University Invention, Entrepreneurship, and Start-Ups

Celestine O. Chukumba and Richard A. Jensen*
Department of Economics and Econometrics
The University of Notre Dame

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Abstract

The Bayh-Dole Act (1980) allows U.S. universities to own and license inventions arising from federally-funded research by their faculty. We examine the question of when commercialization of university inventions occurs in start-up firms instead of established firms. We construct a theoretical model that predicts that start-ups are more likely if their opportunity cost of development and commercialization is lower, due to less profitable alternatives, or if the university's technology transfer officer's (TTO) opportunity cost of searching for a partner among established firms is greater. Using data from the Association of University Technology Managers (AUTM), the National Venture Capital Association Yearbook for 1993-2002, and the National Research Council, we find that inventor quality and TTO experience have a positive impact on start-ups and licenses to established firms. We find evidence that venture capital spending and equity performance, as measured by the S&P 500, are positively related to start-ups. We also find evidence that capital costs have a negative influence on start-ups.

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1 Introduction

The Bayh-Dole Act led to an explosion in the growth of technology transfer offices in universities, as well as a substantial increase in the commercialization of university inventions. Although initially most of this activity took the form of license agreements with established firms, recently there has been an increase in commercialization via new firms, or start-ups. This paper examines reasons for the commercialization of university inventions through start-up firms as opposed to established firms.

Technology transfer officers (TTOs) are responsible for making good-faith efforts to commercialize university inventions. This process begins when a faculty member discloses a potential invention to the TTO, who then tries to find a partner for commercialization. If the TTO is unable to find an established firm willing to purchase a license for the technology, then it shelves the invention. That is, the TTO returns it to the inventor, who may then seek venture capitalists or angel investors to help fund a start-up firm in order to attempt to commercialize the invention. In fact, the TTO may return it to the inventor immediately, without even trying to find a firm to license it. In this event, the TTO may assist the inventor in searching for an investor to fund a start-up, but typically TTOs focus their efforts on licensing inventions to established firms.

We formalize this by developing a game-theoretic model of university licensing. It begins when the inventor discloses an invention to the TTO, which first decides either to shelve the invention or to search for an established firm to which it offers a license contract. If a contract is offered, then the firm decides either to accept or reject the contract. If it accepts, then it pays a fixed fee and a period of further development follows, in which both the inventor and the licensee may expend effort to improve the probability of success. The firm then decides either to terminate the project, after which the TTO shelves the invention, or to expend the resources necessary to attempt to commercialize it, after which its success or failure becomes common knowledge. If it succeeds, the firm produces and pays royalties. If the TTO shelves the invention, the inventor may attempt to find an investor for a start-up firm to pursue licensing, further development, and commercialization. The TTO may assist in this process, but does so with a minimal expenditure of effort.

The model provides two main implications regarding commercialization by start-up firms rather than established firms. First, if the TTO's utility cost of searching is the same for both types of firms, then start-ups occur in equilibrium only if a start-up firm earns greater expected profit, gross of any license payments, than an established firm, so that the TTO can earn greater net utility from licensing to a start-up under the optimal contract. This occurs if a start-up firm has an advantage in the cost of additional development or commercialization. Although established firms may have cost advantages for inventions that are closely related to their current product line, they may not have these advantages for those that do not fit well in their existing product lines. These costs include the potential profits from foregone opportunities, and established firms typically have alternatives that are more closely related to their current business, and therefore more profitable. Moreover, venture capitalists routinely deal with new products and processes, so they may well have better access to and/or information about the expertise needed to develop and commercialize embryonic inventions, which would provide a start-up firm with a cost advantage. Similarly, inventor-founded start-ups may well have cost advantages due to the inventor's superior knowledge of the technology, which can limit transactional and informational problems (Shane 2002). Also, if the start-up has a lower opportunity cost of development effort, then it may provide greater effort in the development stage. Because inventor and firm effort are strategic complements, greater firm effort induces greater inventor effort, and thus a greater probability of success and greater expected profit for the start-up firm. The second main implication is that licensing to a start-up can occur, even if expected profit is the same for both types of firms, simply because the TTO's opportunity cost of searching for an established firm as a licensee is greater. This can occur if the TTO has a pool of higher-quality disclosures available for commercialization, so less attractive ones are immediately shelved.

