modeled.

Two results stand out. First, contracts are likely to be a complex mixture of fees and royalties, because, with the exception of milestones, no single payment type can address moral hazard, risk-sharing, and shelving. Moreover, milestones alone are sufficient to prevent shelving only if the original intent is to prevent rivals from development and the inventor can observe licensee commercialization efforts; otherwise annual payments and upfront fees are called for. Thus, to the extent that licensing professionals think moral hazard, risk, and shelving play a role in inventor and firm incentives, contracts are likely to involve a complex mixture of payment types. Second, while royalties have multiple uses, including moral hazard, that are well understood from the literature, our analysis suggests that their only optimal use in the context of the distortions we address is risk sharing. Taken together our propositions predict the use of royalties only to share risk and the use of milestones, consulting or other payments for moral hazard or shelving.

Thus, there are a number of clear empirical implications of our theory. Unfortunately, as other authors have noted, much of the data to test contract theories is unavailable. For example, if upfront fees do prevent intentional shelving then it is not possible to pair data on intentional shelvers with contracts that employ upfront fees. Further, while data on contract terms are available, data on faculty participation are not paired with these contracts. For these and other reasons, existing studies have relied on survey evidence, and we do as well.

A portion of our data come from our earlier survey of the TTOs of 62 US universities, which was designed to provide information on the types of inventions licensed, their objectives in licensing, and their licensing practices. The data that allow us to examine the extent to which different payment types are related to risk sharing or moral hazard come from a survey of businesses who license from universities. Details of survey design for both surveys are given in Appendix C.

[15] Conditions available from the authors.

	Risk	Moral Hazard	Unintentional Shelving	Intentional Shelving
Fixed fees				
Upfront		0/-		+
Annual			+	
Milestone	+	+		+
Royalty	+	+	-	-
Consulting		+		

Table 1: Theoretical results

5.1 Inventor shirking, risk, and contract terms

We know from our university survey that inventions licensed in early stages, such as proof of concept or lab scale prototype, are riskier from a technical standpoint than later stage technologies (i.e. those for which manufacturing cost is known or those ready for commercialization). Both the university and business surveys reported 75% of the inventions licensed are no more than a lab scale prototype and that a substantial portion require inventor cooperation in development. Respondents to the business survey indicated that half of the inventions they licensed-in from universities failed and that 46% of those that failed did so for technical reasons. Thus both surveys suggest that inventor cooperation and risk are factors in licensing university inventions, and that *ceteris paribus* earlier stage inventions are considered riskier than late stage.

To provide information on business attitudes toward risk and payment types, we asked respondents the importance to them of different payment types for early stage technologies and late stage technologies. To provide information on business attitudes toward inventor cooperation, we asked the importance to them of different payment types when faculty input is critical and when it is not critical.[16] The exact questions are given in Table 2. Immediately below each question respondents were asked to indicate using a 5 point Likert scale from 5 (extremely important) to 1 (not important) the importance of several payment types including royalties, milestones and equity. We included equity since earlier work showed it could be used to address moral hazard (Jensen and Thursby 2001). Thus, for each of the four questions in Table 2 we have the importance attached to each of three payment types. That is, each respondent could provide up to 12 answers: the importance of each of three payments types for each of four technology characteristics. Out of 112 respondents to the survey, 91 answered at least some of the questions (58% provided at least one answer to each question), but not all respondents noted the importance of each of the payment types.[17] Overall, royalties are always more important than

[16] The intent here was to discern business attitudes. Thus alternative measures such as the portion of contracts with various payment types would not be useful since it is an equilibrium result and hence also reflect university attitudes and negotiation.

[17] It is not surprising that many respondents left blank answers for some questions. For example, if a firm has never used faculty in further development, then they would be unable to answer questions regarding the importance of payment types when faculty are critical and when faculty are not critical.

the other payment types, this is followed by milestone payments and then equity. The average given by respondents regarding the importance of royalties is 3.7 while importance for milestones and equity is 2.9, and 1.7, respectively.

