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FOR SALE: THE TALE
OF UNIVERSITY LICENSING

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ABSTRACT

Proponents of the Bayh-Dole Act argue that unless universities have the right to license patentable inventions, many results from federally funded research would never be transferred to industry. Our survey of U.S. research universities supports this view. Results point to the embryonic state of most technologies licensed and the need for inventor cooperation in the commercialization process. Thus, for most university inventions, there is a moral hazard problem with regard to inventor effort. Our theoretical analysis shows that for such inventions, development would not occur unless the inventor's income is tied to the licensee's output by payments such as royalties or equity. Sponsored research can also be critical to commercialization, but it alone does not solve the inventor's moral hazard problem.

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1 Introduction

University licensing has increased dramatically since the passage of the Bayh-Dole Act which gave universities the right to retain title to and license inventions resulting from federally sponsored research. The 1996 *Survey of the Association of University Technology Managers* (AUTM, 1997) reports that licenses executed increased 75% percent between 1991 and 1996, with 13,087 licenses executed over the entire period. Such statistics notwithstanding, the Act has been subject to increasing Congressional review and debate. At issue is whether the commercial application and diffusion of inventions from federally funded research critically depends upon allowing universities to retain title to and license them. This paper speaks directly to this issue by providing survey evidence and theoretical analysis of the licensing practices of sixty-two U.S. universities, and analyzing several related theoretical models of licensing consistent with the types of licenses executed.

University licensing agreements, with the exception of those for software and reagent materials, invariably include both fixed fees and royalties. Many license agreements also include sponsored research clauses, and increasingly, license agreements include equity. The theoretical literature on licensing has largely abstracted from institutional features of this sort and has tended to focus on inventors who maximize profit (or revenue) from the sales of licenses.[1] In a university setting, revenue maximization is rarely the sole objective. Moreover, recent legal suits suggest that there are differences in the objectives of the inventor, technology managers, and university administrators.[2] Indeed, technology managers responding to our survey viewed themselves as balancing the interests of university administrators with those of inventors, who often prefer sponsored research to other objectives.

Perhaps the most striking result of the survey is that when they are licensed, most university inventions are little more than a "proof of concept." That is, at the time of license, most university inventions are at such an early stage of development that no one knows if they will eventually result in a commercially successful innovation or not. Moreover, they are so embryonic that further development with active involvement by the inventor is required for any chance of commercialization.

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[1] For a review, see Kamien, 1992.

[2] In two highly publicized lawsuits, University of California System researchers sued the university claiming the University ignored their financial interests when they negotiated license agreements. See Axelrod, 1996.

Our theoretical analysis therefore focuses on licensing a university invention for which the common knowledge probability of successful commercialization is zero at the time it is licensed. While a licensee-firm must ultimately spend resources to commercialize products based on the invention, further development effort by the inventor is required for *any chance* of commercial success. This assumption is sufficient to show that optimal license contracts cannot rely on only fixed fees, but instead must involve some sort of output-based payments, such as royalties. The intuition is simple. If the licensee pays a fixed fee, then the inventor has no incentive to expend further effort in the development process, in which case there is no chance that the invention will ever be commercially successful. In order to solve this moral hazard problem, the license contract must link some portion of the inventor's license income to effort expended in additional development. Because inventor effort increases the probability of commercial success, royalties can solve the moral hazard problem. There are, of course, other output-based payments, such as a share of profit, or equity, which will solve the moral hazard problem without the inefficiency inherent in royalties.

Our survey and concomitant theory contribute to the growing policy debate over the Bayh-Dole Act. This Act, intended to encourage commercialization of federally funded research, has been the focus of a recent Government Accounting Office review and an April 1998 House Hearing on the Irreplaceable Federal Role in Funding Basic Scientific Research.[3] Proponents of the Act argue that unless universities have the right to license patentable inventions, many results from federally funded research would never be transferred to industry. Our survey shows the majority of inventions licensed were indeed federally funded, and that the vast majority of them are so embryonic that commercialization requires the inventor to participate in further development. In the theoretical models we develop and analyze, some type of output-based license payments are necessary to induce this type of faculty involvement with industry.

These results also bring an institutional dimension and new results to the theoretical literature on licensing. A key result of this literature is that inventor profit can be maximized by using an auction, but not by using fixed fees or royalties.[4] Even if one abstracts from the multiple agents and objectives

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[3] Issues central to the role of the Bayh-Dole Act are highlighted in Claude Barfield's April 22 testimony before the House Science Committee (Barfield, 1998). A review of implementation of the Act in ten universities is given in GAO, 1998.

[4] See Kamien (1992) for an excellent survey.

of universities, our survey indicates an auction is simply not feasible for most university inventions. This literature also abstracts from research and development and issues of uncertainty. Exceptions are Katz and Shapiro (1985), Beggs (1992), Gallini and Winter (1990), and Jensen (1992a and 1992b). Both Beggs (1992) and Gallini and Winter (1990) show that optimal license contracts include combinations of royalties and fixed fees when there is asymmetric information about the invention. In the former, the licensee knows the value of the invention but the inventor does not, while in the latter the converse is assumed. The problem for university inventions is not that one agent knows the value and the other does not, but that at the time the license is executed, no one knows the invention's commercial value. Indeed, the commercial value is endogenous and a function of the license contract.

The work closest to ours is that of Aghion and Tirole (1994a, 1994b) who examine the organization of R&D in an incomplete contract framework.[5] However, their work focuses on the efficiency aspects of whether an invention is owned by the research unit, final customer, or some combination of the two. To this end, they derive conditions under which ownership is irrelevant for efficiency. One of these conditions is that either the research unit or the customer can independently develop the invention without assistance from the other. Applied to university R&D this would mean that is does not matter whether universities or licensees own the invention. Given the dramatic response of universities to the Bayh Dole Act, irrelevance of ownership seems unlikely. Moreover, our survey results make it quite clear that most university inventions could not be developed independently by either the inventor or the firm.

This paper also contributes to the growing empirical literature on the industrial impact of university research, notable examples being Jaffe (1989) and Nelson (1982). With the exception of the work of the Zucker-Darby team, this literature has focused on spillovers from university research via citations to journal articles or to patents, as in the work of Jaffe, Trajtenberg, and Henderson (1993) and Henderson, Jaffe, and Trajtenberg (1995). Zucker and Darby (1996) point out that the commercialization of scientific breakthroughs in biotechnology depends not only upon the publications of "star" scientists, but also their active involvement. Zucker, Darby, and Brewer

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[5] Lerner and Merges (1997) test several of Aghion and Tirole's hypotheses for alliances of biotechnology firms. Lerner and Merges work is particularly interesting because they examine the assignment of control rights and stage of the projects at the time the alliance is signed.

(1998) and Zucker, Darby and Armstrong (1994) use this collaborative activity to explain the geographic location of biotechnology firms created in the last two decades. While we abstract from issues of geographic localization, our survey shows this bridging between universities and businesses by university scientists extends well beyond biotechnology.

In Section 2, we focus on results from our survey, and in subsequent sections, we present several closely related models of university licensing. The models in Section 3 highlight the role of inventor effort in commercialization. The licenses considered in Section 3.1 include royalties and fixed fees, while equity participation is considered in Section 3.2. In Section 4, we consider cases in which development requires both firm and inventor cooperation and show that while sponsored research is critical to development, it does not solve the inventor's moral hazard problem. Section 5 concludes the paper.

2 University Technology Transfer

To understand the nature of university inventions and the types of contracts used to license them, we conducted a survey of sixty-two U.S. research universities. Respondents were either directors or license officers of the technology transfer office (TTO) of each university. While the structure of these offices varies by university, in general, the technology transfer office assumes responsibility for soliciting reports (disclosures) on faculty inventions, assessing the commercial potential of these inventions, filing patent applications, finding potential licensees and executing and monitoring license agreements.[6]

Respondents were asked to complete a questionnaire concerning their licensing activities for fiscal years 1991-1995. Our questions focused on the characteristics of inventions available for license, the objectives of the technology transfer office and the extent to which they reflect objectives of the faculty and the university administration, and the characteristics of the license agreements. The results are discussed below, and issues related to our sample and survey design are addressed in Appendix A.

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[6] Thursby and Kemp (1998) and Thursby and Thursby (1998) provide empirical evidence regarding productivity and other aspects of these offices.

2.1 Invention Characteristics

Table 1 summarizes university responses on the characteristics of inventions disclosed and licensed over the sample period. To account for variation in inventive activity across universities, each university's response is weighted by the number of inventions disclosed or licensed, and the measure reported is the weighted mean.

Most invention disclosures came from research in the schools of science, engineering, medicine, and nursing. The research leading to 63% of the inventions was federally funded, while 17% was sponsored by industry and 18% was unsponsored. To the extent that they are patentable, these inventions are usually considered university property rather than property of either the inventor or the sponsor. This follows from the Bayh-Dole Act in the case of federally funded inventions, and it is university policy regardless of sponsorship for all but two universities in our sample.[7]

Inventions are highly variable in terms of commercial potential. Respondents reported that fewer than half of the inventions disclosed are licensed. Twenty-one percent were licensed exclusively, 10% were licensed exclusively for field of use, and 10% were licensed nonexclusively. In terms of earnings, the top five inventions licensed in each university accounted for 78% of gross license revenue. This skewed earning pattern is similar to Scherer's results in an earlier study of Harvard inventions.[8]

Our most striking results concern the embryonic nature of the inventions that are licensed.[9] Only 12% were ready for commercial use at the time of license, and manufacturing feasibility was known only for 8%.[10] Over 75% of the inventions licensed were no more than a proof of concept (48% with no prototype available) or lab scale prototype (29%) at the time of license!

Thus an overwhelming majority of university inventions require further development once they are licensed. Furthermore, technology managers be-

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[7] In some cases, universities grant ownership to corporate sponsors who cover all direct and indirect research costs. In the case of copyrightable materials, 48% of the respondents reported that inventors in their university retain title to inventions.

[8] Scherer also presents evidence for pharmaceutical inventions and Harhoff, Scherer, and Vopel (1997) provide evidence of skewness for German patents.

[9] Even the most lucrative university patents tend to be quite embryonic when licensed. Reimers (1987) notes the importance of the Cohen-Boyer patents was clear at the beginning, but commercial application was viewed as decades away.

[10] The majority of inventions ready for commerical application are reagent materials or software. In many instances, these were licensed for a fixed fee.

lieve efforts by licensee-firms alone to develop embryonic inventions are unlikely to be successful. For 71% of the inventions licensed, respondents claim successful commercialization requires cooperation by the faculty inventor and the licensee in further development.

2.2 Licensing Objectives

Respondents were asked a variety of questions about their own objectives and their perceptions of faculty and university administration objectives. In part, this was to determine if profit (net revenue) maximization is an appropriate assumption for university licensing. But also, recent lawsuits against the University of California System indicate that faculty-inventors and technology transfer managers may have quite different views concerning the goals of licensing, particularly with regard to royalty income and sponsored research.

We asked respondents the importance of five outcomes of their work: license revenue, license agreements executed, inventions commercialized, sponsored research, and patents awarded.[11] They were asked if they considered each outcome extremely important (EI), moderately important (MI), not very important (NI), or not applicable (NA). They were also asked how important each outcome was to their administration and the faculty they work with. Notice the intent here was not to determine *objectives* of the three groups, *per se*, but to determine technology managers' *perceptions* of their objectives. The reason is that for all universities in the sample, it is technology managers who are responsible for the execution of licenses, and the managers interviewed claimed to balance faculty and administration objectives in the process. The stacked bar charts in Figure 1 show the percentage of EI and MI responses.

