Who Develops a University Invention? The Roles of Inventor Knowledge and Licensing Policies

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March 17, 2003

Abstract

Licensing intellectual property has long been recognized as an important means by which inventors can reap economic rewards from their work. However, scientists recognize that in many fields the inventor's know-how is critical to the successful development of an invention, and the intellectual property plays a secondary role. This characterization has been documented particularly in empirical studies on university technology transfer. This paper models the licensing process at a university to illustrate how the level of inventor know-how affects whether the inventor starts a firm or the invention is licensed to an established firm outright. I also analyze the role and impact of a university licensing office on this process. The model posits a general theory of inventor-entrepreneur behavior in university and corporate research labs based on two factors: the importance of know-how and the distribution of inventors' costs to transfer that know-how.

*This paper benefitted from comments by David Mowery, Steven Klepper and Brian Wright. The author also thanks licensing professionals and administration at the University of California, Carnegie Mellon University, the University of Pittsburgh, Penn State University, and the University of Toronto for hours of interviews and discussion. All remaining errors and omissions are the responsibility of the author.

1. Introduction

The development half of R&D is a pivotal, but difficult, step between laboratory research and commercial products. Perhaps nowhere is this process more difficult than in university technology transfer. It is at this stage that a university inventor must pass the fruits of her labors to an organization equipped with better resources and complementary assets than those immediately available to the inventor to develop the raw invention. The transaction is often more than a mere exercise in licensing intellectual property (IP), however, and typically requires transferring the inventor's accumulated knowledge and experience to successfully develop the invention. In such cases, this two-part "technology transfer" process is complicated by the difficulty of contracting on the inventor's tacit knowledge or know-how[1,2].

The importance of tacit knowledge has been documented in empirical work on university technology transfer in general (Argawal 2000), and more narrowly in the context of start-ups founded by university researchers (Lowe 2001, Lowe 2003, and Shane 2002). Research in this area began with early work by Ed Roberts (summarized in Roberts 1991), but otherwise is fairly recent and empirical in nature. In the process, less attention has been paid to developing a theoretical framework to understand the university technology transfer process (Jensen and Thursby 2001 is an important exception).

University technology transfer differs substantially from previous economics treatments of licensing and new firm entry. In universities, the process is not a bilateral negotiation, but also includes a third party, a technology transfer office (TTO), that balances the interests of the university and the inventor (Jensen and Thursby 2001). In addition, a university inventor does not have a corporate affiliation, and thus lacks immediate access to financial capital and complementary assets. In contrast, many previous papers on licensing focus on oligopolistic interaction between incumbent firms.

In this paper, I model the university technology transfer process to address two questions: *Who develops an invention in the presence of tacit (non-contractible) knowledge, the university inventor or an outside firm*? and *When is the involve-*

[1] As discussed in the next section, tacit knowledge refers to the inventor's know-how or personal knowledge gained from working with the invention over a number of years. Interviews with university scientists indicated that their research an a single, licensed invention is often the culmination of five or more years of active research.

[2] Following the original characterization advanced by Polanyi (1958), I use the terms tacit knowledge and know-how interchangeably.

ment of a technology transfer office Pareto improving? My primary purpose in this paper is to draw on the empirical evidence and descriptions of the university technology transfer process to propose a theory capturing when university inventors start firms and the effect of a university licensing office on this process.

Four points emerge from this study. First, absent institutional influences such as a TTO, inventions associated with considerable tacit knowledge will always be developed by an inventor-founded firm. Even without the TTO's involvement, the inventor can fully extract monopoly rents accruing to the invention given that her continued involvement is sufficiently important.

Second, among inventions with more modest levels of tacit knowledge, royalty-based contracts lead to a separating equilibrium where inventors with a relatively high disutility of effort (or high opportunity cost of their time) will execute licenses with established firms, and inventors with a relatively low disutility of effort will start their own firms. The implication of this finding is that using simple linear contracts, which are characteristic of university licensing, firms share the returns to the invention with inventors who perceive their time as highly costly.

Third, previous scholars noted that the use of royalty rates in university licensing contracts is necessary to induce inventors to exert effort in assisting a licensee to develop an invention (Jensen and Thursby 2001). However, this paper includes the case when an inventor founds a firm to develop her invention, then sells the developed invention to an established firm. Moreover, royalty rates are not necessary to induce further inventor effort, but often remain in university licensing contracts. These royalties, in turn, induce a distortion in the level of final goods output.

Lastly, the involvement of the university can be Pareto improving when the university markets the invention to potential licensees who bid over a fixed fee. However, the improvement in inventor welfare only occurs with respect to some inventions, although university policies may dictate that the university expend at least some marketing efforts on all inventions. This tension lies at the heart of the recent debate over the Bayh-Dole Act.

Licensing innovations has received considerable attention in the economics literature over the past two decades. A number of scholars have studied licensing as a strategic action among firms competing in an industry (see, for example, Gallini 1984, Gallini and Winter 1995, Katz and Shapiro 1986, and Shepard 1994). The general conclusion is that licensing can be a useful tool to shape competitors' information or incentives, and thus behavior within the industry. Given the focus on industry structure and competitive behavior, papers in this stream of research either explicitly or implicitly focus on the actions of incumbent firms.

Another series of work focuses on the terms and forms of licensing contracts to resolve contractual hazards arising (Arora 1995, Gallini and Wright 1990, Jensen and Thursby 2001). Similarly, Aghion and Tirole (1994) and Arora and Merges (2002) each employ a property rights approach to examine how an independent laboratory and a commercializing firm share ownership of an innovation when asset-specific investment is required for development or commercialization. The insight in this area is that attention in the early licensing research on lump-sum payments and auctions may be first-best in a frictionless market, but is rarely applicable in transferring technology from a research organization to commercializing organization. Each of these articles also implicate imperfectly contractible information at the core of market frictions.

This paper builds primarily from the latter set of articles by focusing on informational problems in university licensing, with the added complexity of specifying a particular type of information problem documented in previous empirical work: the difficulty of contracting explicitly on tacit knowledge. Tacit knowledge is important because the inventor has to be actively involved in development of an invention. However, this study marks an important departure from previous work on licensing by focusing on the active decision by the inventor to develop the invention and the timing of when to license to a commercializing firm.

There are at least two benefits to focus the analysis on the specialized licensing transaction between university inventors and established firms. First, university research and licensing practices have emerged as an economically important phenomenon. In the long wake of the Bayh-Dole Act, a number of universities have invested substantial funds in infrastructure to increase university-industry relationships. A substantial portion of these efforts has been devoted to providing support and assistance for licensees that are start-ups because such firms are equated with regional economic growth. Further understanding of how markets for university inventions function is essential to forecasting and assessing the value of these initiatives. This paper offers a first effort to fill this gap.

Second, an examination of this relationship easily lends itself to examining a broader set of economic transactions, including corporate spin-offs. This paper also raises an important, yet fairly undiscussed, topic in entrepreneurship: firms formed explicitly to develop but not commercialize technologies. Lowe (2001) discusses this point in the context of the University of California (UC), however this characterization may also capture the many independent research labs and engineering firms in the semiconductor and biotechnology industries. A number of recent papers have demonstrated the prevalence of corporate spin-offs and start-ups founded by incumbent firms' employees (Klepper 2001). This paper concludes with possible extensions to include this broader group of organizations.

In the next section, I describe a model of technology transfer where an invention is associated with some level of tacit knowledge, and there is a distribution of inventor "types" based on each inventor's willingness to expend effort to transfer this knowledge. I first examine the technology transfer transaction between only the inventor and an established firm to establish a baseline theory of university inventor behavior, then introduce the role of the TTO. Section 3 provides analysis of the model. Section 5 discusses findings and concludes.