To examine the relative importance of payment types in the circumstances outlined in the questions in Table 2, we consider three regressions in which the dependent variable is the importance a respondent attaches to a particular payment type (royalties, milestone payments, equity) as a function of a set of dummy variables that capture characteristics of the technology (early stage, late stage, faculty critical, faculty not critical). That is, we estimate the equations

$$R_{ip} = \beta_{0p} + \beta_{1p} EARLY_{ip} + \beta_{3p} CRIT_{ip} + \beta_{4p} NOTCRIT_{ip} + \varepsilon_{ip},\ i = 1, ..., n,\ p = 1, ..., 3$$

R_{ip} is the importance attached by individual i to payment type p, $EARLY_{ip} = 1$ for a technology that is early stage (0 otherwise), $CRIT_{ip} = 1$ for a technology for which faculty input is critical (0 otherwise), and $NOTCRIT_{ip} = 1$ when faculty input is not critical (0 otherwise). The omitted category is late stage technologies. Notice that these equations take a particular payment type (e.g., royalties) and then consider responses across the four questions listed in Table 2.

Since the responses are ordinal from 5, extremely important, to 1, not important, we use an ordered probit estimator. With each respondent appearing in each equation up to four times (that is, we have a panel of data) we use fixed effects models. Finally, we use robust standard errors. Regression results for payment type are in Table 3. Part A presents the probit coefficients along with t statistics and an indication of the level of significance. Part B provides chi-square statistics in tests for equality of the coefficients given in Part A.

The results for milestone are clear: they are most important when faculty are critical, this is followed by early stage inventions, then late stage inventions (the omitted category) which are not significantly different from faculty not critical. The importance of milestones when faculty are critical supports our argument that milestones serve to mitigate the moral hazard problem. The finding that early stage inventions are next most important supports our theoretical result that milestones serve to share risk – though they can only serve to share technical risk – and the fact that early stage inventions are generally riskier than late stage inventions.

In the equation for royalties we find several clear results. First, we find that there is no significant difference in responses for the cases where faculty are critical and not critical. In other words, royalties are not used to solve the moral hazard problem since if they were then royalties should be more important when faculty are critical.

Second, royalties are more important for late stage than for early stage technologies. This somewhat counterintuitive result is most likely related to the fact that royalties based on sales are the hardest to define for early stage inventions.[18]

[18] In the university survey, we asked an open ended question about the use of royalties. Thirty three percent said that royalties were always or almost always used except for software or technologies for internal firm use only. Common reasons for royalties listed were dealing with risk. As one respondent said "... if we knew how much the invention was going to make for the licensee - in advance - it would be quite reasonable to ask all royalties be paid up front."

Many university inventions are so embryonic that downstream products cannot be defined at the time of license and many inventions have a variety of applications (Shane 2000). Thus, in contrast to Bousquet *et al's* (1998) presumption that milestones may be hard to define, in the case of university licenses, royalties may be more difficult to define. There are therefore two competing effects for royalties: risk sharing which *ceteris paribus* would be more important for early stage technologies, and the difficulty of determining royalty rates which would make them more important for late stage technologies (which still reflect market risk). Our results suggest that the latter effect dominates.

Finally, the equity equation is weakly supportive of the role of equity in dealing with moral hazard: the only significant relationship (at the 10% level) is the greater role of equity when faculty are critical versus when faculty are not critical. Our weak results might well follow from the fact that for large, publicly traded companies, equity and cash are essentially equivalent. We considered this regression after dropping large firms, but the results continued to be poor.

5.2 The role of consulting

In Section 3.3, we showed that consulting and milestones can both address inventor moral hazard. In our business survey, we asked respondents to indicate the percent of time faculty consulting was used when faculty input is critical for further development. On average, respondents indicated that they used consulting 58.7% of the time. There was, however, a lot of variation in responses. The standard deviation was 34% and the range was from 0% to 100%. Some of this variation, we hypothesize, is a function of the seriousness of the moral hazard problem faced by firms.

To test for the link between consulting and moral hazard, we regress the percent of time the firm uses consulting on, among other factors, a measure of the moral hazard problem faced – or perceived to be faced – by the firm ($MILESTONE\_IMPORT$). The measure we use for moral hazard is the importance that firms report they attach to milestone payments when faculty are critical to further development. That is, we use their response to milestones in question 3 in Table 3. If, as the results in the previous section suggest, respondents view milestones as a mechanism for dealing with inventor moral hazard, then we argue the importance of milestone payments is a measure of the respondent's perception of inventor moral hazard faced by the firm.