Several empirical implications follow immediately from the theory. We summarize these in terms of characteristics of the inventor, the TTO, and the invention, and financial market conditions. Essentially, we are more likely to observe commercialization of university inventions by start-up firms in situations in which start-ups are more likely to have a cost advantage in the development or commercialization, or in which the opportunity cost of the TTO's search for an established firm as a partner is higher. We summarize these in terms of characteristics of the inventor, the TTO, and the invention, and financial market conditions.

Our empirical analysis uses data from the Association of University Technology Managers (AUTM) for fiscal years 1993-2002 to examine commercialization of inventions by start-up firms and data from the National Venture Capital Association Yearbook 2004. We estimate models for the annual number of start-ups and licenses and options executed per university in each year. In general, like Di Gregoriao and Shane (2003), our results provide evidence that inventor quality has a positive impact on start-up activity. It appears that universities with higher quality faculty are more likely to commercialize their inventions through start-ups. Our results also show that inventor quality also positively effects licensing in general. We find that TTO experience has significant, positive effects on start-up activity and licensing in general. Conversely, gross licensing royalties negatively impacts start-up activity but positively affects the number of licenses generated by universities in a given year. We find strong evidence that venture capital at the state level positively affects start-up activity even when controlling for universities located in states that received high venture capital disbursements. The returns to venture capital negatively affected start-ups. Finally, our results show some evidence that interest rate changes negatively affect start-up activity and that general market conditions as measured by the S&P 500 are positively related to start-up activity.

2 Literature Review

Our results contribute to the small but growing theoretical literature on the licensing of university inventions. The theoretical literature has predominantly focused on the effects of the Bayh-Dole Act, and the behavior of inventors and TTOs: Jensen and Thursby (2001), Lach and Shankerman (2002), Jensen, Thursby, and Thursby (2003), Thursby, Thursby, and Decheneaux (2004), Hoppe and Ozdenoren (2004), and Macho-Stadler, Perez-Castrillo, and Veugelers (2004). One exception to this is Jensen and Thursby (2004), who study the effects of increased incentives to commercialize university research on the trade-off between applied and basic research, and the quality of education. What distinguishes our theoretical model is that all previous efforts have simply focused on the licensing or commercializing of the invention to some firm, rather than determining the conditions under which commercialization occurs through a start-up firm instead of an established firm.

Our results also contribute to the now extensive empirical literature on the commercialization of university research and start-ups. Much of the literature on university invention has abstracted from examining the role of university inventors and TTOs. Exceptions include Bercovitz *et al.* (2001) and Siegel *et al.* (1999), who take an organizational perspective, Thursby *et al.* (2001), Thursby and Thursby (2001), Jensen, Thursby, and Thursby (2003), and Thursby, Thursby, and Decheneaux (2004), who examine the role of TTOs in structuring license contracts, and Lach and Shankerman (2002), who study the number and value of inventor disclosures. Our work adds to this literature as our approach considers quality of faculty and its effect on the choice between commercialization by established firms and start-ups.

Shane has examined factors influencing the performance of start-ups using data on inventions by MIT faculty. He shows that the formation of start-ups is fostered by both recognition of business opportunities by inventors (Shane 2000) and the presence of technological opportunities (Shane 2001). Shane and Stuart (2002) find that start-ups are more likely to succeed if the founders have relationships with venture capitalists. Di Gregoriao and Shane (2003) examine start-up formation across US universities, using AUTM data for the period 1994-1998, and find a positive relationship between start-up formation and faculty quality, as measured by the Gourman Report (our empirical analysis, in part, updates and extends this study). The latter two studies include financial market factors in the form of availability of nearby sources of venture capital and IPOs, but do not examine more general measures of financial market activity, or measures of TTO experience. Finally, Shane (2002) compares MIT inventions licensed to established and start-up firms. He finds that licensing to inventor-founded start-ups is more likely when patents are ineffective at preventing information problems (such as moral hazard and adverse selection), because the inventor's superior knowledge of the technology precludes such problems in start-ups. However, he also finds that licenses to start-ups perform poorly compared to licenses to established firms, and concludes that licensing to start-ups on a second best solution for TTOs. This supports our assumption that TTOs generally prefer to license to established firms, and put far less effort into searching for start-up licensees. Similarly, Lowe and Ziedonis (2004) compare the outcomes of licenses to start-ups with those to established firms using data from the University of California and find that royalties from start-ups are higher, on average, but successful commercialization tends to occur only after acquisition by an established firm.