2. Model of Technology Transfer

This section begins with a set up of a technology transfer transaction between an inventor and an outside firm. Two pieces of terminology need to kept in mind. First, I use "technology transfer" to include exchanging rights to utilize certain intellectual property for payment ("licensing") as well as communicating tacit knowledge necessary to develop an invention. Second, throughout the paper I distinguish between an "invention," an early stage idea or unproven technology, and an "innovation," a developed technology that is near its final form for commercialization.

2.1. Technology Transfer Process

I build the model based on several stylized facts emerging from research and empirical observation of the university technology transfer process. First, university start-ups are often founded as development organizations whose primary focus is merely to transform an undeveloped invention into a commercially-feasible innovation. Once a technology is developed, the technology and support resources (organize the start-up firm) is then sold to a firm owning the complementary assets necessary for commercialization. This process is illustrated in Table 1.

Table 1 summarizes the status of inventions disclosed between 1986-1995 at the University of California[3] that were licensed by inventor-founded start-ups. The table is sorted by ownership status as of July 2002, and start-up ownership is sorted into three categories: acquired by an established firm, operating independently, and defunct. Columns (a) through (d) describe royalties paid to the university.

[3] This table includes all nine of the University of California campuses.

(Insert Table 1 Here)

By examining the royalties, we can deduce the stage of product development and relative product sales. The university negotiates several types of royalties, included milestone payments based on achieving certain technical hurdles (such as passing a specified clinical trial stage in pharmaceuticals), minimum royalties that specify a guaranteed payment regardless of product sales and "earned royalties" based on actual product sales. Earned royalties also include two instances where the university "cashed out" an equity stake, which can be interpreted as a claim on future product royalties.

Table 1 illustrates two striking aspects of the university start-up process. Only three independent firms have generated sales on their licensed inventions. Two of these firms currently receive revenues primarily through sublicensing the technology. Interestingly, both technologies were fully developed prior to negotiating the license with UC. Among independent firms, the greatest earnings came from a cash out of the equity in a biotechnology firm; however, the firm was still developing its technology to improve the effectiveness of orally-administered pharmaceuticals. In contrast, all but two of the acquired firms have product sales. One of these firms has developed its inventions licensed from the university that are used as a targeted drug research platform within its parent and with the firm's collaborators.

In sum, Table 1 suggests that the exit strategy for UC inventor-entrepreneurs is to sell their start-up to an established firm rather than growing their own firm into a larger business. Those firms that actually have succeeded in generating sales have done so under the wing of a larger firm[4].

Based in part on this description, I model the technology transfer process as a sequential game in three stages, as illustrated in Figure 1. In the first stage, the inventor discloses an invention and a contract is offered to an outside firm a license contract[5]. The firm chooses to accept or reject the contract. If the firm accepts the contract, the inventor chooses a level of effort e in the second stage. The level of effort is not contractible. The firm then chooses an optimal production level x

[4]The skeptical reader may counter that Chiron and Genentech are well-known examples of firms based on UC research that grew to be large, successful firms. However, over 180 firms have been founded with UC technology through July 2002, and Chiron and Genentech stand out alone in terms of their independent commercial success among the many UC start-ups.

[5]As mentioned in the introduction, I first model this process without the involvement of a TTO to establish a base case for comparison. Hence, the contract is offered be the inventor to the firm. When the TTO is included in the following section, the TTO offers the contract.

in the final stage.

(Insert Figure 1 Here)

If the firm rejects the contract in the first stage, then the inventor decides whether to start a firm. This decision is akin to developing the invention herself and is modelled as the inventor's commitment to a high level of effort, $\bar{e}$. If the inventor decides not to start a firm, then the licensing game ends, and each party receives payoffs equal to zero. If the inventor starts a firm, she develops the invention with maximum effort $\bar{e}$ and then offers another contract to a firm on the developed invention.

Under both scenarios, the firm is required for commercialization. At the end of the third stage, net profits P are generated, and any royalty payments due per the licensing contract are paid to the inventor.

2.2. Model Assumptions

Contracts The inventor offers a license contract $K(S, r)$ specifying a fixed sum S paid immediately plus a royalty rate r: S is a non-negative number and r is a percentage between 0% and 100% of the firm's profits accruing to the licensed invention. Thus, cases where the inventor pays the licensee to develop the invention (that is, S or r are negative) are excluded in the analysis. All contracts with incentives for inventor effort are exclusive to one firm since such contracts will presumably preclude inventors from consulting for a number of firms. For calculating royalties all final product sales are assumed to be commonly observable.

The contract is specified to have a royalty or outcome-based component as a means to induce the inventor to work with the licensee to transfer knowledge necessary to the further development of the invention (Jensen and Thursby 2001). Simple, linear contracts are characteristic of the vast majority of contracts at university TTOs[6].

Technology Inventions can be thought of as either final goods or components of a system technology. Profit and utility functions refer to the rents accruing to the licensed invention; that is, additional rents accruing to complementary assets and complementary products are not formally modelled.

[6] The linear nature of university licensing contracts can perhaps be explained by the need for robust contracts across inventions, as discussed in Hart and Holmström (1987).

Inventions cannot be imitated or copied. While this assumption is clearly not descriptive of many product inventions, it helps to focus the analysis. For a study of exclusive versus non-exclusive licensing with imitation, see Gallini and Wright (1990).

Market structure To model the licensing process, I make two characterizations of the market for an invention and an innovation. A key starting point in this paper is that the market for an invention is complicated by tacit knowledge necessary for development. Since the research is at an early stage, firms may not be able– at a reasonable cost– to integrate and develop an invention, particularly if the invention incorporates (tacit) knowledge very different than the firms' current knowledge bases or scientific approaches. As a result, I place no constraints on the market structure or number of bidding firms at this stage of the game.

In contrast, the market for innovations (developed but not yet commercialized technologies) is assumed to be competitive. That is, if a technology is developed, the inventor can sell it to any of several firms, each of which is equally capable of commercializing the invention and has access to the necessary complementary assets. In the model, the effect of this market structure is that firms bid up the fixed fee portion of a contract for the technology. Thus, in this model, *the more developed a technology is, the (weakly) more competitive the bidding process for the technology, ceteris paribus.*

The case study of Nitres, documented more completely in Lowe (2001), can be used to illustrate the market structure captured in these assumptions. Nitres was founded by Professors Steve DenBaars and Umesh Mishra, at the University of California- Santa Barbara to develop a semiconductor, gallium nitride (GaN). GaN's properties offer several advantages over existing semiconductors for both consumer and military applications. Most commonly, GaN is noted because it emits bright blue light and other colors not available from other semiconductors.

GaN first emerged as a potentially important technology in the late 1960's, with several major companies, including Matsushita, RCA, and Bell Labs, sponsoring work on the compound in their basic research labs. The interest of these companies and other companies implies shared expectations that the market for GaN technologies appeared promising. Over time, the decreasing role of basic research labs combined with slow progress on the technology and research on GaN virtually ceased. However, after several technological advances in the 1980's and early 1990's, GaN appeared to be commercially feasible. Following a breakthrough by a Japanese scientist, Shuji Nakamura, in the early 1990's, a number of research efforts on GaN were started and restarted at companies and universities, including a new lab managed by DenBaars and Mishra in 1994. A number of major electronics firms, including Philips, Siemens, Agilent, General Electric, and Matsushita, also started (or restarted, in some cases) research programs on GaN.