Recall that respondents provide measures of importance ranging from 5 (extremely important) to 1 (not important). In this analysis we do not use the actual responses since respondents likely define levels of importance differently – for example, two respondents might view some payment type for some technology as equally important, but one scores it as a "5" while the other scores it as a "4." To get around this problem we compute the measure of importance as the deviation of a response from the average response a respondent makes to all questions.[19]

[19] We do not need to make this adjustment for the econometric models considered earlier since

Additional regressors include a dummy variable for small firms ($SMALL$). Here we define small as firms with fewer than 100 employees. Our reason for including a measure for size is based on discussions with university technology transfer professionals who told us that it is more common for small firms to use consulting as a means for obtaining faculty input.

We also include a variable to measure distance of a firm from the universities from whom they license ($DISTANCE$). The further a firm is from the faculty inventor, the more difficult is a consulting arrangement. In our survey we asked for the five universities most important in terms of licensing. Our measure of distance is the average distance from the universities listed by each respondent.

The use of consulting may depend, in part, on the stage of development of the technology. To control for stage of development we include the percent of the time that the firm licenses in technologies that are only a proof of concept ($PROOF$) and the percent of time that they license in technologies for which there is only a lab scale prototype ($PROTOTYPE$). These are the two earliest stages for technologies licensed in.

Finally, firms may also use sponsored research to obtain faculty input. In our survey we not only asked about the percent of time that consulting was used but also the percent of time sponsored research was used when faculty are critical. On average respondents indicated that they used sponsored research 46.8% of the time when faculty are critical. Our final variable is the percent of time sponsored research is used ($SPONRESEARCH$). Note that sponsored research and consulting, while not mutually exclusive, are very likely to be simultaneously determined. For that reason we use two-stage least squares (with robust standard errors). The instrument for sponsored research is the percent of in-house research conducted by the firm that is basic. In Thursby and Thursby (2003) we find a significant and positive relationship between sponsored research and in-house basic research.

Table 4 gives the results. Due to missing data we have only 36 observations. Nonetheless, we are able to uncover some significant relationships. Not surprisingly, the greater the distance between the firm and universities the less likely are consulting arrangements. Small firms, as expected, are more likely to use consulting. Finally, the coefficient of the importance attached to milestone payments when faculty are critical is positive and significant, which we argue shows that the more serious the moral hazard problem faced by the firm, the more likely it is to observe consulting contracts.

5.3 Shelving and contract terms

Propositions 2, 3, and 4 provide the conditions under which payment terms can separate shelvers from non-shelvers. The problem with testing these propositions is that if such separating contracts exist, then, in practice, shelving should not occur. Further, given the Bayh-Dole "march in" clause, it is difficult to believe that either TTO or businesses would accurately report problems with shelving. Nonetheless,

we used a fixed effects model.

the data we have indirectly support the models in Section 4.

In our business survey, we asked respondents how often they licensed in inventions for a variety of reasons. Reasons included product development, research tools, process improvement, and preventing a rival company from licensing the technology. Only 7 percent indicated that blocking a rival was an important reason. This is somewhat interesting since in Cohen et al.'s (2000) survey of R&D labs, the overwhelming reason that firms reported they patented inventions was to block rivals. Note, however, that blocking a rival need not involve shelving as the licensee could develop the invention and commercialize it to block their rivals.

Several questions in the university survey indicate that TTO personnel consciously attempt to prevent shelving. While we did not ask about milestone payments or fixed fees directly, we asked about the usefulness of annual payments in lieu of royalties.[20] Not surprisingly, the most common response to this question had to do with technologies for which it is hard to track a sales record (for example, when the technology is used for internal firm purposes). However, 10 of the 54 respondents (18.5%) who answered this question volunteered that annual fees were used to ensure due diligence to prevent shelving. In many cases, the respondents were clearly concerned about unintentional shelving. Several responses specifically noted intentional shelving, however, with one respondent noting the use of annual fees because of "fear that companies are only licensing technology to 'shelve' it due to a competitive market."