Notice first that none of the respondents view revenue as their sole motivation for licensing inventions. Few respondents rate any of the outcomes as unimportant (NI or NA). This outcome could not have occurred had we asked managers to rank the outcomes (or restricted them to indicate only one outcome as EI, one as MI, etcetera), but we did not want to preclude

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[11] Some of these items can be viewed as inputs for others. For example, one can view a patent awarded as affecting the revenue that can be obtained from an invention. Clearly the existence of a license agreement is necessary for commercialization, and so on. We settled on this list of outcomes based on discussions with the test group. Also, previous AUTM surveys indicate that these outcomes are the major criteria used by technology transfer offices to measure their success.

the possibility that all of the outcomes might be elements of a manager's objective function. Second, note that patents awarded are considered relatively unimportant. This result is similar to results of industrial surveys by Cohen, Nelson, and Walsh (1997) and Levin, Klevorick, Nelson, and Winter (1987), but we expect the reasons for the patent ranking in these studies is different. Many of the managers interviewed said that for financial reasons their policy is to apply for patents only after the invention has been licensed.[12] Finally, there are clear differences among the perceived objectives of the technology transfer office (TTO), administration (ADM), and faculty (FAC).

To examine the ranks accorded different outcomes by the TTO, ADM, and FAC, we considered both ordered logit and probit models with dependent variables equal to the manager's response for an outcome (EI, MI, or NI) and independent variables which are dummies indicating the particular question (outcome). At a 10% significance level, both approaches give the same rankings (which include a number of tied ranks). These ranks, along with any ties, are listed to the right of Figure 2.[13]

Technology managers and university administrators (as perceived by TTO managers) consider license revenue more important than any other outcome. Almost as important to the TTO, however, are inventions commercialized and numbers of licenses executed. This is consistent with managers' statements throughout the interview process identifying their job primarily as implementing the Bayh-Dole Act. Sponsored research ranks only ahead of patents in importance to TTO managers. On the other hand, managers believe the faculty consider sponsored research more important than any other objective, and they perceive little faculty interest in patents or the execution of license agreements, *per se.*

Finally, we used a variety of tests (Kendall's τ, Cohen's κ, and McNemar's Test) of agreement between TTO and FAC (and between TTO and ADM) responses for each of the five outcomes. All three tests gave the same results. Technology managers believe their objectives match those of the administration more closely than the faculty. TTO and ADM agreement is accepted for each outcome, while we only accept agreement of TTO and FAC responses for inventions commercialized and sponsored research.

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[12] Notice in Table 2 that only 28% of license agreements are for inventions with patents awarded at the time of license.

[13] We also ranked outcomes by a dual scaling procedure which allows us to estimate the scale assigned to EI, MI, NI, and NA. This procedure gives the same results as our logit and probit estimates.

2.3 License Characteristics

We asked a variety of questions concerning licensing procedures and contracts executed. We were particularly interested in whether the process can be modeled as an auction in which multiple firms bid for the same license (with the highest bidder paying a lump-sum fee). Only two respondents cited examples of inventions which had been licensed in a manner consistent with an auction model. On the contrary, most respondents claimed it was often difficult to find companies interested in licensing inventions in such early stages of development. Indeed, as noted in Table 2, only 22% of the licenses executed during the sample period had multiple bidders.

Table 2 also presents information on the types of payments included in licenses. Our results concerning royalties and fees are similar to those of earlier studies of business licenses (Caves, Crookell, and Killing, 1984; Macho-Stadler, Martinez-Giralt, and Perez-Castrillo, 1996). Most license agreements include a combination of payment types. Up-front or license-issue fees, annual fees, and royalties appear in roughly 80% of the licenses executed. It is also common to see milestone payments in agreements, and three fourths of the agreements include patent reimbursement.

In terms of revenue received, up-front and annual fees each account for less than 10% of license revenue, and running royalties (royalties as a function of output) account for three fourths of revenue. While not a large fraction, equity is included in 23% of the license agreements executed. Indeed, the most *AUTM Survey* reported that the use of equity in licenses has increased substantially in the last five years. The technology managers we interviewed indicated that licenses with equity tend to be for enabling technologies to start-up companies. Agreements which include equity also tend to include up-front fees and royalties. Finally, roughly a third of the licenses covered by the survey include sponsored research.[14]

3 University Licensing with Inventor Involvement

This section focuses on a theoretical analysis of university licensing. In contrast to the usual approach of characterizing optimal incentive contracts,

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[14] For a number of universities in the sample, the technology transfer office is not responsible for obtaining sponsored research.

it is designed to predict and evaluate the types of licenses executed by research universities in the United States. Key features are the nature of the inventions to be licensed and the objectives of the managers who execute licenses. We follow survey results in assuming the invention to be licensed is so embryonic that at the time the license is executed no one knows if it will lead to a commercially successful product or process. Although the licensee must eventually commit resources to commercialize the invention, further development by the inventor is essential early on if it is to be successful.

We assume that the invention is owned by the university and the TTO is responsible for executing the license contract. As noted, this is the case for virtually all patentable university inventions, either because of Bayh-Dole or university policy. Faculty are assumed to disclose such inventions to the TTO, at which point the TTO evaluates the invention and searches for a potential licensee. We model the technology manager's objectives as balancing those of the administration and the inventor. This follows our survey evidence, but it is also natural since license revenue from patentable inventions is split between the university and the inventor. On average, inventors in our sample are entitled to 40% of revenue, with the remainder allocated to the inventor's school or department, or the TTO or some other unit within the university.

In Section 3.1, we consider the most prevalent type of contract in our sample, license contracts with output-based royalties and fixed fees (84%). We then consider the less common, but growing practice of equity participation by the university (23%). Finally, in Section 4 we examine contracts which also include sponsored research (33%).

3.1 Licensing by Royalties

Given our survey results, constructing a model of university licensing involves using elements of the literatures on optimal patent licensing, principal-agent problems, and incomplete contracting. We consider a situation in which a faculty-inventor has already disclosed an invention, and the TTO has determined that a given firm is a potential licensee. The invention can be either a new product or process whose profitability is uncertain; in particular, neither the inventor nor the technology transfer office nor the firm knows whether the invention will be a commercial success or not.

The problem is modeled as a game that unfolds over time with the following sequence of actions. The TTO first decides whether to shelve the invention, in which case the game ends, or to offer a license contract to the firm. If a contract is offered, then the firm decides whether to reject the contract, in which case the game ends, or to accept it. If it accepts the contract, a period of further development follows in which the inventor can expend effort to improve the probability of success. The outcome of this development is an updated probability of success, observed at the end of this period. After this the firm decides whether to terminate the project, in which case the game ends, or to expend the resources necessary to commercialize the invention, after which both the TTO and the firm learn whether the invention is a success or not. If it fails, the game ends. If it succeeds, the firm produces.

Consider the efforts of the inventor to improve the chances of success. We assume that e, the "effort cost" of the inventor I, is not contractible, but instead is chosen at the beginning of the development period (after the licensing agreement has been executed). Thus, the inventor is subject to moral hazard in that her effort cannot be effectively monitored and/or enforced. This assumption accords well with statements made by the technology managers we interviewed, who overwhelming viewed their own actions (and, in fact, the types of contracts they execute) as important for ensuring further development on inventions.[15] The license contract will therefore need to specify payoffs in a way that induces effort from the inventor. In this section, we confine our attention to licenses that specify a lump-sum fee and a fee per unit of output paid by the firm to the university. We adopt the standard notation of denoting the fee per unit of output by r, the royalty rate. We denote the lump-sum fee by m because it is typically referred to as a "minimum royalty (Hill, 1993)." Given a license characterized by (r, m), the equilibrium level of effort chosen in the next stage is then written as $e^*(r, m)$.

Given any level of inventor effort e, let $p(e)$ be the probability that the invention is a commercial success. In our assumptions on $p(e)$, we are thinking of the 71% of university inventions that are so embryonic that commercial success requires further development by the inventor, but for which no amount of inventor effort can guarantee success. Thus, we assume $p(0) = 0$ and $p(e) \in [0, 1)$ for all $e \geq 0$. We also assume $p(e)$ is increasing and concave.

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[15] While our focus here is moral hazard of the inventor, this problem is really one of double moral hazard. The licensee is also subject to moral hazard, and the march-in rights of the federal government per Bayh Dole Act are crafted precisely to deal with this problem. The annual fees included in many license agreements are also motivated by this problem.

Now suppose additional development, characterized by a positive level of e, has taken place and the invention is revealed to be a success. Then we assume the firm chooses output to maximize its profit (net of any license fees). The optimal output will, in general, depend on the method of licensing. In particular, although a lump-sum license fee has no effect on the choice of output, the royalty rate will operate like the price of an input in its effect on the optimal output. We denote this optimal output by $x(r)$. We assume that this output is positive if there is no royalty, and that it is decreasing in the royalty. We further assume royalty revenue is strictly concave in the royalty rate, and takes a unique maximum at a positive but finite value of the royalty, r_m. These assumptions on output and royalty hold for a broad class of new process innovations licensed to a single firm (including, but not limited to, the case of linear demand and constant marginal cost).

Next let $\Pi(x)$ be ordinary firm profit (gross of any license fees), and let $E > 0$ be the lump-sum cost of attempting to commercialize the invention. Then given a contract (r, m), the profit earned from a successful invention is $\Pi(x(r)) - rx(r) - m - E$, while that from a failure is just $-m - E$. Hence, the firm's expected profit from the invention given a contract (r, m) and effort level e is

$$P_F(e, E, r, m) = p(e)[\Pi(x(r)) - rx(r)] - m - E. \tag{1}$$

The firm accepts this contract and attempts to commercialize the invention (after development) if $P_F(e, E, r, m) \geq 0$.

Although inventor effort is not contractible, it does depend on the contract (r, m). Formally, we assume that the inventor chooses effort e to maximize her expected utility, where utility depends on income and effort. We make the familiar assumption that her utility is separable, $U_I(Y_I) - V(e)$, where $U_I(Y_I)$ is utility from license income Y_I and $V(e)$ is disutility of effort. We assume the marginal utility of income is positive and nonincreasing, so she is either risk-averse or risk-neutral, and the marginal disutility of effort is positive and increasing. We allow the possibility of risk-neutrality to emphasize that our results depend on moral hazard in development, not risk-sharing. Thus, if α is her share of license revenue, then license income from a success is $\alpha[m + rx(r)]$, and that from a failure is αm, so her expected utility is

$$P_I(e, r, m) = p(e)U_I(\alpha m + \alpha rx(r)) + (1 - p(e))U_I(\alpha m) - V_I(e). \tag{2}$$

The first order necessary condition for an interior choice of effort is:

$$\partial P_I/\partial e = p'(e)[U_I(\alpha m + \alpha r x(r)) - U_I(\alpha m)] - V_I'(e) = 0. \tag{3}$$

Note that if there is no royalty, then she earns the same amount, αm, whether she expends any effort or not. Because the marginal disutility of effort is positive, it follows immediately that she will not choose to expend effort in development unless the royalty rate is positive. However, a positive royalty rate is not sufficient to guarantee inventor effort in development. The expenditure of effort must result in an increase in the expected utility of income that exceeds the disutility of that effort. It is also necessary that the firm accept the contract and attempt to commercialize the invention.