In their lab, DenBaars and Mishra had early success in developing several production processes for GaN and related materials. Their work was made publicly available through conference presentations, journal publications, and patents applications filed by the University of California in 1996. Despite apparent interest in the technology, UC was unable to license the technology to any existing firms. Interestingly, neither of the two companies funding their laboratory, Hughes Electronics and Stanley Electric, negotiated licenses on the early stage technology, either. Field interviews with a number of inventors indicate that this experience is common in other fields, as well (Lowe 2001). Firms, although quite interested in a technology, proceed on their own internal research efforts particularly when a technology is undeveloped. The above assumption on market structure for an invention simply reflects that in this environment, the market for an invention is uncertain relative to a developed innovation.

In 1997, Mishra, DenBaars, and several graduate students founded Nitres (originally Widegap Technologies) to develop their invention. Nitres spent several years in development, building working prototypes and scaling the technology and processes for commercial production. Nitres was approached by and eventually acquired by Cree in 2001, a public company also working on GaN and related semiconductor technologies. The second characterization of the market is that several of the firms conducting research in this field could have acquired the developed technology. A competitive bidding process amongst two or more firms seems to be a reasonable characterization of this market.

Probability of Success: Development, Knowledge, and Inventor Effort As mentioned in the introduction, the transfer of technology includes two components: formal intellectual property (IP) rights and inventor knowledge. Intellectual property rights merely grant a right of usage, or more technically a right to exclude others' usage.

The inventor's knowledge has a more direct impact. In the model, inventor's knowledge improves the probability of successful development of the licensed invention. Not all inventions require inventor knowledge. Many pharmaceutical drugs are reverse-engineered to produce generic equivalents without any inventor involvement. Thus, one factor in successful development is the degree to which the inventor needs to be involved with the licensee to transfer her personal knowledge and experience. That is, how "tacit" is the knowledge related to the invention?

In the model, this notion is represented by a continuous density function $f(t, e)$ where t indexes the level of tacit knowledge needed to further develop the invention and is an exogenous characteristic of the invention. Recall that e is the level of effort put forth by the inventor to transfer her knowledge, such as the number of hours in a week the inventor consults for the company. The range for the tacit knowledge parameter is $0 \geq t \geq 1$, where $t = 0$ characterizes "off the shelf" inventions: inventions that can be developed without further inventor input, and additional inventor effort does not improve the probability of success.

The purpose of including both arguments (t and e) is to capture the intuition that many inventions are associated with almost no tacit knowledge (t approaches 0) and effort e does not greatly improve the success of development. Other inventions may have higher levels of tacit knowledge, and still have some (small) probability of successful development without any involvement by the inventor.

Effort ranges from inventors unwilling to put forth any effort $\underline{e}$ (*e.g.* zero hours of work per week) to those willing to put forth considerable effort $\overline{e}$ (*e.g.* every working hour each week). Among inventions with some tacit knowledge, greater effort improves the probability of successful implementation, albeit at a decreasing rate. That is, for $t \geq 0$: $\frac{\partial f(t,e)}{\partial e} \geq 0$ with a strict relationship for $t > 0$. I further assume $\frac{\partial f(t,e)}{\partial t \partial e} < 0$. These assumptions capture the notion that tacit inventions demand more inventor effort than "off-the-shelf" inventions; however, the returns to additional effort are decreasing within any narrow range of t.

The inventor and firm both know t and $f(t, e)$. The inventor maintains private information over her own type or willingness to put forth effort. Firms cannot observe individual inventor types, but recognize the distribution of all inventor types based on observing the range of disutilities of effort $V(e)$, described further below. Hence, firms know the types of inventors, but cannot identify a given inventor's type upon inspection. An important distinction in this model is the difference between inventor quality and inventor willingness to exert effort. To focus on contracting on effort, quality differences are not modelled. Thus, $f(t, e)$ is the same across all inventor types for a given level of effort e.

Profit and Utility Functions Since contracts are exclusive and are for non-imitable inventions, the firm is a monopolist for final products. Thus, the firm's expected profit function for an optimal production quantity x is $P = f(t, e)\Pi(x, r)(1-r) - S$. The market demand is assumed to have some elasticity such that for an output-based royalty $r > 0, \Pi(x, r) < \Pi(x, 0) \equiv \Pi(x)$.

Inventors have simple utility functions based on their income level and the cost of their effort. Total utility for an inventor is $T = S + rf(t,e)\Pi(x,r) - V(e)$[7]. $V(e)$ is the inventor's disutility from effort and $V(0) = 0$. $V(e)$ is a continuous, convex function that conditions whether an inventor will be willing to put forth a high level or low level of effort. I limit my analysis to the case of risk neutral inventors to separate the effects of contracting mechanisms from risk and other preferences[8].

I restrict analysis to two types of inventors: I_H inventors are those with a high disutility of effort, and I_L inventors are those with a low disutility of effort. The two inventor types have cost functions $V_i(e)$ for $i = H, L$, and $V_H(e) > V_L(e)$ for a given e.

As mentioned above, the primary purpose of this paper is to examine under what conditions the inventor will develop the invention through a start-up firm. I characterize the start-up firm as a credible commitment to full effort to transfer technology; for example, the inventor must spend her full work week at the firm. Thus, starting a firm requires $\overline{e}$ *irrespective of the optimal number of hours to transfer technology.* Stated differently, modelling a new firm in this fashion captures the commitment an inventor makes to transferring her personal knowledge.

2.3. Equilibria Criteria

To account for the dynamic nature of decisions in the game, equilibria examined will be perfect Baysian equilibria (PBE), whereby each equilibrium is sub-game perfect and strategies are optimal given beliefs about the other player's type and actions. These beliefs are formed using Bayes' Rule. In this model, stage equilibria are a partition (S, r), and a complete strategy is simply a contract offer specifying payment schemes across stages.

I first establish the payment mechanisms in the game in Lemmas 1 and 2. Then, in solving the game, I develop conditions for licensing at Stage 3b in Figure 2. Recall that at this stage, the inventor has already chosen a level of effort $\overline{e}$ by starting a firm. Since PBE precludes the simple backward induction method of solving the game, I set up possible conditions for equilibria in the post-start-up round. Working backwards, I examine equilibria during the initial license acceptance at Stage 2a. These findings are used to propose the full game equilibria

[7] The model holds for more general characterizations of the inventor's utility function, $T = U(rf(t,e)\Pi(x,r) + S) - V(e)$ where the inventor's utility follows the von Neumann-Morgenstern axioms. However, little explanatory power is gained by generalizing the utility function.

[8] Kihlstrom and Laffont (1979) develop a formal general equilibrium model examining the relationship between entrepreneurial risk and new firms.

after analyzing negotiations in the initial licensing stage *conditional on* outcomes after a start-up has been founded (3b in the Game Tree).

Lemma 1. *A lump sum payment S is sufficient (a first-best contract) when further inventor effort is not required: $K(S,0)$.*

See Appendix for Proof

Further inventor involvement is not required chiefly in two cases: when the inventor founds a firm and fully develops the invention, and when the invention requires no further development after the inventor discloses the invention ($t = 0$). The latter category includes "off the shelf" inventions that can be readily used or integrated at the licensee firm following an initial license.

Lemma 2. *A contract specifying royalty rate $r > 0$ of profits is necessary when further inventor effort is required: $K(S,r)$. The royalty gives incentives for an inventor to put forth ex post effort, and S allows the inventor to capture some of the residual rents on the invention.*

Lemma 2 is a reflection of the analysis in Jensen and Thursby (2001).

3. Direct Negotiation

To establish a benchmark, I first examine the licensing transaction with direct negotiation between the inventor and a firm– that is, without the involvement of a TTO. This model then generates a theory relating tacit knowledge, cost of inventor effort, and an inventor's decision to start a firm by which to compare the role and affect of a TTO.