Other recent literature has examined start-up firm activity and licensing in general. Shane and Somaya use AUTM data and patent litigation data during 1991-2000 to examine the effects of patent litigation on university licensing efforts. Siegel *et al.* (1999) examine the relationship between licenses, TTO staff and legal expenditures in their analysis of university technology transfer. Feldman, Feller, Bercovitz and Burton (2002) find an increase in the use of cashed-in-equity in licensing agreements. Our analysis adds depth by examining factors related to commercialization of inventions in both established and start-up firms.

3 The Theoretical Model

The model is a reasonably straightforward compilation and extension of those in Jensen and Thursby (2001) and Jensen, Thursby, and Thursby (2003). We model the problem as a multistage game with four players: the TTO, the inventor, an established firm, and an investor/entrepreneur. Our model assumes that the TTO's basic approach is to seek a license with an established firm first, then turn to the possibility of a start-up firm only as a last resort after the effort to find an established firm has failed. That is, our approach is more appropriate for universities like Stanford, where the TTO shelves an invention when her estimate of its value is below a threshold value, than for MIT, where there is a culture of favoring start-up firms.

The game begins when the inventor discloses an invention to the TTO. The TTO first decides either to shelve the invention (i.e., return it to the inventor), or to search for an established firm to which it offers a license contract. If a contract is offered, then the firm decides either to accept or reject the contract. If it accepts, it pays a fixed license fee, $M \geq 0$, and then a period of further development follows. If it rejects the contract, the TTO shelves the invention. If the contract is accepted, the further development results in an updated probability of success, which is common knowledge. The firm then decides either to terminate the project, after which the TTO shelves the invention, or to expend the resources necessary to attempt to commercialize it, after which whether the invention succeeds becomes common knowledge. If it fails, the game ends. If it succeeds, the firm produces and pays total royalties of $R \geq 0$.

In the development period, the inventor and the firm may expend further effort to increase the probability of success. We assume these efforts are not contractible, but instead are chosen at the beginning of the development period (after the licensing agreement has been made) as the equilibrium outcomes $e_F \geq 0$ and $E_F \geq 0$ of a noncooperative subgame between the inventor and licensee, which in general will depend upon the contract. That is, equilibrium efforts are $e_F^* = e_F^*(R_F, M_F)$ and $E_F^* = E_F^*(R_F, M_F)$.

As is well-known by now, university inventions are typically embryonic. Their commercial potential is uncertain, and the likelihood of their success is very small. We assume that the probability of success $p(e_F, E_F; Q, H)$ depends not only on the efforts, but also on a measure of the quality of the inventor, Q, and a measure of the historical success of the TTO, H.

We assume that p is increasing in not only in the efforts, but also inventor quality and past TTO success. It is evident that efforts and inventor quality are inputs in the "production" of a probability of success Including TTO success as an input as well implies that, *ceteris paribus*, an invention drawn at random from a faculty member at a university with a superior track record of success is more likely to be a success. We also assume that p is jointly concave in all its arguments, and that $p \in (0,1)$ for all $(e, E; Q, H)$. Finally, we assume that additional effort 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, $\frac{\partial^2 p}{\partial e \partial E} > 0$. That is, effort by the inventor and firm are "complements" in development, in the sense that they complement each other in the production of a positive probability of success.