Theorem 1 *Development will not occur unless the contract specifies a positive royalty rate,* $e^*(m,0) = 0$. *Given a positive royalty rate, the necessary condition for the inventor to expend effort in development,* $e^*(r,m) > 0$ *for* $r > 0$, *is*

$$p'(0)[U_I(\alpha m + \alpha r x(r)) - U_I(\alpha m)] > V_I'(0), \tag{4}$$

which is also sufficient if the firm accepts the contract. If development occurs:

(i) If the inventor is risk-averse, then her optimal effort is decreasing in the minimum royalty (lump-sum fee), $\frac{\partial e^*(r,m)}{\partial m} < 0$. *If she is risk-neutral, then her effort does not depend on the minimum fee,* $\frac{\partial e^*(r,m)}{\partial m} = 0$.

(ii) Inventor effort is increasing (decreasing, constant) in the royalty rate as total royalty revenue is increasing (decreasing, constant) with respect to the royalty rate; $\frac{\partial e^*(r,m)}{\partial r} > 0 (< 0, = 0)$ *as* $x + r\frac{\partial x}{\partial r} > 0 (< 0, = 0)$.

Suppose that a contract is chosen such that the inventor undertakes development. Because the inventor receives her share of the fixed fee before the development period, a larger fee decreases her incentive to put effort into development. That is, as long as she is risk-averse, a larger m decreases the expected marginal benefit of her effort, $\frac{\partial^2 P_I}{\partial e \partial m} < 0$, so she chooses a lower level of effort. However, if she is risk-neutral, then a change in the fixed fee has no effect on the expected marginal benefit of effort, and thus no effect on the level of effort chosen.

The effect of a change in the royalty rate on the expected benefit of inventor effort, however, depends on its effect on total royalty revenue. Suppose royalty revenue is increasing in the royalty rate. Then an increase in the royalty rate increases royalty revenue and the inventor's royalty income, which increases the expected marginal benefit of her effort and induces her to devote more effort to development. This is certainly the case for low enough royalty rates (i.e., $\frac{\partial[rx(r)]}{\partial r} = x(0) > 0$ at $r = 0$). Inventor effort therefore parallels royalty revenue as the royalty rate changes. That is, as the rate increases, both effort and revenue initially increase, reach a maximum, then eventually decrease.

To complete the model, we need to specify the objectives of the technology transfer office. Although the TTO's objectives are not obvious, a priori, our survey indicates that technology managers view themselves as juggling the interests of faculty and administration. Moreover, the managers we interviewed clearly view their administration as risk averse, so we assume the payoff to the university administration (A) is given by the utility function $U_A(Y_A)$, where Y_A is its share of the income from licensing. The expected utility of the university is then

$$P_A(e, r, m) = p(e)U_A((1-\alpha)[m + rx(r)]) + (1 - p(e))U_A((1-\alpha)m). \quad (5)$$

Note that the university's expected utility differs from the inventor's not only in the (possibly) different share of the license revenue, but also in the fact that it suffers no disutility from the additional effort required to develop the invention to potential commercialization.

We therefore assume the TTO's objective is to maximize a weighted average of the expected utility of the university administration and that of the inventor. Assuming that the weight placed on the inventor's objectives is $\beta \in (0, 1)$, the TTO's objective function is thus

$$P_T(e, r, m) = \beta P_I(e, r, m) + (1 - \beta)P_A(e, r, m). \quad (6)$$

Obviously using this payoff function implies that the technology transfer office views itself as having the same objectives as the university, and as acting on behalf of the inventor. That is, the TTO's objective is to maximize a weighted average of its utility and the inventor's utility, rather than simply maximizing its own utility subject to the constraint that the inventor's utility is no less that his/her reservation level. Thus, we assume that the university cannot simply treat the inventor as an agent (in the standard principal-agent paradigm). As justification for this approach, we note that the surveys indicate that the vast majority of university inventions require some inventor involvement in continuing development in order for a licensee to determine their commercial potential, if any. Moreover, the only inventions the TTO can try to license are those revealed to it by inventors. In these circumstances it seems unrealistic to give all the "bargaining power" to the university by treating the inventor as an agent.

The TTO's problem is then to choose a contract (r, m) to maximize its expected payoff subject to the licensee's participation constraint that it earn nonnegative expected payoff, or

$$\text{maximize } P_T(e^*(r,m), r, m) \text{ subject to } P_F(e^*(r,m), E, r, m) \geq 0 \tag{7}$$

(where we have assumed for convenience that the licensee's payoff in the absence of an agreement is 0). We shall consider only contracts with nonnegative royalty rates and minimum fees, essentially because we never observe universities subsidizing licensees. The solution to the TTO's problem thus has several possible forms. Because the royalty rate must be positive to induce effort from the inventor, there are essentially only two concerns. One is whether the solution has no fee, $m = 0$, or the fee is set so that the nonnegativity constraint on expected firm payoff is binding, $m = p(e)[\Pi(x(r)) - rx(r)] - E$.

Theorem 2 *If the inventor is risk-neutral, or not too risk-averse, then the expected payoff to the TTO is strictly increasing in the minimum fee for any positive royalty rate for which the firm accepts a license contract. Hence, if the invention has enough commercial potential that a contract is executed and development occurs, then that contract must involve both a positive royalty rate and a positive fixed (minimum) fee.*

Ceteris paribus, an increase in m increases the income and expected utility of the administration and the inventor, and thus increases expected payoff of the TTO. Thus, a priori, one would expect the minimum fee to be set so as to extract all of the "excess" expected payoff of the firm, in which case the constraint would bind with equality. We assume (as do all principal-agent and patent licensing models) that the firm will still accept the contract, and then engage in development, even if its expected payoff 0. In this case, this seems a particularly innocuous assumption because the actual minimum fee paid, will be the expected profit from a success net of the firm's commercialization expenditure. That is, if (r^*, m^*) is the contract, then $m^* = p(e^*)[\Pi(x(r^*)) - r^*x(r^*)] - E$. Given a small probability of success, m^* will be quite small, especially compared to the net profit earned if the invention succeeds, $\Pi(x(r^*)) - r^*x(r^*)$.

This, of course, does not imply that the TTO will succeed in licensing all inventions. It is entirely possible that the invention does not have the potential profitability to induce the firm to attempt to commercialize it, even if it were free and the inventor expended effort. That is, suppose for any given $e > 0$, $p(e)\Pi(x(0)) - E$ is never positive for the given $E > 0$. Then obviously the firm will never attempt to commercialize the invention, and so would not buy a license even at very low royalty rates and minimum fees. Excluding this possibility, we have shown that an optimal contract must involve both royalties and fixed fees[16].

3.2 Licensing by Equity

In this section,we consider whether the moral hazard problem of the inventor can be solved by an alternative method of licensing. Although not as common as royalties, both our interviews and the *AUTM Survey* indicate a dramatic increase in the portion of license contracts involving equity participation in the last few years. The problem is exactly the same as that in the preceding section except that now equity replaces royalties in the contract. In particular, the contract takes the form (ρ, m), where $\rho \in [0, 1]$ is the university's equity position in the firm, namely the fraction of profits to which it is entitled. We assume control remains with the firm, so the university merely collects its share of the profits without influencing the decisions made by the firm. The optimal level of effort chosen by the inventor is now written as $e^*(\rho, m)$.

The equity share is simply a lump-sum transfer from the firm to the university. However, unlike the minimum fee, this transfer occurs only when development occurs, the invention succeeds, and production occurs (which is necessary to solve the moral hazard problem). Because optimal output in this case is $x(0)$, the firm's expected profit from the invention given a contract (ρ, m) and effort level e is now

$$P_F(e, E, \rho, m) = p(e)(1 - \rho)\Pi(x(0)) - m - E, \tag{8}$$

and the inventor's expected utility is

$$P_I(e, \rho, m) = p(e)U_I(\alpha m + \alpha\rho\Pi(x(0)) + (1 - p(e))U_I(\alpha m) - V_I(e). \tag{9}$$

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[16] There is some possibility that, if we arbitrarily set $m = 0$, the corresponding royalty rate chosen by the TTO, r_0, will be such that the firm's participation constraint exactly holds. In this case, in fact, the optimal contract is $(r^*, 0)$. Except for this razor's edge case, we have shown that if the firm accepts the contract, it will involve a positive fee.

The expected utility of the university is now $P_A(e, \rho, m) = p(e)U_A((1 - \alpha)(m + \rho\Pi(x(0))) + (1 - p(e))U_A((1 - \alpha)m)$and the TTO's problem is to choose a contract (ρ, m) to maximize its objective function $P_T(e, \rho, m) = \beta P_I(e, \rho, m) + (1 - \beta)P_A(e, \rho, m)$ subject to optimal behavior by the inventor and the firm's participation constraint.

Again, given the marginal disutility of effort, the inventor will not expend effort in development unless the university's equity share is large enough.

Theorem 3 *Development will not occur unless the contract specifies a positive equity share,* $e^*(0, m) = 0$*. Given a positive share, the necessary condition for the inventor to expend effort in development,* $e^*(\rho, m) > 0$ *for* $\rho > 0$*, is*

$$p'(0)[U_I(\alpha m + \rho\Pi(x(0)) - U_I(\alpha m)] > V_I'(0), \tag{10}$$

which is also sufficient if the firm accepts the contract. If development occurs:

(i) Inventor effort is increasing in the equity share, $\frac{\partial e^*(\rho,m)}{\partial \rho} > 0$.

(ii) Inventor effort is decreasing in the minimum fee if she is risk-averse, $\frac{\partial e^*(\rho,m)}{\partial m} < 0$*, but does not depend on the fee if she is risk-neutral,* $\frac{\partial e^*(\rho,m)}{\partial m} = 0$.

(iii) The license contract also uses a positive minimum fee if the inventor is risk-neutral, or not too risk-averse.

An increase in the equity share increases the inventor's income from a success and induces her to devote more effort to development. Unlike a royalty, equity has an unambiguous effect on inventor effort because it does not distort the firm's production decision. An increase in the royalty rate reduces output and profit from a success. An increase in the equity share has no effect on output and profit from a success, but instead merely gives the university a larger share of that profit.

Given the predominant use of royalties, and the apparent reluctance of many universities to use equity, the most interesting question is whether one method is superior.

Theorem 4 *If maximized profit from a successful invention is decreasing in the royalty rate, then a contract with equity is more efficient than a contract with royalties.*

Recall we have assumed that optimal output with a successful invention is decreasing in the royalty rate. Hence, this result simply says that a contract with equity is Pareto superior if the output distortion introduced by royalties results in lower maximized profit for the licensee (as is true for a broad class of inventions). To see this, consider the equity contract that is income-equivalent to the optimal royalty. Let $\rho(r^*, m^*)$ be the equity share that provides the inventor and university with the same income from a success that they received under the optimal royalty, $\rho(r^*, m^*)\pi(x(0)) = r^*x(r^*)$. If the TTO switches from the royalty contract to this equity contract, and the inventor expends the same effort, then by construction the inventor and university are no worse off (ex ante) because each anticipates the same level of expected utility. However, if maximized profit from a success is decreasing in the royalty rate, $\pi(x(r^*)) < \pi(x(0))$, then expected profit is greater under this income-equivalent equity. The optimal royalty contract is therefore Pareto inferior to the income-equivalent equity contract. The optimal equity contract will not be $(\rho(r^*, m^*), m^*)$, of course, because expected profit under this contract is strictly positive. The TTO will need to adjust both the fee and equity share to attain the optimal equity contract. However, these changes simply involve reoptimization that necessarily increases the TTO's expected payoff,[17] and cannot reduce the firm's expected profit below 0 (because it can always reject the contract). Hence, the optimal equity contract must be Pareto superior to the optimal royalty contract. Finally, it is worth noting that expected consumer surplus will undoubtedly be higher under the optimal equity contract because output with a successful invention is higher.