Consider the conditions for licensing after an inventor has founded a firm. From Lemma 1, the inventor offers some $K(\widetilde{S},0)$ to the firm, where $\widetilde{S}$ specifically denotes the lump sum a firm pays to an inventor to acquire the technology and the inventor's firm. The firm's participation constraint for a license at this stage requires that in equilibrium the expected gross profit for a monopolist paying no royalty $P_M = f(t,\overline{e})\Pi(x)$ be greater than the lump sum payment– that is, $P_M \geq \widetilde{S}$ where the inventor's participation constraint is based on her private value of effort,

$V(\overline{e}) \leq \widetilde{S}$. In equilibrium, feasible contracts at this stage will stipulate $K(\widetilde{S}, 0)$ for $P_M \geq \widetilde{S} \geq V(\overline{e})$[9].

Lemma 3. *Since no information on inventor types is revealed, inventors extract the full monopoly rents accruing to the invention after starting a firm. In equilibrium, contracts* $K(\widetilde{S}, 0)$ *specify* $\widetilde{S} = f(t, \overline{e})\Pi(x)$ *for all* $\Pi(x) > 0$ *and* $\widetilde{S} > V_i(e)$ *for inventor* i.

Lemma 3 effectively establishes a floor for the contracts an inventor is willing to accept in the first round. That is, an inventor will not negotiate a license initially if she cannot be compensated the equivalent of full monopoly rents minus the cost of her full effort.

Recall the two inventor types, I_H for inventors with high disutility of effort and I_L for low disutility. In negotiating contracts during the initial licensing round, an inventor of type i has a rationality constraint requiring that any contract must provide the inventor at least as much as her net benefit from starting a firm:

$$rf(t, e_i)\Pi(x, r) + S - V_i(e_i) \geq f(t, \overline{e})\Pi(x) - V_i(\overline{e}) \tag{1}$$

where e_i is the optimal choice of effort in equilibrium. Optimal effort for a given r is derived from

$$argmax\ rf(t, e)\Pi(x, r) + S - V_i(e) \tag{2}$$

Lemma 3 establishes that a firm strategy of waiting for inventors to start firms and develop the invention is never a strictly dominant strategy, and is often suboptimal, because inventors can extract the full monopoly rent accruing to the invention. Given this possibility, the firm would like to offer a contract during the

[9] This set up is intuitive: among inventions not initially licensed, inventors found firms and subsequently license the developed invention provided:

1. The invention carries a relatively high commercial benefit to cover the inventor's full effort, or
2. The inventor's disutility from exerting effort is relatively low.

These two conditions suggest a range of possible Nash equilibria in the post-start-up stage, including $P_M = \widetilde{S} \geq V(\overline{e})$– that is, inventors extract the full monopoly rents as firms bid up the price. In addition, the second condition suggests an interesting characteristic of the model. Some inventors may found firms for nearly any level of tacit knowledge needed to develop the invention since their disutility from doing so is low.

initial licensing stage such that inventors reveal their types. The firm can share monopoly rents via a royalty payment with I_H inventors, while I_L inventors will still found firms. I now examine equilibria where some inventions are licensed initially, and others are only licensed after an inventor has founded a firm.

In this transaction, the firm faces a participation constraint that any license negotiated in the first round must yield non-negative profits:

$$f(t,e)\Pi(x,r)(1-r) - S \geq 0 \tag{3}$$

For purely lump sum contracts $K(S,0)$, this constraint becomes $f(t,e)\Pi(x) \geq S$.

In examining equilibria in the full game, I first consider the two extreme cases. When the level of inventor knowledge needed to develop an invention is extremely high ($t \to 1$ in the limit), the optimal level of inventor effort e approaches full effort $\overline{e}$. As optimal effort increases, inventors extract full rents by starting a firm.

Proposition 1. *Inventions with sufficiently high tacit knowledge will only be developed through an inventor-founded firm.*

The proof of Proposition 1 requires demonstrating that there does not exist a contract $K(S,r)$ that satisfies both the inventor's and the firm's constraints for negotiating the initial license when the optimal level of inventor effort e approaches full effort $\overline{e}$.

Inventors will not be willing to accept less in the initial licensing round than if they started their own firms– monopoly rents with the costs of full inventor effort. Recall the inventor rationality constraint in (1). As the optimal level of inventor effort approaches the full effort (e.g., the knowledge related to an invention is highly tacit):

$$rf(t,\overline{e})\Pi(x,r) + S - V(\overline{e}) \geq f(t,\overline{e})\Pi(x) - V(\overline{e}) \tag{4}$$

where the left side of the inequality is the inventor's expected utility from licensing initially, and the right side is the inventor's expected utility from starting a firm.

Thus, the inventor would only agree to a contract at the initial stage if $S \geq f(t,\overline{e})[\Pi(x) - r\Pi(x,r)]$. However, the firm faces a rationality constraint that the contract negotiated initially must be expected to yield a non-negative return $f(t,\overline{e})[\Pi(x,r)(1-r)] \geq S$. Therefore, an equilibrium would have to stipulate some S that satisfies:

$$f(t,\overline{e})[\Pi(x,r)(1-r)] \geq S \geq f(t,\overline{e})[\Pi(x) - r\Pi(x,r)] \tag{5}$$

This inequality simply reduces to the criteria $\Pi(x,r) \geq \Pi(x)$. However, for $r > 0$ and monopoly markets with demand that is not perfectly inelastic, $\Pi(x,r) < \Pi(x)$.

The intuition behind Proposition 1 is straightforward. Given that inventors must expend virtually full effort, they are only interested in the trade off between how they get paid: royalties versus lump sum. If they get paid through a royalty contract, the contract must be at least as good as extracting full rents. But, the nature of a positive royalty with elastic demand requires that $\Pi(x,r) < \Pi(x)$[10]. Thus it is always better for inventors to found firms when considerable effort is required to transfer their knowledge.

The proof of Proposition 1 also illustrates that incumbent firms' ability to bargain over the residual, S in (4), reduces the level at which an inventor would be willing to license initially rather than start a firm. In the other extreme, it should be noted that the inventor can extract full monopoly rents through a fixed fee even if no tacit knowledge is present since the market opportunity is common knowledge. Based on Lemma 1, when no inventor effort is required, a license contract specifies a fixed fee S.

Proposition 2. *"Off-the-shelf" inventions (no tacit knowledge) will be licensed initially for a fixed fee $S = f(0,0)\Pi(x)$.*

These corner solutions are useful to establish the analytical boundaries for the model. I now turn to the more interesting case, when a moderate level of tacit knowledge is involved. Conceptually, the model features a tension between the inventor improving the probability of successful development and ensuring a given inventor will undertake development efforts. On the one hand, firms might always prefer that inventors improve the probability of successful implementation by founding firms, and in the process expending a high level of effort to further develop the invention before licensing. This would result in a pooling equilibrium where all inventors start firms prior to licensing, and all inventions have a relatively high probability of successful implementation.

On the other hand, since founding a firm is a considerable commitment for inventors, an inventor will only found a firm if she can be compensated for her efforts, $S + r\Pi(x,r) \geq V(\bar{e})$. This leads to a relatively high minimum payment even for inventions that require little or no inventor effort. In extreme cases, inventors

[10] The trivial exception to this statement is when $r = 1$, which is the equivalent of a lump sum payment.

with a very high cost of effort $V(e)$ will not be willing to expend the considerable additional effort to start a firm even when these inventors require have inventions requiring little additional effort. These inventions will go undeveloped.

Proposition 3. *There exists a separating equilibrium where inventors with low disutility of effort start firms, and inventors with high disutility of effort license their inventions for an outcome-based royalty r^* provided the cost of full effort is sufficiently high for I_H inventors.*

The proof of Proposition 3 requires demonstrating that there exists some r^* such that the royalty is sufficiently low that the I_H inventors are willing to accept the contract while I_L will still found a firm because the monopoly rents net of I_L's full effort has a greater expected value than the royalty contract. By doing so, the firm can potentially keep some of the net profits accruing to an invention by bargaining over the residual rents captured in S after a license, in contrast to the simple lump sum contract when all inventors found firms as described in Proposition 1.