Despite the caveat that we would expect underreporting, we asked TTO respondents if they had problems with shelving despite their best attempts at due diligence.[21] Eleven of 61 (18%) respondents indicated that they had had problems with firms licensing a technology with the intention of shelving. Interestingly, none of the 10 who volunteered that annual fees were used to ensure due diligence indicated that they had problems with shelving. This is evidence, *albeit* weak, that fees can serve to deter those who initially intend to shelve.

Finally, it is important in our shelving discussion that the university can credibly threaten to terminate a license. In our university survey we asked for reasons universities terminated contracts.[22] Thirty-six of the 46 respondents (78%) to this question noted due diligence problems and/or non-payment. Only one university said it had never terminated a contract. The federal government has never exercised its march-in rights under Bayh-Dole, and it has been suggested that this is a shortcoming of the Act (Rai and Eisenberg 2003). Our theoretical results along with the apparent willingness of universities to terminate licenses suggests the opposite–that the march-in provision has been effective in providing the incentive for universities to execute separating contracts.

[20] Specifically, we asked the open ended question "In what circumstance is it desirable to include annual license fees in a license agreement instead of running royalties?"

[21] Our question was "Have you had problems with companies despite proper due diligence terms acquiring a technology and shelving it to prevent its commercialization?"

[22] Our question was "When the university has terminated an agreement, what was the most common reason?"

6 Conclusion

University-industry technology transfer is an important part of the national innovation system 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 payment in overcoming these distortions and argue that commonly observed license contracts can be explained by the presence of multiple distortions. We show that in the presence of moral hazard and adverse selection, contracts with simple fixed fees and royalties are unlikely to be optimal. Both our theoretical and empirical results suggest that milestones are prevalent because of inventor moral hazard. Royalties are not used to address moral hazard and the risk sharing role of royalties is mitigated by difficulties in defining them for early stage inventions. They also suggest that consulting as a part of license contracts is related to inventor moral hazard. Our results on adverse selection support the use of annual payments to deter unintentional shelving and milestones to prevent licensing by intentional shelvers. The existence of such separating contracts, however, depends crucially on the university's incentives to take back inventions. A university is more likely to take back inventions the higher is its disutility from the failure to commercialize, the higher is the probability it can find another licensee, and the lower are its search costs.

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 federal 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.

It is the university ownership of the invention that makes our contracting problems fundamentally different from those of Aghion and Tirole (1994). 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, Jean Jacques Laffont 1989). This solution is reminiscent of a commonly observed practice in university licensing, which consists of letting the inventor start up 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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7 Appendix A: Proof of Proposition 2

Suppose that the TTO offers $\{m^{**}, f^{**}\}$ to a firm. We show that if beliefs are such that a) if the firm accepts the contract, it must be a non-shelver and b) if the inventor turns in the firm for shirking, it must indeed have shirked, then $\{m^{**}, f^{**}\}$ is a Perfect Bayesian Equilbrium satisfying all incentive constraints and maximizing the TTO's payoff when the other players behave in accordance with sequential rationality.

First, we analyze the TTO's behavior if the firm turns down the offer. The TTO can either abandon the project, or search for another firm. If it searches and finds another firm, it is clear that it will offer $\{m^{**}, f^{**}\}$ to the other firm and the expected profit from search is:

$$z(1-\alpha)p(e^{**})m^{**} - K - (1 - zp(e^{**})q)L \tag{14}$$

while the expected payoff from abandoning the project is equal to -L. Thus, the TTO will search if, and only if (14) is greater than -L. Rearranging, this is equivalent to $(1-\alpha)zp(e^{**})m^{**} + zp(e^{**})qL \geq K$, which holds if K is sufficiently low.

Suppose now that the first firm offered the contract accepts. At the technical development stage, the inventor chooses effort and the firm chooses its investment level. Suppose for now that a non-shelver picks X with probability one (we check later that this is optimal). If shelvers turn down the contract in equilibrium, then, upon observing that the firm accepts, the inventor believes that it is a non-shelver. Thus, the updated probability that the firm is a non-shelver is equal to one in this case. Therefore, the inventor maximizes:

$$\alpha p(e)m^{**} - V(e). \tag{15}$$

with respect to e. The solution to (15) is e^{**}.