If additional development occurs and the invention is a success, then the firm chooses output to maximize its profit (net of any license fees). In general, because the firms's marginal cost depends on the royalty rate, but not the fixed fee, its maximal output is decreasing in the royalty rate but does not depend on the fixed fee. If $r \geq 0$ is the royalty rate per unit of output, denote profit-maximizing output by $x(r)$. We assume that $x(0) > 0$ and $x'(r) < 0$, and that total royalty revenue $R = rx(r)$ is strictly concave in r and takes a unique maximum at some positive but finite value.[1] Because the "effort" provided by the firm can include materiel and personnel as well as cash grants, we denote the cost of its effort by $C_F(E_F)$, which we assume is increasing at an increasing rate: $C_F(0) = 0$, $C'_F > 0$, and $C''_F > 0$. Finally, the firm must also pay a lump-sum cost to attempt to commercialize the invention, $K_F > 0$. Thus, if $\Pi(x(r))$ is the firm's maximized profit (gross of royalty payments) for any royalty rate r, then its expected payoff from accepting a contract (R_F, M_F) is

$$P_F(e_F, E_F) = p(e_F, E_F; Q, H)[\Pi(x(r_F)) - R_F] - M_F - C_F(E_F) - K_F, \quad (1)$$

where r_F is the royalty rate associated with the contract (R_F, M_F) (i.e., $R_F = r_F x(r_F)$).The firm accepts this contract and attempts to commercialize the invention (after development) if $P_F(e_F, E_F) \geq 0$.

Conversely, suppose that the TTO shelves the invention, by which we mean the TTO returns it to the inventor and expends effort in searching for a licensee. This can occur initially after disclosure, or after rejection of

[1] These assumptions on royalty revenue 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).

a contract offer by a potential licensee.[2] In this case, an attempt to commercialize the invention occurs only if a venture capitalist or angel investor can be found to provide the effort required to create a new firm, or start-up, based on the invention, as well as to assist in additional development. The TTO may assist in the process of searching for an investor and start-up firm as a licensee, but with a minimal level of effort. The effort expended by the inventor may be greater in this case, as it typically includes search for investors as well as additional development. To save on notation, we let e_S and E_S denote the total efforts expended by the inventor and the venture capitalist.

Nevertheless, if a start-up is created, then it is the job of the TTO to offer this firm a license contract for the use of the invention. We assume it takes the same form, a combination of royalty and fixed fee, (R_S, M_S), where the royalty rate is r_S and total royalties are $R_S = r_S x(r_S)$. Again we assume these efforts are the equilibrium outcomes e_S and E_S of a noncooperative game between the inventor and venture capitalist, which in general depend upon the contract, $e_S^* = e_S^*(R_S, M_S)$ and $E_S^* = E_S^*(R_S, M_S)$. The start-up firm's cost of effort is $C_S(E_S)$, which we again assume satisfies $C_S(0) = 0$, $C_S' > 0$, and $C_S'' > 0$. If its lump-sum cost to attempt to commercialize the invention is $K_S > 0$, then its expected payoff from accepting the contract (R_S, M_S) is

$$P_S(e_S, E_S) = p(e_S, E_S; Q, H)[\Pi(x(r_S)) - R_S] - M_S - C_S(E_S) - K_S. \quad (2)$$

The venture capitalist assists in the creation of a start-up firm, which accepts this contract and attempts to commercialize the invention (after development), if $P_S(e_S, E_S) \geq 0$.

Assume that, if additional development occurs, then for each $j = F, S$, $\hat{E}_j$ is the maximum effort that firm j could devote to development. The continuity and strict concavity of each P_j guarantees that it is maximized at some $E_j \in [0, \hat{E}_j]$, and so there exists a firm j best-reply function $b_j(e_j)$. Moreover, $\frac{\partial P_j(e_j,0)}{\partial E_j} > 0 > \frac{\partial P_I(e_j,\hat{E}_j)}{\partial E_j}$ is sufficient to guarantee that P_j has an interior maximum at some $E_j \in (0, \hat{E}_j)$, in which case the first order necessary condition is:

$$\frac{\partial P_j}{\partial E_j} = \frac{\partial p}{\partial E_j}[\Pi(x(r_j)) - R_j] - -C_j'(E_j) = 0. \quad (3)$$

[2]The firm could agree to a contract, and then refuse to attempt to commercialize it after the development period if it is indifferent, $P_L(R_L, M_L) = 0$. In this case we assume the firm attempts the commercialization.