Rearranging Equation 1, it is sufficient to show that the minimum contract an inventor of type $i = H, L$ is willing to accept specifies $rf(t, e_i)\Pi(x, r) \geq f(t, \overline{e})\Pi(x) + V(e_i) - V_i(\overline{e})$, where e_i is the optimal level of effort for inventor type i and contract $K(0, r)$ derived from (2). Define $P_M = f(t, \overline{e})\Pi(x)$ as the monopoly profits from a given invention gross of payments to the inventor, and $P_i = f(t, e_i)\Pi(x, r)$ for $i = H, L$ as the gross profits *in equilibrium* when an inventor of type H or L exerts optimal effort given some r. The equilibrium royalty r^* must be high enough to induce I_H to participate in the licensing agreement and is a binding constraint $r^* P_H - V_H(e_H) \geq P_M - V_H(\overline{e})$. Rearranging,

$$r^* \geq \frac{P_M + V_H(e_H) - V_H(\overline{e})}{P_H} \tag{6}$$

The analogous constraint for I_L inventors is that r^* must be low enough that I_L still prefers to found a firm at I_L's optimal level of effort:

$$r^* P_L - V_L(e_L) \leq P_M - V_L(\overline{e}) \tag{7}$$

Combining constraints (6) and (7), r^* exists for inventions where the following inequality holds:

$$V_H(\overline{e}) \geq (1 - \frac{P_H}{P_L})P_M + V_H(e_H) - \frac{P_H}{P_L}[V_L(e_L) - V_L(\overline{e})] \tag{8}$$

By construction, $\frac{P_H}{P_L} < 1$. Thus, a separating equilibrium exists for V_L and V_H if and only if the cost of full effort for an I_H inventor is sufficiently high, subject to the firm's participation constraint from (3): $P_H(1 - r^*) \geq 0$. The minimum royalty $\frac{P_M + V_H(e_H) - V_H(\overline{e})}{P_H}$ that can be negotiated with I_H is less than unity since the specified range for r is $0 \geq r^* > 1$. The specified range for r^* meets this criterion, but solutions only exist when

$$V_H(\overline{e}) \geq P_M + V_H(e_H) - P_H \tag{9}$$

Equation (9) indicates that the firm's constraint binds if the cost of full effort for I_L is sufficiently high since $(1 - \frac{P_H}{P_L})P_M + V_H(e_H) < P_M + V_H(e_H)$.

A final analytical point is to ensure that the separating equilibrium dominates pooling equilibria. It is trivial to show that a given separating equilibrium dominates any pooling equilibrium where inventors always start firms since the inventors can extract the full monopoly rents after starting a firm. The other category of pooling equilibria to analyze is when all inventions are licensed initially. That is, the firm offers some royalty for which both inventor types agree to a license.

Proposition 4. *Separating equilibria dominate pooling equilibria provided there are a sufficient number of I_H inventors.*

For a pooling equilibrium in which all inventors license their inventions, the firm must offer a royalty that ensures I_L's rationality constraint binds. This strategy dominates other royalty rates since the firm needs to offer I_L inventors just enough for them to be indifferent between an initial license and founding a firm. Offering a higher royalty leaves some rents with the I_L inventors

Denote this equilibrium royalty r_L. Rearranging (7):

$$r_L = \frac{P_M + V_L(e_L) - V_L(\overline{e})}{P_L}$$

Proposition 4 states that for a proportion α of I_H inventors:

$$(1-\alpha)P_{L|L}(1-r_L) + \alpha P_{H|L}(1-r_L) \leq (1-\alpha)(P_M - V_L(\overline{e})) + \alpha P_{H|H}(1-r_H) \tag{10}$$

where $P_{i|j}$ denotes the gross profits given inventor type i's optimal effort conditional on negotiating a royalty that is binding for inventor type $j = H, L$. The royalty is derived from (6) and (7). For example, $P_{H|L}$ denotes the firm's expected profits given I_H's optimal effort when presented with the royalty rate r_L. $P_{L|L} = P_L$.

The left side of (10) represents the firm's expected profits from offering both inventor types r_L under a pooling equilibrium. The right side of the inequality represents the firm's expected profits generated from the separating equilibrium discussed in Proposition (3).

For explication, consider the extreme case as $\alpha \to 1$ in the limit. (10) reduces to $P_{H|L}(1-r_L) \leq P_{H|H}(1-r_H)$. By definition, $P_{i|j}(1-r_j) < P_{i|i}(1-r_i)$ for $i \neq j$ since P_i is based on the optimal royalty given inventor i's reaction function. Therefore, Equation 10 holds for the extreme case when there are only I_H inventors, otherwise the firm's offer of $P_{H|H}$ from would not be an optimal strategy.

To solve explicitly for the minimum proportion of I_H inventors, expand and rearrange (10):

$$P_{L|L}(1-r_L)-P_M+V_L(\bar{e}) \leq \alpha[P_{L|L}(1-r_L)-P_M+V_L(\bar{e})+P_{H|H}(1-r_H)-P_{H|L}(1-r_L)]$$

Let $Z = P_{L|L}(1-r_L)-P_M+V_L(\bar{e})$, then the above relationship can be expressed as

$$\frac{Z}{Z + P_{H|H}(1-r_H) - P_{H|L}(1-r_L)} \leq \alpha$$

Based on the above discussion, $P_{H|H}(1-r_H) > P_{H|L}(1-r_L)$. Since its always the case that $\frac{Z}{Z+P_{H|H}(1-r_H)-P_{H|L}(1-r_L)} \leq 1$, there exists an α such that separating equilibria dominates pooling equilibria.

4. The University as an Intermediary

The university serves a number of functions in the licensing process. Three functions in particular emerge as areas where the university directly impacts the licensing transaction. First, universities perform an administrative function related to filing for intellectual property and managing the patent process. In this function, the university has a cost advantage over independent inventors because the university can spread the fixed administrative cost of filing, managing, and enforcing (litigating) patents across many inventions within the university.

Second, universities perform a marketing function in both seeking out potential licensees and working with potential licensees suggested by the inventor. In a survey of one thousand one hundred forty licenses at six institutions, inventors contributed slightly more than half (54%) of the leads for executed licensees (Jansen *et al.* 1999). Even among these inventions, the university has an active marketing role since licensing officers can contact other potential licensees to "shop the technology around." Licensing officers' contacts and marketing efforts were the second most prevalent source (19% of successful leads), but their impact varied widely among institutions– ranging from 12% at University of Florida to 46% at Oregon Health and Science University (Jansen, et al. 1999). These survey responses are self-reported by licensing officers and thus indicate an upper limit for the impact of university marketing efforts. Nonetheless, even in cases where the inventor contributed the eventual licensee's name, university licensing officers contacted these companies and negotiated the license. Marketing efforts are one of the primary functions of the university.

Lastly, since the university virtually always retains title to the invention under the Bayh-Dole Act and campus policies, the university is typically solely responsible for negotiating contract terms with potential licensees. Note that when an inventor is interested in founding a firm, the inventor must also negotiate a license with the university.

To specify the university's utility function, I employ the same logic behind the basic model that Jensen and Thursby (2001) derive from their survey results. Their survey results indicate that the most important goal for licensing officers and university administration is maximizing revenue[11]. There is also a need for inventors to be involved to transfer their knowledge, and inventors presumably will have future interactions with the technology transfer office as the providers of technology to license. The technology transfer office needs to balance the university's goals (revenue maximization) and the inventor's interests. Following Jensen and Thursby, I define γ to indicate the weight the university places on faculty interests. Effectively, the university gives weight γ to the inventor's utility function and $1-\gamma$ to revenue maximization.