4 University Licensing with Sponsored Research

Another salient feature of our survey results is that sponsored research is the preferred form of compensation for faculty-inventors (recall Figure 1). Indeed, for the most embryonic inventions, it is not uncommon to observe research contracts funded by licensee-firms. Such license agreements typically have three important characteristics. One is that they grant exclusive rights to patents arising from the research support that the firm provides. They also very clearly specify the focus and content of the research project to

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[17] Given the fact that the TTO is maximizing a weighted average of inventor and administration utility, we cannot prove, in general, that the inventor and administration are both better off in the optimal equity contract. However, at least one must gain, and that gain must be large enough to offset any possible loss suffered by the other. The same qualification applies to Theorem 10 in Section 4.2.

be conducted. Finally, the firm may support the research by providing not only funds, but also equipment and even personnel. Thus, in this section we consider a situation in which the licensee is actively involved in development via sponsored research. The problem unfolds over time in the same way as before with one exception. Now, in the development period both the inventor and the firm can expend effort to improve the probability of success.

In the development stage the inventor again chooses effort e, and now the firm chooses sponsored research S. We assume neither of these is contractible, but instead are chosen simultaneously at the beginning of the period, after the licensing agreement has been executed. Now both the inventor and the firm are subject to moral hazard in that neither the inventor's effort nor the firm's expenditure can be effectively monitored and/or enforced. The outcome of development is again an updated probability of success. Given any (e,S), let $q(e,S)$ be the probability that the invention is a commercial success. We assume this is increasing at a decreasing rate in both its arguments, but that no amount of effort or sponsored research can guarantee success (i.e., $q(e,S) \in [0,1)$ for all $e \geq 0$ and $S \geq 0$). Moreover, inventions for which firms sponsor research tend to be so embryonic that both inventor effort and firm expenditure (or resources) are necessary for any chance of commercial success. That is, $q(0,S) = 0$ for all $S \geq 0$ and $q(e,0) = 0$ for all $e \geq 0$.[18] Lastly, we assume $\frac{\partial^2 q}{\partial e \partial S} > 0$ for all $e \geq 0$ and $S \geq 0$ because additional expenditure by the firm (in the form of more or better equipment, for example) should increase the marginal impact of inventor effort on the probability of success.

4.1 Licensing with Royalties

We return to our benchmark case of contracts that specify a royalty rate and minimum fee. Given a contract (r, m), we model development is a simultaneous move game between the inventor and firm in which the firm chooses sponsored research S to maximize expected profit

$$P_F(e,S,E,r,m) = q(e,S)[\Pi(x(r)) - rx(r)] - m - S - E, \qquad (11)$$

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[18] It is worth noting that the necessity of both inventor and firm involvement in the development phase implies that the probability of success cannot be separable in e and E. This assumption is in contrast to that of Aghion and Tirole, who assume inventor effort and firm expenditure are additively separable.

and the inventor chooses effort to maximize expected utility

$$P_I(e,S,r,m) = q(e,S)U_I(\alpha m + \alpha r x(r)) + (1 - q(e,S))U_I(\alpha m) - V_I(e). \quad (12)$$

We write the Nash equilibrium outcomes of this development game as $e^n(r,m)$ and $S^n(r,m)$. In this situation the expected utility of the university is $P_A(e,S,r,m) = q(e,S)U_A((1-\alpha)[m + rx(r)]) + (1 - q(e,S))U_A((1-\alpha)m)$, and the TTO's problem is to choose a contract (r,m) to maximize its expected payoff $P_T(e,S,r,m) = \beta P_I(e,S,r,m) + (1-\beta)P_A(e,S,r,m)$subject to optimal behavior by the inventor and firm, and the firm's participation constraint.

The first order necessary conditions for interior (positive) choices of sponsored research by the firm and effort by the inventor are:

$$\frac{\partial P_F}{\partial S} = (\frac{\partial q}{\partial S})[\Pi(x(r)) - rx(r)] - 1 = 0 \quad (13)$$

and

$$\frac{\partial P_I}{\partial e} = (\frac{\partial q}{\partial e})[U_I(\alpha m + \alpha r x(r)) - U_I(\alpha m)] - V'(e) = 0. \quad (14)$$

These define best reply (reaction) functions in the usual fashion. From the perspective of both the inventor and the firm, effort and sponsored research are strategic complements because they are "complements" in development. That is, they complement each other in the "production" of a positive probability of commercial success for the invention, $(\frac{\partial^2 q}{\partial S \partial e}) > 0$.

Theorem 5 *Inventor effort and sponsored research are strategic complements. That is, the firm's best reply* $b_F(e)$ *and the inventor's best reply* $b_I(S)$ *are both positively sloped.*

It follows immediately from our assumptions on the probability of success and the expected payoff functions that $(e^n(r,m), S^n(r,m)) = (0,0)$ is a Nash equilibrium of this development game. Without inventor involvement, the invention surely fails, so the firm should spend nothing on development, $b_F(0) = 0$. Similarly, the invention surely fails without some expenditure by the firm, so the inventor should expend no effort on development, $b_I(0) = 0$. Nevertheless, because the best replies are positively sloped, it is possible that there exists another equilibrium with $e^n(r,m) > 0$ and $S^n(r,m) > 0$. For such an equilibrium to exist and be stable, it is sufficient that the best replies have the properties of those graphed in Figure 2.

Theorem 6 *No development is a Nash equilibrium,* $(e^n(r,m), S^n(r,m)) = (0,0)$*. However, if*

$$\begin{aligned} b'_F(0) &> 1/b'_I(0), b''_I(S) < 0, b''_F(e) < 0, \text{ and} \\ b'_F(e^m) &= 1/b'_I(b_F(e^m)) \text{ for some } e^m > 0 \end{aligned} \quad (15)$$

then there exists exactly one other Nash equilibrium with development, $e^n(r,m) > 0$ *and* $S^n(r,m) > 0$*. Moreover, this development equilibrium is locally stable, whereas the no development equilibrium is not.*

As shown in Figure 2, the best reply functions intersect at the origin, so that is an equilibrium. The condition $b'_F(0) > 1/b'_I(0)$ ensures that the firm's best reply is more steeply sloped than the inventor's best reply at the origin, and that this equilibrium is locally unstable. The conditions $b''_I(S) < 0$, $b''_F(e) < 0$, and $b'_F(e^m) = 1/b'_I(b_F(e^m))$ for some $e^m > 0$ guarantee that the best replies are concave enough for another intersection at $e^n(r,m) > e^m$ and $S^n(r,m) > 0$, which is a locally stable equilibrium. Naturally we are most interested in this development equilibrium, and how its existence and properties are influenced by the licensing choices of the TTO.

Theorem 7 *Assume (15), and consider the levels of effort and expenditure in the Nash equilibrium with development,* $e^n(r,m) > 0$ *and* $S^n(r,m) > 0$*.*

(i) If the inventor is risk-averse, then equilibrium inventor effort and sponsored research are decreasing in the minimum fee, $\frac{\partial e^n(r,m)}{\partial m} < 0$ *and* $\frac{\partial S^n(r,m)}{\partial m} < 0$*. If the inventor is risk-neutral, then changes in the minimum fee have no effect on inventor effort and sponsored research,* $\frac{\partial e^n(r,m)}{\partial m} = 0$ *and* $\frac{\partial S^n(r,m)}{\partial m} = 0$*.*

(ii) In general, changes in the royalty rate have an ambiguous effect on the equilibrium inventor effort and firm expenditure. However, the inventor's best reply effort is decreasing in the royalty rate, in which case $\frac{\partial e^n(r,m)}{\partial r} < 0$ *and* $\frac{\partial S^n(r,m)}{\partial r} < 0$*, only for rates for which royalty revenue is decreasing in the royalty rate.*

Suppose the inventor and firm undertake development. Comparative statics with respect to the minimum fee are similar to those in the benchmark case of Section 3.1. The inventor's best reply is affected by the minimum fee only if the inventor is risk-averse, in which case it rotates back to the left (effort decreases for all $S > 0$). Since the firm's best reply does not depend on the fixed (minimum) fee m, a change in this fee has no effect on equilibrium effort or sponsored research when the inventor is risk-neutral.

However, an increase in the royalty rate affects both firm profit and inventor income. An increase in the royalty rate decreases the firm's profit from a success, and thus its expected marginal benefit from sponsored research. Hence, an increase in r decreases sponsored research for all $e > 0$. *Ceteris paribus*, because they are strategic complements, inventor effort tends to decrease also. However, other things are not equal because the increase in r changes royalty income. In a fashion similar to our benchmark case in 3.1, the effect of a change in r on the marginal benefit of effort parallels royalty revenue as the royalty rate changes. As long as profit-maximizing output is inelastic with respect to the royalty rate, royalty revenue and the marginal benefit of effort will increase with an increase in r, so effort increases for all $S > 0$. Again, because they are strategic complements, sponsored research tends to increase. The net effect, of course, is ambiguity (consider Figure 2 when $b_F(e)$ rotates down and $b_I(S)$ rotates to the right).

These results suggest that, as in our benchmark case, the use of output-based payments such as royalties may be essential in the development of embryonic inventions. The reason remains that inventor involvement is required for any chance of success. As long as that effort causes disutility for the inventor, there is a moral hazard problem in the development of such inventions which cannot be solved by contracts relying on only lump-sum fees and sponsored research.

Theorem 8 *No development is the unique equilibrium of the development game if the license contract does not specify a positive royalty rate. That is, a positive royalty rate is a necessary condition for development to occur in equilibrium:* $e^n(r,m) > 0$ *and* $S^n(r,m) > 0$*only if* $r > 0$. *If the inventor is risk-neutral or not too risk-averse, then the contract must involve a positive minimum fee as well.*

If the inventor is risk-neutral, or not too risk-averse, then the expected payoff to the TTO is strictly increasing in the minimum fee for any positive royalty rate. Hence, if the invention has enough commercial potential that a contract is executed and development occurs, then that contract must involve both a positive royalty rate and a positive fixed (minimum) fee.