We now examine a shelver's incentive constraints. Suppose that contrary to equilibrium behavior, a shelver accepts the contract. Under what conditions will it invest in development? In equilibrium, the inventor turns in a firm that does not invest, but does not misreport and turn in a firm that invests, and the TTO always searches if the inventor turns a firm in. Thus, if a shelver does not invest, but the inventor exerts e^{**}, the second firm still has a probability of success equal to $p(e^{**})$. If the shelver does not invest in technical development, its expected profit is:

$$zp(e^{**})q\pi^d + (1 - zp(e^{**})q)\pi^m.$$

If it invests, it's expected profit:

$$\pi^m - p(e^{**})m - X.$$

Thus, a shelver that accepts the contract will invest with probability $v > 0$ only if the latter exceeds the former: or

$$zp(e^{**})[qD - m] - X \geq 0. \tag{16}$$

But since $e = e^{**}$ and $m = m^{**}$, by definition $p(e^{**})[q\pi(x) - m^{**} - C] - X = 0$.Thus, if $q\pi(x) - C > zqD \iff D < \frac{q\pi(x)-C}{zq} = \tilde{D}_1(> 0)$, (16) cannot hold.

We now check that the TTO would take the license back and license successfully with probability z in case the inventor reported that the first firm did not invest. At this stage, since the risk neutral TTO believes that the inventor worked with the first firm, it is indifferent between offering offers a fixed fee contract $\{f^n\}$ or a milestone only contract based on a probability of success $p(e^{**})$ as long as all rents are extracted from the second firm. However, to support in equilibrium, we require that the TTO offers a milestone only contract with milestone equal to m^n given by:

$$p(e^{**})[q\pi - m^n - C] - X = 0 \iff m^n = q\pi - C - \frac{X}{p(e^{**})}. \tag{17}$$

Thus, the TTO's incentive constraint is

$$\begin{aligned} z(1-\alpha)p(e^{**})m^n - K - (1 - zp(e^{**})q)L &\geq -L \\ \iff z(1-\alpha)[p(e^{**})(q\pi - C) - X] + zp(e^{**})q)L \geq K. & \end{aligned} \tag{18}$$

which is satisfied, again, for K sufficiently low.

It remains to check that all other equilibrium conditions are satisfied. Consider the inventor's incentive constraints. At the technical development stage, after having exerted effort $e(m^{**})$, on the equilibrium path, the inventor earns the following expected payoff:

$$\alpha p(e^{**})m^{**} - V(e^{**}).$$

Suppose the inventor works, but deviates and "turns in" the firm for shirking. Since the inventor turning a firm in should not be observed in equilibrium, Bayes's rule cannot be used to compute the TTO's and the second firm's updated probability that the firm truly shirked based on the inventor's report. Suppose that the TTO and the second firm believe that the firm shirked if the inventor reports that it did. Then, the TTO will take the license back and license it again with probability z. The inventor's payoff is then:

$$\alpha zp(e^{**})m^n - V(e^{**}).$$

Substituting for m^n in the above, it is easy to see that deviating yields a lower payoff than conforming since $p(e^{**})m^{**} > zp(e^{**})m^n$.

Suppose now that the inventor sets $e = 0$ instead of $e = e^{**}$, and turns the firm in for shirking. Since in this case, the TTO believes that the inventor worked but the firm did not, it will search for another firm. However, since the TTO offers a milestone only contract to the second firm, the inventor obtains a payoff of zero in this case, which is less than what it obtains from conforming to the equilibrium strategy; i.e., $\alpha p(e^{**})m^{**} - V(e^{**}) > 0$.

Finally, it must be the case that $\{m^{**}, f^{**}\}$ is the contract that maximizes the TTO's expected payoff in the first stage. The relevant part of the TTO's expected payoff is what it obtains with the first firm if the firm is a non-shelver:

$$(1 - s)[(1 - \alpha)p(e)m + f - (1 - p(e)q)L] \tag{19}$$

and the only constraint is given by a non-shelver's participation constraint $p(e)[q\pi - m - C] - X - f \geq 0$ with inventor effort solving $\max_e\{\alpha p(e)m - V(e)\}$. It is clear that the solution to the maximization of (19) is indeed $\{m^{**}, f^{**}\}$.