In the model, the university incurs a fixed cost C to market and manage an invention. This is a cost committed to an invention once a university agrees to pursue patenting and licensing an invention disclosed by a faculty member.

[11] Jensen and Thursby (2001) also report that the number of licenses executed and inventions commercialized are "close seconds" among licensing officers' and university administration's priorities.

By incurring the marketing cost, the university improves the share of the fixed fee that is bargained over between inventor and licensee during initial license negotiations. The subsequent improvement in bargaining position includes a factor λ, where $\frac{(1-r)f(t,e)\Pi(x,r)}{S^k} \geq \lambda \geq 1$, that represents the marginal effect of university marketing on the inventor's ability to bargain for a fixed fee. S^k represents the counterfactual: the fixed fee that the kth inventor would have negotiated if the university were not involved[12]. The upper limit on λ simply indicates that the university could not negotiate more than the net profits and captures the licensee's participation constraint. The lower limit on λ assumes that once the university incurs C, the university can do at least as well as the inventor in bargaining. By incurring cost C, the TTO can improve the inventor' share of a negotiated fixed fee by λS^k.

I make two additions to the model to capture the university licensing process. Jensen and Thursby (2001) report that virtually all the universities surveyed have prespecified percentages or a sliding scale method to share fixed fees S and royalties r between the inventor and the university. I parameterize the share of payments between inventor and the university to include how the university and inventor divide rents on the invention. Let α indicate the share of fixed fee and β indicate the share of royalties that the inventor keeps.

Second, at many U.S. universities, if a technology is initially licensed to an inventor– so that the inventor can start a firm– that license remains in effect even after the inventor sells the firm. The license is transferred to the acquiring firm, which is then responsible to pay royalties on future product sales for the duration of the license. For example, the acquiring firms listed in Table 2 pay royalties on the licensed technology after acquiring the inventor's start-up.

An extreme example of this transaction is the case of Xenometrix, discussed in greater detail in Lowe (2001). Xenometrix was a biotechnology firm that licensed two inventions discovered at the University of California-Berkeley and Harvard University. The firm was formed with two venture capitalists and the principal inventors, Spencer Farr (Harvard University) and Pauline Gee (UC-Berkeley). Harvard and Xenometrix jointly hold a patent on one of Farr's inventions "Methods and Kits for Eukaryotic Gene Profiling" (U.S. Patent 5,811,231), and as a result, revenues on the invention are shared between Xenometrix and Harvard University, although a portion of the payments to Harvard are inventor's shares paid back to Spencer Farr. After filing for the patent, Farr left Xenometrix

[12] Note that S^k is conditional on a royalty rate r in equilibrium since the contract terms are negotiated simultaneously.

to start another company, Phase-1 Molecular Toxicology. In the meantime, the patent issued and a non-exclusive license was negotiated with Phase-1. In 2001, Discovery Partners International, Inc. (DPII) acquired Xenometrix. Royalties on any of Phase-1's sales are then paid to DPII and Harvard, with a portion of the Harvard royalties flowing back to Farr at Phase-1 (Gee 2001).

The university's utility function is thus $Y = (1-\gamma)[(1-\alpha)S + (1-\beta)rP_i - C] + \gamma[\alpha S + \beta r P_i - V(e_i)]$, where P_i is the expected profits in equilibrium for an inventor type i. The game unfolds in a similar fashion as depicted in Figure 1. The primary difference is that now the university negotiates the initial contract with an outside firm, or if the inventor founds a firm, the contract is negotiated with the inventor. If an established firm accepts the initial contract, the university divides a fixed fee and royalties with the inventor.

If the inventor founds a firm, the inventor agrees to a contract with the university stipulating $K(S, r)$. The inventor pays S upfront, and royalties r are not paid until product sales begin after the inventor has developed her invention and sold the developed technology to a firm for commercialization. Having developed her invention, the inventor sells the technology for a fixed fee equal to the expected value of the invention to an outside firm: $S = (1-r)f(t, \overline{e})\Pi(x, r)$. The net effect of this transaction and the inventor's upfront fixed fee is that the university keeps $(1-\alpha)S$ and the inventor keeps αS. Any licensing royalties stipulated in the contract with the inventor are then passed on as an obligation to the firm acquiring the inventor's start-up. For any positive royalty $r > 0$, the sale price of the inventor's firm is less than if the university were not involved in the transaction $(1-r)f(t, \overline{e})\Pi(x, r) < f(t, \overline{e})\Pi(x)$.

The inventor also receives her portion of the royalties so that her total income from the license and development is $\alpha(1-r)f(t, \overline{e})\Pi(x, r) + \beta r f(t, \overline{e})\Pi(x, r)$ which is less than she receives under the simple sale of her firm without the university's involvement. That is, $\alpha(1-r)f(t, \overline{e})\Pi(x, r) + \beta r f(t, \overline{e})\Pi(x, r) < f(t, \overline{e})\Pi(x)$. The insight for university policy is that even if the university pursues a course to only maximize the inventor's benefit (that is, $\alpha = \beta = 1$) rather than placing partial weight on revenue maximization, the inventor is still worse off with the university's involvement because the enforced royalty reduces the firm's optimal output level. In this "best case" for the inventor, the above equation simply reduces to $f(t, \overline{e})\Pi(x, r) < f(t, \overline{e})\Pi(x)$, which is true by the standard assumption of elastic demand for the final good.

The involvement of the university in an inventor start-up then has two effects, as summarized in Proposition 5:

Proposition 5. *When an inventor founds a firm with a university license, a university royalty "distorts" final output: the output level is less than that under a simple contract relationship between inventor and firm. Inventors are worse off due to reduced final output and sharing royalties with the university.*

A corollary of Proposition 5 is that a pure fixed fee contract, such as where the university merely takes a portion of equity in the inventor's firm rather than requiring a future royalty rate, does not distort output and provides a Pareto efficient solution for transferring technology. One could argue for the university keeping a fixed fee or equity stake to cover its cost of administering or managing intellectual property for an inventor. Each of the acquiring firms in Table 2 pay UC a royalty rate on sales after acquiring the inventors' firms, a policy enforced by many universities, however. This policy is the standard among university TTO's.

Under the Bayh-Dole Act, universities maintain the opportunity to share in licensing revenue presumably under the pretense that revenue sharing gives the university incentive to encourage and assist inventors in commercialization efforts with licensees. In the case of inventor-founded firms, however, such an incentive is hardly necessary as the inventors have clearly chosen to actively pursue such a path. Another explanation for sharing royalties put forth by licensing officers is that the university can share royalties with inventors who were not founders. Once again, its not clear why a lump sum fee or equity could not provide a reasonable reward. This discussion implicates an important area for further thinking on managing and regulating university technology transfer: the structure of and limits on the university's contract terms.

However, when the university negotiates an initial license with an outside firm, the result can be a Pareto improvement for the inventor relative to negotiating a license without the university's involvement. The advantage stems from the university's ability to market inventions and find suitable licensees.

The base case to first consider is when the university does not improve the number of potential licensees bidding for a technology or the inventor's bargaining position with respect to splitting S, the net profits (after royalty payments), with the licensee. In such cases, it is readily seen that the university simply "taxes" the invention, resulting in less effort to transfer knowledge by the inventor. The inventor is then worse off than without the university. This reduction in the inventor's share is due to both the royalties extracted by the university and the reduction in final output as a result of the higher variable cost (via output-based royalties) faced by the commercializing firm.