4.2 Licensing with Equity

As before, we consider equity as an alternative to royalties. In particular, we consider the licensing game of the preceding subsection where royalties are replaced by an equity share ρ. In this situation, given a contract (ρ, m), the firm chooses expenditure on sponsored research S to maximize expected profit

$$P_F(e, S, E, \rho, m) = q(e, S)(1 - \rho)\Pi(x(0)) - m - S - E, \tag{16}$$

and the inventor chooses effort to maximize expected utility

$$P_I(e, S, \rho, m) = q(e, S)U_I(\alpha m + \alpha\rho\Pi(x(0)) + (1 - q(e, S))U_I(\alpha m) - V_I(e). \tag{17}$$

The expected utility of the university is $P_A(e, S, \rho, m) = q(e, S)U_A((1 - \alpha)(m + \rho\Pi(x(0))) + (1 - q(e, S))U_A((1 - \alpha)m)$and the TTO's problem is to choose a contract (ρ, m) to maximize its expected payoff $P_T(e, \rho, m) = \beta P_I(e, \rho, m) + (1 - \beta)P_A(e, \rho, m)$ subject to optimal behavior by the inventor and firm, and the firm's participation constraint.

Given an equity contract, denote the Nash equilibrium levels of effort and sponsored research by $e^n(\rho, m)$ and $S^n(\rho, m)$. The analysis of this development game is entirely analogous to that with a royalty contract.

Theorem 9 *In the development game with an equity contract (ρ, m):*

(i) Inventor effort and sponsored research are strategic complements.

(ii) No development is a Nash equilibrium, $(e^n(\rho, m), S^n(\rho, m)) = (0, 0)$.

(iii) If the inventor and firm best replies satisfy (15), then there also exists exactly one other Nash equilibrium with development, $e^n(\rho, m) > 0$ and $S^n(\rho, m) > 0$. The equilibrium with development is locally stable, but the no development equilibrium is not.

(iv) In the development equilibrium:

(a) Inventor effort and sponsored research are decreasing in the minimum fee if the inventor is risk-averse, but do not vary with the minimum fee if the inventor is risk-neutral.

(b) Changes in the equity share have an ambiguous effect on inventor effort and sponsored research.

The one difference between these results and those for royalties is that a change in the university's equity share has a definite effect on the inventor as well as the firm. An increase in equity decreases the firm's marginal expected payoff, and definitely increases the inventor's marginal expected utility (because equity has no distortionary effect on output, just as in Section 3.2). Because the firm's best reply rotates down and the inventor's best reply rotates to the right), the effect of the equity share increase is ambiguous (recall Figure 2).

Theorem 10 *If maximized profit from a successful invention is decreasing in the royalty rate, then even in the presence of sponsored research a contract with equity is more efficient than a contract with royalties.*

As in the benchmark case, this follows from the fact that an equity contract avoids the output distortion induced by royalties. Suppose the TTO switches from the optimal royalty contract (r^n, m^n) to the income-equivalent equity contract $(\rho(r^n, m^n), m^n)$, where $\rho(r^n, m^n)\pi(x(0)) = r^n x(r^n)$. If the inventor expends the same effort, and the firm provides the same sponsored research, then the inventor and university are no worse off, but the firm's expected profit is greater because maximized profit from a success is decreasing in the royalty rate. The optimal royalty contract is thus Pareto inferior to the income-equivalent equity contract, and so must be Pareto inferior to the optimal equity contract. Further, expected consumer surplus will undoubtedly also be higher under the optimal equity contract because output from a success is greater.

5 Concluding Remarks

In the policy debate surrounding the Bayh-Dole Act, proponents argue that unless universities have the right to license and collect revenue from patentable inventions, many results from federally funded research would never be transferred to industry. One of the goals of our survey was to collect information that might shed some light on the debate. In particular, by asking technology managers about the stage of development of inventions licensed, as well as the usual types of payments included in the license agreements, we were able to determine (at least what these managers perceived as) salient aspects of technology transferred by licensing. Our results point, not only to the embryonic state of most technologies licensed, but more importantly, to the need for inventor cooperation in the commercialization process. Thus, for most university inventions, there is a moral hazard problem with regard to inventor effort. For such inventions, our theoretical analysis shows that development would not occur unless the inventor's return is tied to the licensee's output when the invention is a commercial success. This can be done with royalties, and in fact, our survey results show that the vast majority of agreements include royalty payments. Increasingly, however, technology managers are including equity participation by the university. In fact, we show not only that equity can induce the required inventor cooperation, but also that contracts with equity are Pareto superior to those with royalties.

We also focused on the role of sponsored research in situations where inventions could not be successful without licensee expenditure early on in the process. While our results point to the importance of sponsored research in the commercialization process, they also show that sponsored research alone does not solve the moral hazard problem on the part of the inventor. In our analysis, some output-based payment such as royalties or equity is necessary for development to occur. As before, we show that equity contracts are more efficient.

It is worth noting that our models are special in that they focus only on exclusive licensing and are static. In future work, we plan to explore these and other aspects of our survey not covered here. For example, sponsored research often is provided in exchange for the rights to options for future licenses on any inventions arising from the research. That is, sponsored research also has a dynamic component in the sense that the licensees are looking to future inventions as well as the one currently under development. These dynamic linkages seem well worth examining. Alternatively, executing contracts that induce inventor involvement in current development may be necessary for commercialization, but this clearly reduces the time the inventor can spend in research that could lead to other, future embryonic inventions. This trade-off, and its potential effects on the long-run rate of invention, innovation, and growth also seem well worth examining.

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Table 1
Invention Characteristics

Invention Disclosures (1991-1995)	Weighted Mean [a] (%)
1. Filed by Faculty in Schools of	
Science	19
Engineering	25
Medicine and Nursing	44
Agriculture	5
Other	7
2. Resulting from	
Federal Sponsored Research	63
Corporate Sponsored Research	17
3. Subject to	
Exclusive License	21
Exclusive License for Field of Use	10
Non-Exclusive License	10
Not Currently Licensed	61
4. Revenue from top 5 inventions	78
5. Stage of Development for inventions which were licensed [b]	
Proof of concept but no prototype	48
Prototype available but only lab scale	29
Some animal data available	25
Some clinical data available	5
Manufacturing feasibility known	8
Inventor cooperation required	71
Ready for practical or commercial use	12

Source: Authors' calculation.

Notes:

[a] Weighted Mean = $\Sigma x_i w_i / \Sigma w_i$, where x_i is the percentage for each university, and w_i is university i's weight. w_i is number of invention disclosures for 1, 2 and 3, the gross revenue for 4 and the number of license agreements for 5. Data for disclosures, license agreements and revenue are from the AUTM Survey.

[b] Stage of development at the time the license was executed. Percentages need not sum to 100.

Table 2
License Characteristics

	Weighted Mean [a]
1. Frequency of more than one company	
signing confidentiality agreement	63
bidding for a single license	22
2. Percentage of revenue by payment type	
License issue or up-front fees	7
Running royalties	75
Annual or minimum royalty fees	6
Progress or milestone payments	3
Patent fee reimbursement	7
Equity	3
Other	1
3. Percentage of licenses which include	
Up-front fee	84
Running royalties	84
Annual fees or minimum royalty fees	78
Progress or milestone payments	58
Patent reimbursement	78
Equity	23
4. Of licenses with equity, percentage with	
up-front fee	67
running royalty	79
Other	51
5. Percentage of licenses including sponsored research	33
6. Patent issued at time of license [b]	28
7. (Net Revenue) distribution [c]	
Inventor [d]	40
University	35
Department, School or TTO	25

Source: Authors' calculations

Notes:

[a] Use the gross revenue as weight for 2 and 8, and the number of licenses for the others.

[b] Or copyright registered.

[c] Patentable Inventions only. The distributions of revenue from copyrightable inventions is negotiable for 41% of the universities surveyed.

[d] For 15% of the universities surveyed, the inventors' share of net revenue is 1/3; with 1/3 to the university and 1/3 to other university units. Also, 24% of the surveyed universities have sliding scales.