It is worth noting that the firm expends effort on additional development, independently of the inventor, only if it can independently increase the probability of success.

The inventor's utility function takes the form $U_I(Y_I, \vartheta) - V_I(e)$, where Y_I is his income and ϑ is an indicator function that equals 1 if a license is sold and 0 if not. That is, the inventor gains utility both from income and the prestige associated with the successful sale of a license (to an established firm or a start-up),[3] but suffers disutility from the effort in further development, $V_I(e)$. Naturally we assume positive but nonincreasing marginal utility from income (the inventor can be risk-neutral or risk-averse), positive marginal utility from sale of a license, and positive and increasing marginal disutility of effort. That is, $\frac{\partial U_I}{\partial Y_I} > 0 \geq \frac{\partial^2 U_I}{\partial Y_I^2}$, $U_I(Y_I, 1) > U_I(Y_I, 0)$, $V_I' > 0$, and $V_I'' > 0$. Thus, if α_I is his share of license income, then for each $j = F, S$, his expected utility is

$$\begin{aligned} P_I(e_j, E_j) \quad = \quad & p(e_j, E_j; Q, H)U_I(\alpha_I(M_j + R_j), 1) + \\ & (1 - p(e_j, E_j; Q, H))U_I(\alpha_I M_j, 1) - V_I(e_j). \end{aligned} \tag{4}$$

Now assume that $\hat{e}$ is the maximum effort that the inventor could devote to development. Then for each $j = F, S$, the continuity and strict concavity of P_I guarantees that it is maximized at some $e_j \in [0, \hat{e}]$, and so there exists an inventor best-reply function $b_I(E_j)$. Moreover, $\frac{\partial P_I(0,E_j)}{\partial e} > 0 > \frac{\partial P_I(\hat{e},E_j)}{\partial e}$ is sufficient to guarantee that P_I has an interior maximum at some $e_j \in (0, \hat{e})$, in which case the first order necessary condition is:

$$\frac{\partial P_I}{\partial e_j} = \frac{\partial p}{\partial e_j}[U_I(\alpha_I(M_j + R_j), 1) - U_I(\alpha_I M_j, 1)] - V_I'(e_j) = 0. \tag{5}$$

It is worth noting that, as in Jensen and Thursby (2001), the inventor expends effort on additional development only if the royalty rate is positive.[4]

Theorem 1 *Under the assumptions on the payoff functions and strategies, for each $j = F, S$ and given contract (R_j, M_j), there exists a Nash equilibrium $(e_j^*(R_j, M_j), E_j^*(R_j, M_j))$ for the development subgame between the firm and inventor. Furthermore, the equilibrium is:*

(i) No development, $e_j^* = E_j^* = 0$, if $\frac{\partial P_I(0,\hat{E}_j)}{\partial e} < 0$ and $\frac{\partial P_j(\hat{e},0)}{\partial E_j} < 0$;

[3] See Stephan (1996) for a survey of empirical support for the assumption that inventors also receive utility from nonpecuniary sources, such as seeing an invention licensesd or patent granted.

[4] If $r_j = 0$, then $e_j = 0$ because he earns his share of the fixed fee, $\alpha_I M$, whether he expends any effort or not, and the marginal disutility of effort is positive, $V_I'(0) > 0$.

(ii) Both inventor and firm j expend effort in development, $e_j^* > 0$ and $E_j^* > 0$, if $\frac{\partial P_j(0,0)}{\partial E_j} > 0$ and $\frac{\partial P_I(0,0)}{\partial e_j} > 0$; and
(iii) Unique and locally stable if and only if $b_I'(b_j'(e_j^*)) < 1$.