This point is readily seen by comparing the first order conditions (FOC) for the inventor's utility functions with and without the university's involvement. Consider the inventor's best bargaining position as a generalized case. The inventor's generalized utility function is then $\alpha S + \beta r f(t,e)\Pi(x,r) - V(e)$, or expanding S:

$$\alpha(1-r)f(t,e)\Pi(x,r) + \beta r f(t,e)\Pi(x,r) - V(e) \tag{11}$$

where $\alpha = \beta = 1$ when the university is not involved and $0 < \alpha, \beta < 1$ when the university is involved. Under this scenario, the FOC with university involvement is:

$$[\alpha + r(\beta - \alpha)]\frac{\partial f(t,e)}{\partial e}\Pi(x,r) = \frac{\partial V(e)}{\partial e} \tag{12}$$

and the FOC for the inventor's utility without the university's involvement is:

$$\frac{\partial f(t,e)}{\partial e}\Pi(x,r) = \frac{\partial V(e)}{\partial e} \tag{13}$$

Since $[\alpha + r(\beta - \alpha)] < 1$, the inventor's optimal effort in strictly less when the university is involved. It is trivial to show that a similar result holds for any $S < (1-r)f(t,e)\Pi(x,r)$.

This general scenario includes cases where the licensee maintains some rights to the invention (such as "first right of refusal") because the licensee funded the research. While this scenario only accounted for 7% of licensed inventions across all institutions in the Jansen survey, the survey suggests that at some schools this can be common. Licensees that also funded the research accounted for 25% and 23% of licensed inventions at Tulane University and the University of Florida, respectively (Jansen, *et al.* 1999).

This scenario also includes cases where the inventor suggested a licensee; however, the university may still improve the inventor's share of S even when the licensee is suggested by the inventor. The university can invite other potential licenses to examine an invention and bid up the price. The university may also have a better or more credible ability to estimate the market potential– although the market potential is assumed to be commonly observable in this model– or better negotiating skills than a university inventor.

Proposition 6. *The university's involvement in an initial license can be Pareto improving for inventors when the university incurs a marketing cost and sufficiently improves the inventor's bargaining position.*

The involvement of the university is thus only Pareto improving over some range of inventions. It is sufficient to show that there exists some λ for which the inventor is made strictly better off when the university is involved:

$$\alpha\lambda S^k + \beta rp(t,e)\Pi(x,r) > S^k + rp(t,e)\Pi(x,r) \tag{14}$$

$$\lambda > \frac{1}{\alpha} + \frac{(1-\beta)}{\alpha\Delta}\frac{r}{1-r} \tag{15}$$

where $\Delta = (1-r)p(t,e)\Pi(x,r) - S^k$ is a parameter for the inventor's relative bargaining position conditional on a royalty rate r. Note that $\alpha > 0$; that is, universities pay some portion of the fixed fee to the inventor. By the assumptions in the model, λ then exists for inventions as long as the royalty rate $r < 1$.

Finally, the role of marketing costs illustrates a fundamental trade-off that university technology transfer offices make in licensing. By purely maximizing the university's total utility, the university will license some inventions which have an expected negative return: $(1-\alpha)S + (1-\beta)rP_i < C$. The result follows from the weight that the university puts on maximizing the inventor's utility since the inventor does not incur C. As a result, university technology transfer offices may seek only to cover costs across the population of inventions during a given year, or even run a deficit. For example, the University of California as a system had positive net income in 2001, but three individual campuses incurred a net loss[13] (University of California 2002).

If the university restricts its population of inventions to only those whose expected income on an individual invention outweighs the marketing and management costs, then some inventions will be passed over for which the inventor may have licensed the invention if operating independently. These cases where $C < (1-\alpha)\lambda S^k + (1-\beta)rP_i$ and $rP_i \geq V(e)$ represent inventions that "die" in the licensing office but could have been commercialized without the university[14,15].

[13] Santa Barbara (-\$415,000), Santa Cruz (-\$212,000), and San Diego (-\$1,904,000). Riverside essentially broke even, posting \$8,000 is net income.

[14] When the university chooses not to pursue an invention, technically the university can forfeit its rights to the inventor However, interviews with UC licensing officers indicate that this virtually never happens. Although the inventor could contract privately with a licensee, the inventor and licensee do so at the risk of litigation by the university.

[15] An interesting counter example is the University of Toronto, which maintains an "opt-in" for university faculty (Munsche 2002). In this case, inventors can sort themselves as to their need for the university to assist in marketing and managing the invention.

This tradeoff raises an important point for the effects of broad university policies on faculty inventions. Bayh-Dole created a mechanism for U.S. universities to enforce broad ownership rights for inventions discovered by a faculty member or other university researcher on campus beyond those inventions that are federally-funded, and hence covered by the Bayh-Dole Act. Broad rights across all inventions implies that there will be some inventions for which $C < (1-\alpha)\lambda S^k + (1-\beta)rP_i$. The establishment of technology transfer offices indeed assists inventors where they may not have been able to successfully market inventions. The cost of doing so is that some inventions with lower commercial opportunities may not leave the university, depending on the criteria the technology transfer uses in choosing which inventions to pursue[16].

5. Concluding Remarks

This paper examined how the relationship between inventor knowledge and effort to transfer that knowledge influences who develops an invention. Modelling the licensing transaction between an independent inventor and an established firm demonstrated two main findings. First, under the assumptions of the model, inventions associated with high levels of tacit knowledge will always be developed via inventor-founded start-up firms. In these cases, the inventor can extract full monopoly rents related to the invention. Second, for inventions requiring some inventor effort, though less than the full-effort case, there is a separating equilibrium where inventors who perceive their effort as very costly license their invention initially rather than pursue a start-up provided there are a sufficient number of such inventors.

Universities play an active role in this process. When an inventor founds a firm, university policies requiring a royalty rate distort final output and result

[16] Several papers have empirically studied the change in patent importance since passage of the Bayh-Dole Act (Trajtenberg, Henderson, and Jaffee 1997; Mowery and Ziedonis 2002; Mowery, Sampat, and Ziedonis 2002). These studies suggest some, albeit limited, evidence of a decline in average "quality" among academic patents, raising the concern that some universities–apparently those universities that are new to the patenting game–pursue patents that might not have merited such investment if owned by an inventor without the support of a university. These studies relate to the model and analysis in this chapter, although further discussion on this point is beyond the scope of the present chapter: this chapter examines licensing and inventor effort, but does not posit a relationship between patenting and licensing. Relating the analysis of licensing in this chapter and in Chapters 2 and 3 to broader trends in university patenting promises to shed light on this important topic.

in a transfer from inventor to university with no apparent added productivity. However, the university can improve the inventor's welfare by marketing and negotiating the licensing contract to secure a higher fixed fee payment.

The model in this paper is built on several key assumptions that deserve further consideration. First, the founding of a firm is characterized as a commitment to full effort by the inventor. Indeed, starting a new firm does entail a considerable amount of effort, both in further scientific research as well as administrative costs. However, an inventor could found a firm and not put in sufficient effort to develop the invention for the second round of licensing. With enough noise in the signal to established firms, there may be inventions that have not been developed sufficiently in the inventor's start-up firm. This consideration imposes some uncertainty over licensing in the second round that is not modelled in this paper. Another role for the university may be as a monitor or disciplining mechanism in this process.

Second, the scope of intellectual property rights do not play a prominent role in the analysis, primarily because a number of recent scholars have addressed how the scope of property rights affects the licensing transaction (see for example Klemperer 1990; Gilbert and Shapiro 1990;Arora 1995).