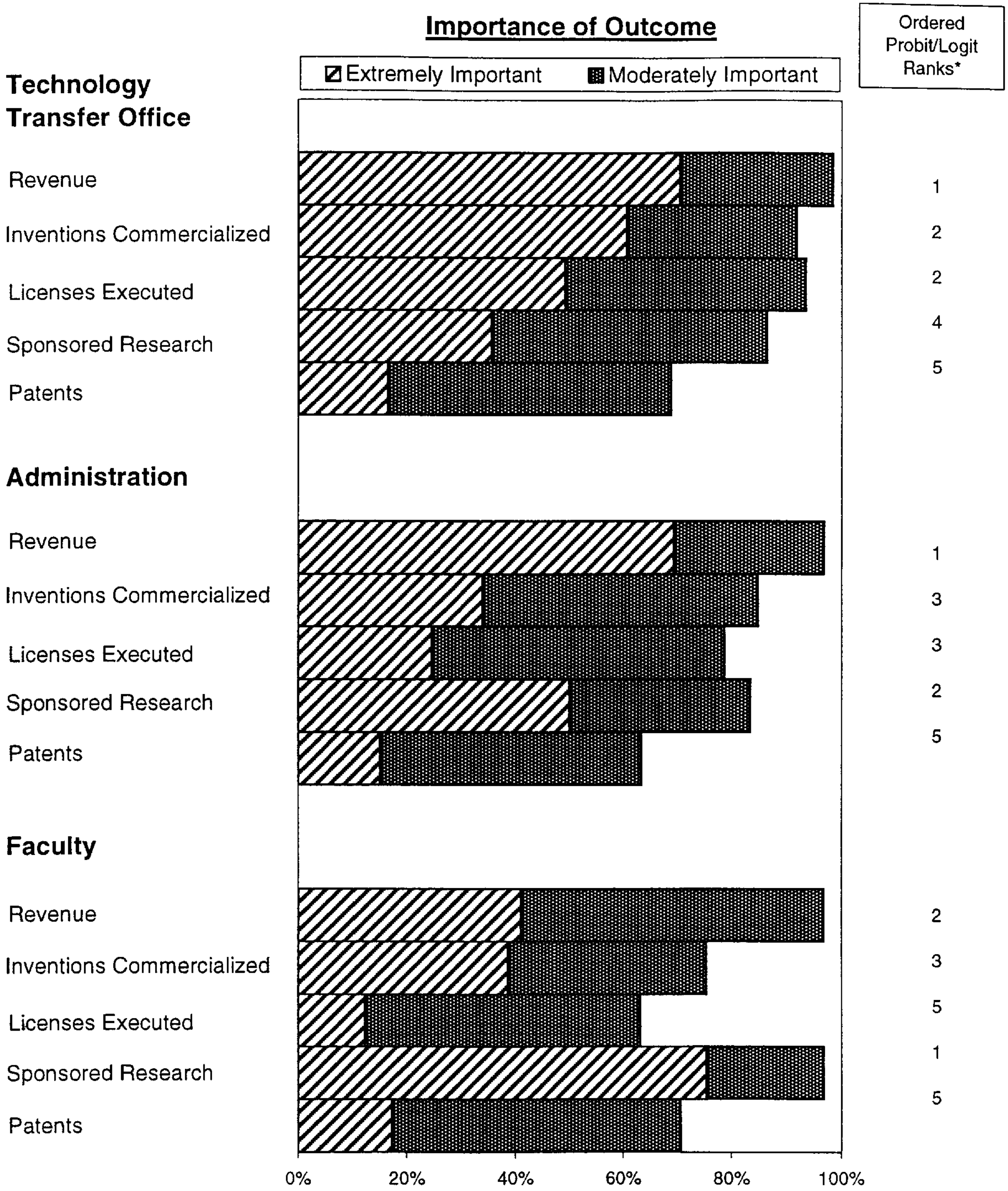

Figure 1
OUTCOMES OF TECHNOLOGY

* Significant at 10%

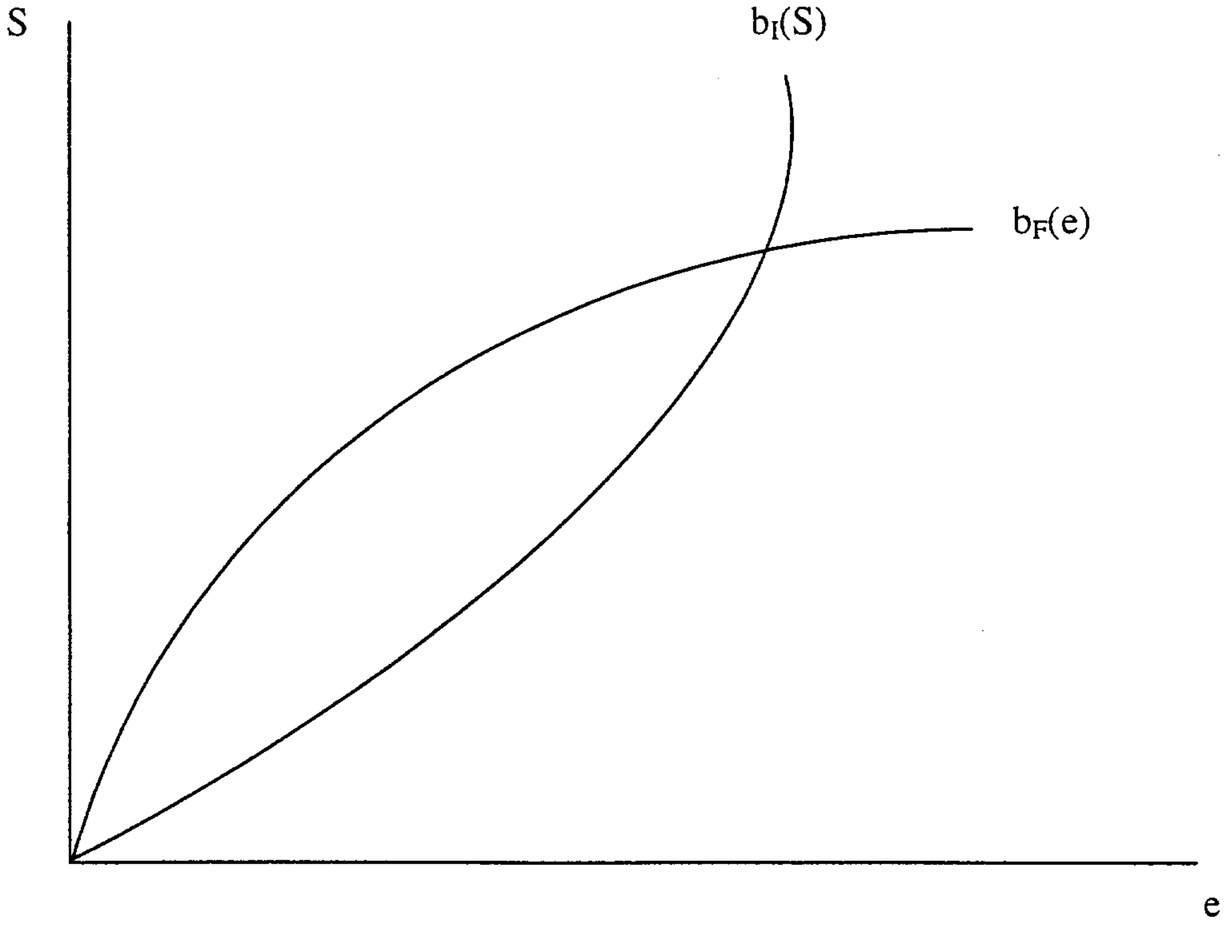

Figure 2

A Appendix on Survey Design

A.1 Sample

Questionnaires were sent to the top 135 universities in terms of licensing revenue according to the 1996 *AUTM Survey*, and responses were received from 62 universities: Alabama, Birmingham; Arizona State; Baylor; California, Berkeley; California, Los Angeles; California, San Diego; California, San Francisco; California, System Office; California Institute of Technology; Carnegie Mellon; Chicago; Cincinnati; Clemson; Colorado State; Colorado; Columbia; Dartmouth College; Dayton, Duke; Emory; Florida Atlantic; Florida State; Georgia Institute of Technology; Harvard; Illinois, Urbana/Champaign; Indiana; Iowa State; Johns Hopkins; Kentucky; Lehigh; Marquette; Massachusetts Institute of Technology; Michigan State; Michigan Technological; Michigan; Minnesota; Mississippi State; Missouri; New Jersey Institute of Technology; New Mexico State; North Carolina, Chapel Hill; Northwestern; Ohio State; Pennsylvania State; Pennsylvania; Purdue; Rhode Island; Rochester; Rutgers; Stanford; State University of New York; Tennessee; Texas A&M; Thomas Jefferson; Tulane; Utah; Virginia Tech; Wake Forest; Washington, University of; Wisconsin; Woods Hole; and Yale.

A.2 Questionnaire

The content of our questionnaire was influenced by: (i) the policy debate over the impact of the Bayh-Dole Act, and, in particular, the role of university licensing practices on the industrial impact of university research; (ii) potential conflicts between the objectives of inventors and technology transfer managers; and (iii) our interest in determining whether university licensing practices are consistent with results from the theoretical literatures on optimal contracts and patent licensing.

To maximize the likelihood that questions were interpreted accurately and that respondents could provide reliable information, we pretested the questionnaire on eleven experienced university technology transfer managers. These managers came from a mixture of private and public universities. The majority of managers in our test group had at least ten years experience in university technology transfer. Each individual was asked to complete the test questionnaire for their own institution and to think about whether technology managers with less experience or from a variety of universities would be able to answer the questions. All individuals in the test group were interviewed face-to-face, and all questions in the questionnaire were discussed to minimize ambiguity. For the actual survey, follow up telephone interviews were also used to minimize ambiguity.

There is undoubtedly noise in the survey data. In part, this is because respondents provided estimates of quantitative data which were not available from university files, but also because a number of our questions require judgment about quantitative data. Consider, for example, the question: "what percentage of the invention disclosures licensed in the last five years were in the following stages of development at the time the license agreement was executed." Few universities maintain files providing such information, but even so, managers' responses may be in error either because the true stage of development was misjudged or because respondents perceive questions differently. To minimize errors of this type, we used the categories listed in Table 1, part 5, all of which were identified by our test group as standard for evaluating stage of development

For questions with a semantic scale (categorical questions), respondents may indeed perceive the same environment but use the scale differently. To minimize error of this type, we based the scale underlying Figure 1 on research results from the literature on optimal rating scales. As discussed by Krosnick and Fabrigar (1997), research on the reliability of rating scales suggests people can distinguish among and have consistent interpretations of the four point scale, "extremely important," "moderately important," "not very important," and "not applicable." One problem with this scale for our purposes is that we are interested in the importance of five outcomes that our test group suggested are the major criteria used by technology transfer offices to measure their success. Note that this necessarily implies tied responses for rankings of some outcomes.

Finally, items in Table 2 (except for part 2) are based on respondent estimates of the frequency of an event or contract term. Managers were asked to identify the frequency as "almost always," "often," "sometimes," "rarely," or "never." To quantify the responses, we assigned numerical values according to values reported by Mosteller and Youtz (1990) for the average value assigned to these terms in twenty studies on probabilities associated with categorical data. Values assigned were .91 for almost always, .65 for often, .28 for sometimes, .9 for rarely, and .1 for never.

B Appendix for Proofs

B.1 Proof of Theorem 1

First, note that if $r = 0$, then $P_I(e, 0, m) = U_I(\alpha m) - V_I(e)$, which is maximized for all $e \geq 0$ at $e = 0$ because $U_I(\alpha m)$ is fixed, and both $V'(e) > 0$ and $V''(e) > 0$ for $e \geq 0$. Next note that if $r > 0$, then $\frac{\partial^2 P_I}{\partial e^2} = p''(e)[U_I(\alpha m + \alpha r x(r)) - U_I(\alpha m)] - V_I''(e) < 0$. Thus, if $r > 0$, then the condition in (4) implies that $\frac{\partial P_I}{\partial e} > 0$ at $e = 0$, and therefore $P_I(e, r, m)$ must be maximized at some $e > 0$. To guarantee $e^*(r, m) > 0$, we also must assume the firm accepts the contract (and attempts to commercialize the invention), because if it did not, then the inventor would not expend effort to develop it even if $P_I(e, r, m)$ is maximized at some $e > 0$.

Totally differentiating (3) gives $\frac{\partial e^*}{\partial m} = -(\frac{\partial^2 P_I}{\partial e \partial m} / \frac{\partial^2 P_I}{\partial e^2})$, where $\frac{\partial^2 P_I}{\partial e \partial m} = \alpha p'(e)$ $[U_I'(\alpha m + \alpha r x) - U_I'(\alpha m)]$. Recalling that $\frac{\partial^2 P_I}{\partial e^2} < 0$, then $\frac{\partial e^*(r,m)}{\partial m} < 0$ if $U_I'' < 0$, but $\frac{\partial e^*(r,m)}{\partial m} = 0$ if $U_I'' = 0$. Similarly, $\frac{\partial e^*}{\partial r} = -(\frac{\partial^2 P_I}{\partial e \partial r} / \frac{\partial^2 P_I}{\partial e^2})$ where $\frac{\partial^2 P_I}{\partial e \partial r} = p'(e) U_I'(\alpha m + \alpha r x)\alpha[x + r\frac{\partial x}{\partial r}]$, so statement (ii) follows immediately from our assumptions on $p(e)$ and U_I. Q.E.D.

B.2 Proof of Theorem 2

From (2), (5), and (6), differentiation gives $\frac{\partial P_T(e^*(r,m),r,m)}{\partial m} = \beta[\frac{\partial P_I(e^*(r,m),r,m)}{\partial m}] + (1 - \beta)[\frac{\partial P_A(e^*(r,m),r,m)}{\partial m}]$ where $\frac{\partial P_I(e^*(r,m),r,m)}{\partial m} = (\frac{\partial P_I}{\partial e})(\frac{\partial e^*}{\partial m}) + \frac{\partial P_I}{\partial m} = \frac{\partial P_I}{\partial m}$ by the envelope theorem, and $\frac{\partial P_A(e^*(r,m),r,m)}{\partial m} = (\frac{\partial P_A}{\partial e})(\frac{\partial e^*}{\partial m}) + \frac{\partial P_A}{\partial m}$. Further note that $\frac{\partial P_I}{\partial m} = \alpha p(e) U_I'(\alpha m + \alpha r x) + \alpha(1 - p(e)) U_I'(\alpha m) > 0$, $\frac{\partial P_A}{\partial e} = p'(e)[U_A((1 - \alpha)(\alpha m + \alpha r x)) - U_A((1 - \alpha)m] > 0$, and $\frac{\partial P_A}{\partial m} = (1 - \alpha)[p(e) U_A'((1 - \alpha)(m + \alpha r x)) + (1 - p(e)) U_A'((1 - \alpha)m)] > 0$. Hence, if the inventor is risk-neutral, then $\frac{\partial e^*}{\partial m} = 0$ from Theorem 1 and $\frac{\partial P_T(e^*(r,m),r,m)}{\partial m} > 0$. It therefore follows that $\frac{\partial P_T(e^*(r,m),r,m)}{\partial m} > 0$ if $\frac{\partial e^*}{\partial m} < 0$ but small, which from the proof of Theorem 1 occurs if the inventor is not too risk-averse. Q.E.D

B.3 Proof of Theorem 3

If $\rho = 0$, then $P_I(e, 0, m) = U_I(\alpha m) - V_I(e)$, which is maximized for all $e \geq 0$ at $e = 0$. Next note that if $\rho > 0$, then $\frac{\partial^2 P_I}{\partial e^2} = p''(e)[U_I(\alpha m + \alpha \rho \Pi(x(0)) - U_I(\alpha m)] - V_I''(e) < 0$, and so (10) implies that $\frac{\partial P_I}{\partial e} > 0$ at $e = 0$, and therefore $P_I(e, \rho, m)$ must be maximized at some $e > 0$. To guarantee $e^*(\rho, m) > 0$, we also must assume the firm accepts the contracts and attempts to commercialize the invention.