Proof. See the appendix. ■

Inventor and firm efforts, whenever they are interior, are strategic complements because they are complements in development: that is, $\frac{\partial^2 p}{\partial e \partial E} > 0$ implies $b_I'(E_j) > 0$ and $b_j'(e_j) > 0$. As long as their best-reply functions have the appropriate relative slopes, as depicted in figure 1, then there is a unique and locally stable equilibrium in which development occurs and each contributes to that development, $e_j^*(R_j, M_j) > 0$ and $E_j^*(R_j, M_j) > 0$ for each $j = F, S$.

The TTO's utility function is $U_T(Y_T, \vartheta) - V_{Tj}(Q, H)$, where Y_T is income and ϑ is the indicator function above. That is, the TTO also gains utility both from income and the prestige associated with the successful sale of a license, but suffers disutility from the search for a licensee. Again we assume positive but nonincreasing marginal utility from income, and positive marginal utility from sale of a license: $\frac{\partial U_T}{\partial Y_T} > 0 \geq \frac{\partial^2 U_T}{\partial Y_T^2}$ and $U_T(Y_T, 1) > U_T(Y_T, 0)$. We also assume that the utility cost of search depends on the type of licensee, a measure of the quality of the inventor, and a measure of the historical success of the TTO. In particular, we assume the disutility of search is decreasing at a nonincreasing rate in inventor quality and past TTO success: $\frac{\partial V_{Tj}}{\partial Q} < 0$, $\frac{\partial^2 V_{Tj}}{\partial Q^2} \leq 0$, $\frac{\partial V_{Tj}}{\partial H} < 0$, and $\frac{\partial^2 V_{Tj}}{\partial H^2} \leq 0$. We further assume that, as indicated above, the TTO may assist the inventor in the process of searching for an investor for a start-up, but with much less effort than it uses in searching for an established firm as a licensee. That is, *ceteris paribus*, the utility cost of licensee search is smaller for a start-up firm: $V_{TF}(Q, H) > V_{TS}(Q, H) \geq 0$. For $j = F, S$, the TTO's expected payoff from licensing with contract (R_j, M_j) to firm j is then

$$\begin{aligned} P_T(R_j, M_j) &= p(e_j^*, E_j^*; Q, H) U_T(\alpha_T(M_j + R_j), 1) + \\ &\quad [1 - p(e_j^*, E_j^*; Q, H)] U_T(\alpha_T M_j, 1) - V_{Tj}(Q, H), \end{aligned} \tag{6}$$

where $\alpha_T \in (0, 1)$ is its share of license income and $\alpha_T + \alpha_I \leq 1$. If a potential licensee is located, the TTO's problem is to choose a contract to maximize its expected payoff (6) subject to the licensee's participation constraint, or

$$\max_{(R_j, M_j)} P_T(R_j, M_j) \text{ s.t. } P_j(e_j^*, E_j^*) \geq 0. \tag{7}$$

We denote these optimal choices by (R_j^*, M_j^*). If a license contract with positive royalty rate and fixed fee is sold, then the first order conditions are that the participation constraint holds and

$$\frac{\frac{\partial P_T}{\partial R_j}}{\frac{\partial P_T}{\partial M_j}} = \frac{\frac{\partial P_j}{\partial R_j}}{\frac{\partial P_j}{\partial M_j}}. \tag{8}$$

This condition, of course, requires a tangency between the expected-payoff indifference curves in curves in (R_j, M_j)-space. An example of this is depicted in Figure 2.

4 Empirical Implications

Our theory provides two types of empirical implications. First, it provides predictions regarding factors that increase the likelihood of commercialization of university inventions via either established firms or start-ups.

Theorem 2 *Licensing to either an established firm or a start-up firm is more likely in the equilibrium of this dynamic licensing and development game for inventors with higher quality and/or lower disutility from development effort, TTOs with greater historical success and/or lower disutility of search for licensees, and inventions with lower costs of development and/or commercialization for potential licensees.*

Proof. Obvious. ■

Next, our theory provides predictions regarding factors that increase the likelihood of commercialization of university inventions via start-ups. To derive these implications, we consider those conditions necessary and sufficient for commercialization in start-up firms rather than established firms. Specifically, these are the conditions under which the unique equilibrium is that the TTO sells a license to a start-up firm.