As mentioned in the Introduction, this paper was motivated by recent work on university technology transfer highlighting the importance of inventor involvement after negotiating licenses to outside firms. A number of papers cited herein have documented this important aspect of university technology transfer. The paper contributes a careful examination of the relationship between inventor, licensee, and university to shed light on the potential benefits and costs in applying broad university policies, facilitated by the Bayh-Dole Act, on how raw inventions are developed.

The paper also presents a more general framework which could be adapted from the formal structure that was imposed to mirror the university licensing process. An obvious extension is to consider the incentives for scientists working in corporate research labs. This extension introduces a final theme not addressed in the present paper: how differences in organizational structure between universities and companies support or impede inventor start-ups. Further empirical evidence is needed on corporate spin-offs, as well as the more general consideration of how organizational structures affect a would-be entrepreneur's incentives. This paper offers some early steps to move down the path linking inventor knowledge and the incentives to start firms, and understanding the role of intermediaries– such as a university– in licensing.

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6. Appendix

Lemma 1 A lump sum payment $\widetilde{S}$ is sufficient (a first-best contract) to transfer technology when inventor effort is not required.

Lemma 1 merely follows from the observation that once the inventor has exerted effort, or no further effort is required, a fixed fee can be used to capture the full rents available to the inventor. For each royalty-based contract that might be offered, a lump-sum contract can be written that is at least as good for the firm and inventor. That is, for a given contract offer $K(S,r) = K(\widetilde{S},0)$ and an alternative $K(\widehat{S},r)$ where $r > 0$, there exists some $\widetilde{S}$ such that in equilibrium

$$f(t,\overline{e})\Pi(x) - \widetilde{S} \geq f(t,\overline{e})\Pi(x,r)(1-r) - \widehat{S} \tag{16}$$

If 16 were not true, then it must always be the case that

$$f(t,\overline{e})\Pi(x) - \widetilde{S} < f(t,\overline{e})\Pi(x,r)(1-r) - \widehat{S} \tag{17}$$

$$f(t,\overline{e})[\Pi(x) - \Pi(x,r)(1-r)] < \widetilde{S} - \widehat{S} \tag{18}$$

Case 1, let $\widetilde{S} = \widehat{S}$, then

$$\frac{\Pi(x)}{\Pi(x,r)(1-r)} < 0 \tag{19}$$

Since $r > 0$, for a monopolist $\Pi(x) > \Pi(x,r)(1-r)$ and there cannot be a contract for which 17 is true.

Case 2, let $\widetilde{S} > \widehat{S}$. From 18,

$$f(t,\overline{e})[\Pi(x) - \Pi(x,r)(1-r)] < \widetilde{S} - \widehat{S}$$

Trivially, this relationship cannot exist in equilibrium since an inventor would always be able to specify $\widetilde{S}$ such that $\widetilde{S} \geq \widehat{S}$ since if $\widetilde{S} \leq f(t,\overline{e})\Pi(x,r)(1-r)$ in equilibrium (the firm's participation constraint), it must be the case that $\widetilde{S} \leq f(t,\overline{e})\Pi(x)$.

Table 1. Royalties by inventor-founded firms at the University of California on inventions disclosed between 1986-1995

	Industry	Ownership	Product Status	(a) Earned + Minimum + Milestone	(b) Earned + Minimum	(c) Earned Royalties	(d) Royalties on final products
1	Biotechnology	Acquired	Commercial Sales[1]	$ 305,386.72	$ 305,386.72	$ 305,386.72	**Y**
2	Pharmaceuticals	Acquired	Commercial Sales	$ 1,013,735.38	$ 1,013,735.38	$ 1,013,735.38	**Y**
3	Medical devices	Acquired	Commercial Sales	$ 13,000.00	$ 13,000.00	$ -	N
4	Medical devices	Acquired	Commercial Sales	$ 287,549.93	$ 267,549.93	$ 267,549.93	**Y**
5	Pharmaceuticals	Acquired	Commercial Sales	$ 91,249.07	$ 26,249.07	$ 26,249.07	**Y**
6	Biotechnology	Acquired	Commercial Sales	$ 17,851.02	$ 17,851.02	$ 17,851.02	**Y**
7	Pharmaceuticals	Acquired	Biotech tool integrated in parent's platform	$ 75,000.00	$ -	$ -	N
8	Advanced materials	Acquired	Commercial Sales	$ 525,000.00	$ 525,000.00	$ 100,000.00	**Y**
9	Biotechnology	Acquired	Commercial Sales	$ 140,945.32	$ 140,945.32	$ 945.32	**Y**
10	Pharmaceuticals	Independent	In development	$ -	$ -	$ -	N
11	Advanced materials	Independent	In development	$ -	$ -	$ -	N
12	Pharmaceuticals	Independent	In development[2]	$ 85,752.00	$ 85,752.00	$ 85,752.00	N
13	Pharmaceuticals	Independent	Early clinical trials	$ -	$ -	$ -	N
14	Medical devices	Independent	In development	$ -	$ -	$ -	N
15	Computer hardware	Independent	Working prototype	$ -	$ -	$ -	N
16	Pharmaceuticals	Independent	Early clinical trials	$ -	$ -	$ -	N
17	Medical devices	Independent	In development	$ -	$ -	$ -	N
18	Pharmaceuticals	Independent	Early clinical trials	$ -	$ -	$ -	N
19	Biotech/Pharmaceuticals	Independent	Early clinical trials	$ -	$ -	$ -	N
20	Biotech/Pharmaceuticals	Independent	Stem cell registry, Clinical trials	$ 10,000.00	$ 10,000.00	$ -	N
21	Pharmaceuticals	Independent	In development	$ -	$ -	$ -	N
22	Biotechnology	Independent	In development	$ -	$ -	$ -	N
23	Biotechnology	Independent	In development	$ -	$ -	$ -	N
24	Pharmaceuticals	Independent	Clinical trials	$ 58,333.00	$ -	$ -	N
25	Medical devices	Independent	Commercial Sales	$ 2,100.00	$ 2,100.00	$ 2,100.00	**Y**
26	Pharmaceuticals	Independent	In development	$ 6,000.00	$ -	$ -	N
27	Pharmaceuticals	Independent	Early clinical trials	$ -	$ -	$ -	N
28	Pharmaceuticals	Independent	In development	$ -	$ -	$ -	N
29	Biotech/Pharmaceuticals	Independent	Early clinical trials	$ -	$ -	$ -	N
30	Pharmaceuticals	Independent	In development	$ -	$ -	$ -	N
31	Pharmaceuticals	Independent	In development	$ -	$ -	$ -	N
32	Biotechnology	Independent	Commercial Sales/Sublicensing	$ 80,000.00	$ 80,000.00	$ -	**Y**
33	Software algorithm	Independent	Sublicensing	$ 14,411.79	$ 14,411.79	$ 14,411.79	**Y**
34	Biotechnology	Independent	Early clinical trials	$ -	$ -	$ -	N
35	Biotechnology	Independent	In development	$ -	$ -	$ -	N
36	Computer hardware	Independent	In development	$ -	$ -	$ -	N
37	Medical devices	Independent	Commercial Sales	$ -	$ -	$ -	N
38	Biotechnology	Independent	Research partnerships	$ -	$ -	$ -	N
39	Biotechnology	Independent	In development	$ -	$ -	$ -	N
40	Advanced materials	Defunct		$ 6,000.00	$ 6,000.00	$ -	**Y**
41	Biotechnology	Defunct		$ -	$ -	$ -	N
42	Test and Measurement	Defunct		$ -	$ -	$ -	N
43	Biotechnology	Defunct		$ -	$ -	$ -	N

Note: Royalties reported gross of delayed or installment payments through July 2002
(1) Proportion ($272,450) of earned royalties is equity cash out
(2) Entire $85,752 of earned royalties is equity cash out

Figure 1. Technology Transfer Process