To prove statements (i) and (ii), note that the first order necessary condition for an interior (positive) choice of effort by the inventor is: $\frac{\partial P_I}{\partial e} = p'(e)[U_I(\alpha m + \alpha\rho\Pi(x(0)) - U_I(\alpha m)] - V_I'(e) = 0$. Because $\frac{\partial^2 P_I}{\partial e^2} < 0$, it follows that the sign of $\frac{\partial e^*}{\partial m}$ is given by the sign of $\frac{\partial^2 P_I}{\partial e \partial m} = p'(e)[U_I'(\alpha m + \alpha\rho\Pi(x(0)) - U_I'(\alpha m)]$. Concavity of $p(e)$ gives $\frac{\partial e^*(\rho,m)}{\partial m} < 0$ if $U_I'' < 0$, but $\frac{\partial e^*(\rho,m)}{\partial m} = 0$ if $U_I'' = 0$. Similarly, the sign of $\frac{\partial e^*}{\partial \rho}$ is given by the sign of $\frac{\partial^2 P_I}{\partial e \partial \rho} = p'(e)U_I'(\alpha m + \alpha\rho\Pi(x(0)))\alpha\Pi(x(0)) > 0$.

To prove statement (iii), observe that in this case the expected utility of the university is $P_A(e,\rho,m) = p(e)U_A((1-\alpha)(m + \rho\Pi(x(0))) + (1 - p(e))U_A((1-\alpha)m)$, and the TTO's problem is to choose a contract (ρ, m) to maximize its objective function $P_T(e,\rho,m) = \beta P_I(e,\rho,m) + (1-\beta)P_A(e,\rho,m)$ subject to $P_F(e^*(\rho,m), E, \rho, m) \geq 0$. Thus, $\frac{\partial P_T(e^*(\rho,m),\rho,m)}{\partial m} = \beta[\frac{\partial P_I(e^*(\rho,m),\rho,m)}{\partial m}] + (1-\beta)[\frac{\partial P_A(e^*(\rho,m),\rho,m)}{\partial m}]$, where $\frac{\partial P_I(e^*(\rho,m),\rho,m)}{\partial m} = (\frac{\partial P_I}{\partial e})(\frac{\partial e^*}{\partial m}) + \frac{\partial P_I}{\partial m} = \frac{\partial P_I}{\partial m}$ by the envelope theorem, and $\frac{\partial P_A(e^*(\rho,m),\rho,m)}{\partial m} = (\frac{\partial P_A}{\partial e})(\frac{\partial e^*}{\partial m}) + \frac{\partial P_A}{\partial m}$. That $\frac{\partial P_T(e^*(\rho,m),\rho,m)}{\partial m} > 0$ if $\frac{\partial e^*}{\partial m} = 0$ then follows from $\frac{\partial P_I}{\partial m} = \alpha[p(e)U_I'(\alpha m + \alpha\rho\Pi(x(0))) + (1 - p(e))U_I'(\alpha m)] > 0$, $\frac{\partial P_A}{\partial e} = p'(e)[U_A((1-\alpha)(\alpha m + \alpha\rho\Pi(x(0))) - U_A((1-\alpha)m)] > 0$, and $\frac{\partial P_A}{\partial m} = (1-\alpha)[p(e)U_A'((1-\alpha)(m + \alpha\rho\Pi(x(0))) + (1-\alpha)U_A'((1-\alpha)m)] > 0$. The result then follows from statements (i) and (ii) of the Theorem. Q.E.D.

B.4 Proof of Theorem 4

Consider the optimal contract with royalties, (r^*, m^*), and recall that under this contract inventor effort is $e^*(r^*, m^*)$, which is implicitly defined by (3). Fix the minimum fee and inventor effort at these optimal royalty contract values, m^* and $e^*(r^*, m^*)$. Now let $\rho(r^*, m^*)$ be the equity share that provides the inventor and administration with the same income from a success that they received under the optimal royalty, $\rho(r^*, m^*)\pi(x(0)) = r^* x(r^*)$. If the TTO switches from the royalty contract to this income-equivalent equity contract, and if the inventor expends the same level of effort, then by construction the inventor and university administration are no worse off (*ex ante*) because each anticipates the same level of expected utility. However, if maximized profit from a success is decreasing in the royalty rate, $\pi(x(r^*)) < \pi(x(0))$, then the income-equivalent contract leaves the firm more profit from a success, $[1-\rho(r^*,m^*)]\pi(x(0)) > \pi(x(r^*)) - r^*x(r^*)$. Hence, expected profit under income-equivalent equity contract with the same level of inventor effort $e^*(r^*,m^*)$ is also greater, $p(e^*(r^*,m^*))[\pi(x(r^*)) - r^*x(r^*))] - m^* - E < p(e^*(r^*,m^*))[1-\rho(r^*,m^*)]\pi(x(0)) - m^* - E$. The optimal royalty contract is thus Pareto inferior to the equivalent-income equity contract when the inventor expends the same level of effort under both. Naturally the optimal equity contract will not be $(\rho(r^*,m^*),m^*)$. Indeed, because expected profit under this contract is strictly positive, the TTO will need to adjust both the fee and equity share to attain the optimal equity contract. However, these changes simply involve reoptimization by the TTO that must increase its expected payoff. These changes also cannot reduce the firm's expected profit below 0, because the firm can always reject the contract. Hence, the optimal equity contract is Pareto superior to the royalty contract. Q.E.D.

B.5 Proof of Theorem 5

The firm's best reply is implicitly defined by (13). Totally differentiating this gives $b_F'(e) = (\frac{\partial^2 P_F}{\partial S \partial e})/(-\frac{\partial^2 P_F}{\partial S^2}) > 0$ because $(\frac{\partial^2 P_F}{\partial S \partial e}) = (\frac{\partial^2 q}{\partial S \partial e})\Pi(x) > 0$ and $\frac{\partial^2 P_F}{\partial S^2} = (\frac{\partial^2 q}{\partial S^2})\Pi(x) < 0$. Similarly, the inventor's best reply effort is implicitly defined by (14). Totally differentiating this gives $b_I'(S) = (\frac{\partial^2 P_I}{\partial e \partial S})/(-\frac{\partial^2 P_I}{\partial e^2})$ where $\frac{\partial^2 P_I}{\partial e \partial S} = (\frac{\partial^2 q}{\partial e \partial S})[U_I(\alpha m + \alpha r x) - U_I(\alpha m)] > 0$ and $\frac{\partial^2 P_I}{\partial e^2} = (\frac{\partial^2 q}{\partial e^2})[U_I(\alpha m + \alpha r x) - U_I(\alpha m)] - V''(e) < 0$. Q.E.D.

B.6 Proof of Theorem 6

First note that, because $q(e,0) = 0$ for all $e \geq 0$, $P_I(e,0,r,m) = U_I(\alpha m) - V_I(e)$, which is maximized for all $e \geq 0$ at $e = 0$. That is, $b_I(0) = 0$. Similarly, because $q(0,S) = 0$ for any $S \geq 0$, $P_F(0,S,E,r,m) = -S - E - m$, which is obviously maximized for all $S \geq 0$ at $S = 0$, so $b_F(0) = 0$ also. Hence, $(0,0)$ is an equilibrium. Now consider the function $f(e) = b_I(b_F(e)) - e$. As is well known, (e^n, S^n) is a Nash equilibrium if and only if $f(e^n) = 0$ (in which case $S^n = b_F(e^n)$), and it is locally stable if and only if $b_I'(S^n)b_F'(e^n) < 1$. As shown above, $f(0) = 0$ and $(0,0)$ is an equilibrium. Because $f'(0) = b_I'(0)b_F'(0) - 1 > 0$ by (15), $(0,0)$ is not locally stable. Moreover, $f'(0) > 0$ implies $f(e) > 0$ in a neighborhood above $e = 0$. Now note that (15) also implies $f''(e) = b_I''(b_F(e))[b_F'(e)]^2 + b_I'(b_F'(e))b_F''(e) < 0$ and $f(e^m) = 0$, so f has a unique maximum at e^m and $f'(e) < 0$ for all $e > e^m$. Hence, there exists a unique $e^n > e^m$ such that $f(e^n) = 0$, and thus there exists exactly one other Nash equilibrium $(e^n(r,m), S^n(r,m))$ with $e^n(r,m) > 0$ and $S^n(r,m) = b_F(e^n) > 0$ (because $b_F(0) = 0$ and $b'_F(e) > 0$). This equilibrium is locally stable because $f'(e^n) = b'_I(b_F(e^n))b'_F(e^n) - 1 < 0$. Q.E.D.

B.7 Proof of Theorem 7

Totally differentiating (13) and (14), and using the fact $\frac{\partial^2 P_F}{\partial S \partial m} = 0$, we obtain

$\frac{\partial e^n}{\partial m} = -(\frac{\partial^2 P_F}{\partial S^2})(\frac{\partial^2 P_I}{\partial e \partial m})/H$,

$\frac{\partial S^n}{\partial m} = (\frac{\partial^2 P_F}{\partial S \partial e})(\frac{\partial^2 P_I}{\partial e \partial m})/H$,

$\frac{\partial e^n}{\partial r} = [(\frac{\partial^2 P_F}{\partial S \partial r})(\frac{\partial^2 P_I}{\partial e \partial S}) - (\frac{\partial^2 P_F}{\partial S^2})(\frac{\partial^2 P_I}{\partial e \partial r})]/H$,

and

$\frac{\partial S^n}{\partial r} = [(\frac{\partial^2 P_F}{\partial S \partial e})(\frac{\partial^2 P_I}{\partial e \partial r}) - (\frac{\partial^2 P_F}{\partial S \partial r})(\frac{\partial^2 P_I}{\partial e^2})/H$,

where $H = \left(\frac{\partial^2 P_F}{\partial S^2}\right)\left(\frac{\partial^2 P_I}{\partial e^2}\right) - \left(\frac{\partial^2 P_F}{\partial S \partial e}\right)\left(\frac{\partial^2 P_I}{\partial e \partial S}\right) > 0$ by local stability (recall from the proof of Theorem 7 that (15) implies $b'_I(S^n)b'_F(e^n) < 1$ in the development equilibrium, which implies $H > 0$).