8 Appendix B: Proof of Proposition 3

We first derive conditions that must be satisfied in any equilibrium in which shelvers reject the TTO's contract, but non-shelvers accept it. If such an equilibrium exists, the TTO does not search for a second firm if it observes a technical failure with the first firm. Let $\{m, f\}$ be the contract offered to the first firm. If shelvers reject the TTO's contract, then for K sufficiently low, following a similar argument as in the proof of Proposition 2, the TTO will search for a second firm and offer $\{m^{**}, f^{**}\}$ to that firm. Thus a shelver's payoff from rejecting the contract is

$$zp(e^{**})q\pi^d + (1 - zp(e^{**})q)\pi^m$$

Moreover, since the TTO does not search for a second firm upon a technical failure, a shelver would shirk were it to enter. Thus a shelver's payoff from accepting the TTO is clearly $\pi^m - f$. Therefore a shelver will stay out if and only if

$$f \geq zp(e^{**})qD. \tag{20}$$

Given optimal behavior by the inventor, a non-shelver will accept the TTO's contract if and only if

$$p(e')[q\pi - m - C] - X - f \geq 0. \tag{21}$$

where e' is the solution to

$$\max_e \alpha p(e)m - V(e).$$

The TTO's problem in the first stage is thus to maximize its expected payoff given by

$$(1-\alpha)[(1-s)(p(e')m+f)+s(zp(e^{**})m^{**}]-sK-(1-s)(1-p(e')q)L-s(1-zp(e^{**})q)L \tag{22}$$

subject to (20) and (21). A solution with $m > 0$ (so that $e' > 0$) will exist only if f does not have to be too large to satisfy (20). However, in the limit as D goes to zero, the problem is similar to the case without shelvers, so that we know that a contract satisfying both (20) and (21) exists. By continuity, this will continue to hold true for a range of values of D. Furthermore, it is clear that the TTO will want to set the minimum fixed fee consistent with non-shelver rejecting the contract. This implies that in equilibrium $f = zqp(e^{**})D$. When it exists, let the solution to the above problem be $\{m', f'\}$, where $f' = zqp(e')D > 0 = f^{**}$, from which it follows that $m' < m^{**}$.

To show that for K low, D sufficiently small and z sufficiently large, the contract characterized above is the unique equilibrium in pure strategies, note first that in equilibrium, it cannot be the case that both types of firms enter and work on technical development. In this case, if a technical failure occurs, the equilibrium belief that that the invention does not work must be zero. Thus no second firm will want to license the invention. Therefore shelvers would do better by shirking instead of working. Thus if an equilibrium with both types of firms entering exists, it must be the case that shelvers shirk at the development stage. It follows that if the TTO's contract is $\{m'', f''\}$, its expected payoff is of the form:

$$(1-\alpha)[(1-s)(p(\tilde{e})m''+f'')+sR]-p_F L. \tag{23}$$

where $\tilde{e}$ is optimal inventor effort and R denotes expected revenue from licensing to the second firm (which can be zero) and p_F denotes the probability of commercial failure. Clearly $R \leq (zp(e^{**})m^{**} - K)$. Moreover, in the limit as D goes to 0 and z goes to 1, (22) converges to the TTO's payoff without shelvers, which can easily be shown to be strictly greater than $(1-s)(p(\tilde{e})m''+f'')-p_F L$. This follows from the fact that effort is lower under a contract that accommodates both types of firms including shelvers that shirk at the development stage. For this reason, the probability of commercial failure p_F will also be higher under such a contract. Therefore, there exist values of D and z, $\tilde{D}_2$ and $\tilde{z}$ such that if $D \leq \tilde{D}_2$ and $z \geq \tilde{z}$, in the unique equilibrium in pure strategies, the TTO offers $\{m', f'\}$.