Recall from the proof of Theorem 6 that $\frac{\partial^2 P_F}{\partial S^2} < 0$ and $\frac{\partial^2 P_F}{\partial S \partial e} > 0$. Hence, the signs of $\frac{\partial e^n(r,m)}{\partial m}$ and $\frac{\partial S^n(r,m)}{\partial m}$ are the same as the sign of $\frac{\partial^2 P_I}{\partial e \partial m}$. Statement (i) then follows from the fact that $\frac{\partial^2 P_I}{\partial e \partial m} = (\frac{\partial q}{\partial e})\alpha[U'_I(\alpha m + \alpha r x) - U'_I(\alpha m)]$, so $\frac{\partial^2 P_I}{\partial e \partial m} < 0$ if $U''_I < 0$, but $\frac{\partial^2 P_I}{\partial e \partial m} = 0$ if $U''_I = 0$.

Similarly, recall from the proof of Theorem 6 that $\frac{\partial^2 P_I}{\partial e^2} < 0$ and $\frac{\partial^2 P_I}{\partial e \partial S} > 0$. Note that $\frac{\partial^2 P_I}{\partial e \partial r} = U'_I(\alpha m + \alpha r x)\alpha(\frac{\partial q}{\partial e})[x + r(\frac{\partial x}{\partial r})]$, which is generally ambiguous, and $\frac{\partial^2 P_F}{\partial S \partial r} = -(\frac{\partial q}{\partial S})x < 0$ (where we have used the fact that the envelope theorem for the firm's optimal choice of output given (r,m) implies $\Pi'(x) = r$). So, if $\frac{\partial^2 P_I}{\partial e \partial r} \leq 0$, then it follows that $\frac{\partial e^n}{\partial r} < 0$ and $\frac{\partial S^n}{\partial r} < 0$. But $\frac{\partial^2 P_I}{\partial e \partial r} \leq 0$ only if $x + r(\frac{\partial x}{\partial r}) < 0$. Q.E.D.

B.8 Proof of Theorem 8

Observe from (14) that if $r = 0$, then we have $\frac{\partial P_I}{\partial e} = -V'(e) < 0$ for all $e \geq 0$. Hence, if $r = 0$, the inventors expected payoff is maximized at $e = 0$ for any S. That is, $b_I(S) = 0$ for all S if $r = 0$, and $b_F(0) = 0$, so $(e^n(m,0), S^n(m,0)) = (0,0)$ is the unique Nash equilibrium of the development game for any $m \geq 0$. Consequently, $r > 0$ is a necessary condition for the equilibrium with development.

Straightforward differentiation gives $\frac{\partial P_T}{\partial m} = \alpha[(\frac{\partial P_I}{\partial S})(\frac{\partial S^n}{\partial m}) + (\frac{\partial P_I}{\partial m})] + (1 - \alpha)[(\frac{\partial P_A}{\partial e})(\frac{\partial e^n}{\partial m}) + (\frac{\partial P_A}{\partial S})(\frac{\partial S^n}{\partial m}) + (\frac{\partial P_A}{\partial m})]$, where $\frac{\partial P_I}{\partial S} > 0$, $\frac{\partial P_I}{\partial m} > 0$, $\frac{\partial P_A}{\partial e} > 0$, $\frac{\partial P_A}{\partial S} > 0$, and $\frac{\partial P_A}{\partial m} > 0$. Recall from the proof of Theorem 8 that $\frac{\partial S^*}{\partial m} = 0$ and $\frac{\partial e^*}{\partial m} = 0$ if the inventor is risk-neutral, so $\frac{\partial P_T}{\partial m} > 0$. Further recall that if the inventor is risk-averse, then $\frac{\partial e^n}{\partial m} < 0$ and $\frac{\partial S^n}{\partial m} < 0$, but decrease (in absolute value) to 0 as U_I'' does. Hence, the TTO's payoff is increasing in m for any $r > 0$, so the solution to its problem must involve a positive minimum fee as well. Q.E.D

B.9 Proof of Theorem 9

From (16) and (17), the first order necessary conditions for interior (positive) choices of sponsored research by the firm and effort by the inventor are $\frac{\partial P_F}{\partial S} = (\frac{\partial q}{\partial S})(1 - \rho)\Pi(x(0)) - 1 = 0$ and $\frac{\partial P_I}{\partial e} = (\frac{\partial q}{\partial e})[U_I(\alpha m + \alpha\rho\Pi(x(0)) - U_I(\alpha m)] - V'(e) = 0$. The firm's best reply is implicitly defined by the former, and the inventor's is defined by the latter. We continue to denote these by $b_F(e)$ and $b_I(S)$ (with some minor abuse of notation because we note that they are not, in general, the same as those in the royalty game). Totally differentiating gives $b_F'(e) = (\frac{\partial^2 P_F}{\partial S \partial e})/(-\frac{\partial^2 P_F}{\partial S^2}) > 0$ because $(\frac{\partial^2 P_F}{\partial S \partial e}) = (\frac{\partial^2 q}{\partial S \partial e})(1 - \rho)\Pi(x(0)) > 0$ and $\frac{\partial^2 P_F}{\partial S^2} = (\frac{\partial^2 q}{\partial S^2})(1 - \rho)\Pi(x(0)) < 0$, and $b_I'(S) = (\frac{\partial^2 P_I}{\partial e \partial S})/(-\frac{\partial^2 P_I}{\partial e^2}) > 0$ because $\frac{\partial^2 P_I}{\partial e \partial S} = (\frac{\partial^2 q}{\partial e \partial S})[U_I(\alpha m + \alpha\rho\Pi(x(0)) - U_I(\alpha m)] > 0$ and $\frac{\partial^2 P_I}{\partial e^2} = (\frac{\partial^2 q}{\partial e^2})[U_I(\alpha m + \alpha\rho\Pi(x(0)) - U_I(\alpha m)] - V''(e) < 0$. This proves (i).

Next, because $q(e, 0) = 0$ for all $e \geq 0$, $P_I(e, 0, \rho, m) = U_I(\alpha m) - V_I(e)$, which is maximized for all $e \geq 0$ at $e = 0$. That is, $b_I(0) = 0$. Similarly, because $q(0, S) = 0$ for any $S \geq 0$, $P_F(0, S, E, \rho, m) = -S - E - m$, which is obviously maximized for all $S \geq 0$ at $S = 0$, so $b_F(0) = 0$ also. Hence, $(0, 0)$ is an equilibrium, which proves (ii). The proof of (iii) is then entirely analogous to the proof of Theorem 6.

To prove (iv), totally differentiate the conditions $\frac{\partial P_F}{\partial S} = 0$ and $\frac{\partial P_I}{\partial e} = 0$, and use the fact that $\frac{\partial^2 P_F}{\partial S \partial m} = 0$, to obtain

$\frac{\partial e^n}{\partial m} = -(\frac{\partial^2 P_F}{\partial S^2})(\frac{\partial^2 P_I}{\partial e \partial m})/H$,
$\frac{\partial S^n}{\partial m} = (\frac{\partial^2 P_F}{\partial S \partial e})(\frac{\partial^2 P_I}{\partial e \partial m})/H$,
$\frac{\partial e^n}{\partial \rho} = [(\frac{\partial^2 P_F}{\partial S \partial \rho})(\frac{\partial^2 P_I}{\partial e \partial S}) - (\frac{\partial^2 P_F}{\partial S^2})(\frac{\partial^2 P_I}{\partial e \partial \rho})]/H$,
and
$\frac{\partial S^n}{\partial \rho} = [(\frac{\partial^2 P_F}{\partial S \partial e})(\frac{\partial^2 P_I}{\partial e \partial \rho}) - (\frac{\partial^2 P_F}{\partial S \partial \rho})(\frac{\partial^2 P_I}{\partial e^2})/H$,
where $H = \left(\frac{\partial^2 P_F}{\partial S^2}\right)\left(\frac{\partial^2 P_I}{\partial e^2}\right) - \left(\frac{\partial^2 P_F}{\partial S \partial e}\right)\left(\frac{\partial^2 P_I}{\partial e \partial S}\right) > 0$ by local stability.

Recall from above that $\frac{\partial^2 P_F}{\partial S^2} < 0$ and $\frac{\partial^2 P_F}{\partial S \partial e} > 0$. Hence, the signs of $\frac{\partial e^n(r,m)}{\partial m}$ and $\frac{\partial S^n(r,m)}{\partial m}$ are the same as the sign of $\frac{\partial^2 P_I}{\partial e \partial m} = (\frac{\partial q}{\partial e})\alpha[U_I'(\alpha m + \alpha\rho\Pi(x(0))) - U_I'(\alpha m)]$, where $\frac{\partial^2 P_I}{\partial e \partial m} < 0$ if $U_I'' < 0$, but $\frac{\partial^2 P_I}{\partial e \partial m} = 0$ if $U_I'' = 0$. Similarly, recall from above that $\frac{\partial^2 P_I}{\partial e^2} < 0$ and $\frac{\partial^2 P_I}{\partial e \partial S} > 0$, so noting that $\frac{\partial^2 P_I}{\partial e \partial \rho} = (\frac{\partial q}{\partial e})U_I'(\alpha m + \alpha\rho\Pi(x(0)))\alpha\Pi(x(0)) > 0$ and $\frac{\partial^2 P_F}{\partial S \partial \rho} = -(\frac{\partial q}{\partial S})\Pi(x(0)) < 0$ completes the proof of (iv). Q.E.D.

B.10 Proof of Theorem 10

This proof proceeds entirely analogously to that of Theorem 4. Denote the optimal contract with royalties by (r^n, m^n), and recall that under this contract inventor effort is $e^n(r^n, m^n)$ and sponsored research is $S^n(r^n, m^n)$. Fix the minimum fee, inventor effort, and sponsored research at these values. Now let $\rho(r^n, m^n)$ be the equity share that provides the inventor and administration with the same income from a success that they received under the royalty, $\rho(r^n, m^n)\pi(x(0)) = r^n x(r^n)$. If the TTO switches from the royalty contract to this income-equivalent equity contract, and if the inventor expends the same level of effort and the firm provides the same level of sponsored research, then by construction the inventor and university administration are no worse off (*ex ante*) because each anticipates the same level of expected utility. However, if maximized profit from a success is decreasing in the royalty rate, $\pi(x(r^n)) < \pi(x(0))$, then the income-equivalent contract leaves the firm more profit from a success, $[1 - \rho(r^n, m^n)]\pi(x(0)) > \pi(x(r^n)) - r^n x(r^n)$. Hence, expected profit under income-equivalent equity contract with the same level of inventor effort $e^n(r^n, m^n)$ and sponsored research $S^n(r^n, m^n)$ is also greater, $p(e^n(r^n, m^n))[\pi(x(r^n)) - r^n x(r^n))] - m^n - E < p(e^n(r^n, m^n))[1 - \rho(r^n, m^n)]\pi(x(0)) - m^n - E$. The optimal royalty contract is Pareto inferior to the equivalent-income equity contract when inventor effort and sponsored research are the same under both. Naturally the optimal equity contract will not be $(\rho(r^n, m^n), m^n)$. Indeed, because expected profit under this contract is strictly positive, the TTO will need to adjust both the fee and equity share to attain the optimal equity contract. However, these changes simply involve reoptimization by the TTO that must increase its expected payoff, and cannot reduce the firm's expected profit below 0. Q.E.D.