9 Appendix C: Survey Data

Our data come from two sources. The first is a survey of university based technology transfer professionals and the second is a survey of business executives who actively license-in from universities. The university survey was sent to the top 135 U.S. universities in terms of licensing revenue as reported in the 1996 AUTM Survey and 62 responded. The majority of universities responding were public, and of the public universities responding, 62% were land-grant institutions. Private universities accounted for 37% of the responses. Average industry sponsored research for universities in the sample was \$16.9 million in 1996, and federally sponsored research was \$149.6 million. The average technology office in the sample reported 26.3 licenses executed, 92.3 inventions disclosures, 30.1 new patent applications and \$4.2 million in income for 1996. Compared to the 131 U.S. universities who responded to the 1996 AUTM survey, the respondents to our survey represent 68% of industry sponsored research, 75% of federally sponsored research, 71% of royalty income, 74% of the licenses executed, 70% of the invention disclosures and 48% of the new patent applications. For further details see Jensen and Thursby (2001).

The business survey was designed to be answered by individuals actively engaged in executing licenses, options, and/or sponsored research agreements with universities between 1993-1997. We received responses from 112 business units that had licensed-in university inventions. Firms in our sample accounted for at least 15% of the license agreements and 17% of sponsored research agreements reported by AUTM in 1997. Seventy-nine firms in the sample responded to a question on the top five universities with whom they had contractual agreements. The

85 universities mentioned include 35 of the top 50 universities in terms of industry sponsored research and 40 of the top 50 licensing universities in the 1997 AUTM Survey. The majority of respondents were employed by small firms, with 46% answering for firms with less than one-hundred employees and 17% for firms with more than one hundred but less than five hundred employees. In terms of industry segments, 31% of the respondents identified pharmaceuticals as the main industry in which their firm operated, 36% indicated biotechnology and medical devices as their main industry, and 33% indicated other industries. 91% of the sample conducted some R&D in-house. On average, 37% of the R&D conducted in-house was basic or discovery research, 44% was new product development, and 18% was process improvement. Further details of the survey can be found in Thursby and Thursby (2001, 2003).

Table 2. Business Survey Questions On Importance of Payment Types

1. When you license-in an *early* stage technology (e.g., proof of concept or lab scale prototype only), how important to you is it to include the following payment types?

2. When you license-in a *late* stage technology (e.g., nearly ready for commercial use)), how important to you is it to include the following payment types?

3. When faculty input *is* critical for further development of a technology, how important is it that the license-in agreement include the following payment types?

4. When faculty input *is not* critical for further development of a technology, how important is it that the license-in agreement include the following payment types?

Table 3. Fixed Effects Ordered Probit Results on Payment Type

A. Regression Results

	Milestone			Running Royalties			Equity	
	Coef.	t-Stat		Coef.	t-Stat		Coef.	t-Stat
EARLY	0.327	1.68	*	-0.613	-2.81	***	-0.197	-0.63
CRIT	0.929	3.62	***	-1.464	-6.19	***	0.237	0.64
NOTCRIT	-0.162	-0.85		-1.392	-6.30	***	-0.385	-1.06
No. Obs.	297			300			259	

B. Tests of Equality of Coefficients

	Milestone		Running Royalties		Equity	
Null Hypothesis	Chi-Square Stat		Chi-Square Stat		Chi-Square Stat	
EARLY=CRIT	5.97	**	16.41	***	1.80	
EARLY=NOTCRIT	7.46	***	16.84	***	0.35	
CRIT=NOTCRIT	20.07	***	0.10		2.96	*

*** Significantly different from zero at 1% level.
** Significantly different from zero at 5% level.
* Significantly different from zero at 10% level.

Table 4. Two-Stage Least Squares Results on Consulting

	Coef.	t-Stat	Coef.	t-Stat
SPONRESEARCH	-0.588	-1.54	-0.570	-1.88*
DISTANCE	-0.026	-2.39**	-0.026	-2.64**
MILESTONE_IMPORT	13.821	3.11***	13.745	3.29***
SMALL	19.073	1.81*	18.963	1.89*
PROOF	0.016	0.10		
PROTOTYPE	0.272	1.81	0.260	1.82*
CONSTANT	77.495	5.24***	77.988	5.85***
No. Obs.	36		36	
r-Square	0.50		0.51	

*** Significantly different from zero at 1% level.
** Significantly different from zero at 5% level.
* Significantly different from zero at 10% level.