Theorem 3 *Licensing to a start-up firm, instead of an established firm, is the equilibrium of this dynamic licensing and development game if and only if either:*
(i) $P_F(e_F^*(R_F^*, M_F^*), E_F^*(R_F^*, M_F^*)) < 0$ *or* $P_T(e_F^*(R_F^*, M_F^*), E_F^*(R_F^*, M_F^*)) < 0$, $P_S(e_S^*(R_S^*, M_S^*), E_S^*(R_S^*, M_S^*)) \geq 0$, *and* $P_T(e_S^*(R_S^*, M_S^*), E_S^*(R_S^*, M_S^*)) \geq 0$*; or*
(ii)$P_T(e_j^*(R_j^*, M_j^*), E_j^*(R_j^*, M_j^*)) > 0$ *and* $P_S(e_j^*(R_j^*, M_j^*), E_j^*(R_j^*, M_j^*)) \geq 0$ *for* $j = F, S$, *and* $P_T(e_S^*(R_S^*, M_S^*), E_S^*(R_S^*, M_S^*)) \geq P_T(e_F^*(R_F^*, M_F^*), E_F^*(R_F^*, M_F^*))$.

Proof. This follows straightforwardly from the definition of the game and the fact that the TTO and potential licensee payoffs in these statements are evaluated at the equilibrium values of effort that would prevail in the development subgame if a license were executed. ■

We think of the equilibrium with licensing to a start-up firm unfolding as follows. The TTO, given a disclosure, first considers licensing to an established firm. It determines the solution to (7) for $j = F$, the contract (R_F^*, M_F^*), conditional on equilibrium behavior by the inventor and firm in the development subgame. Licensing to this firm is not the equilibrium either if the firm cannot earn nonnegative profit, so it rejects the contract, or if the TTO cannot earn nonnegative expected net utility, so it does not even attempt to search for an established firm as a licensee. The TTO next considers shelving the invention, or returning it to the inventor, and providing minimal assistance in searching for an investor to assist in a start-up firm. This yields the contract (R_S^*, M_S^*) that solves (7) for $j = S$, conditional on equilibrium behavior by the inventor and firm in the development subgame. Licensing to this firm is an equilibrium only if the firm can earn nonnegative profit, so it accepts the contract, and the TTO can earn nonnegative expected net utility, so it assists in the search for an investor for the start-up. Finally, this is also the equilibrium if a contract can be sold to either type of firm, and the TTO can earn nonnegative expected net utility in either case, but its payoff is greater with the optimal start-up contract.

If the TTO's utility cost of searching is the same for both types of firms, then we face the apparent conundrum that start-ups occur only if a start-up firm would earn greater (positive) expected profit, gross of any license payments, so that the TTO can earn greater net utility from licensing to a start-up under the optimal contract. Although this may seem unlikely, *a priori*, it is not impossible. Each firm's expected profit depends on the costs of its effort in development and its attempt to commercialize the invention. Established firms with in-house R&D and marketing staffs, and with given distribution channels, undoubtedly have a cost advantage in the development and commercialization of inventions that are closely related to their current product line. However, it is not obvious that they have such advantages with potential products that do not fit well in their existing product lines. These costs include the potential profits from foregone opportunities, and established firms typically have alternatives available that are more closely related to their current product lines, and so more profitable. Conversely, venture capitalists routinely deal with new products and processes that don't fit well in existing product lines, so they may well have cost advantages due to better access to and information about the technological expertise needed to develop and commercialize embryonic inventions. Thus, for inventions that are not closely related to product lines, or that are simply very embryonic, established firms may well have higher opportunity costs of development and commercialization.

Moreover, the expected profit of a start-up firm, gross of license payments, may be higher. In particular, if the equilibrium of the development subgame involves greater inventor and/or firm effort, then the probability of success, and so expected profit, is greater. This can happen, for example, if the start-up has a lower opportunity cost of development effort, due to either fewer profitable alternatives, or perhaps to some advantage in acquiring development expertise that an established firm does not have because the potential product is very different from its current product mix. Because inventor and firm effort are strategic complements, greater firm effort induces greater inventor effort, and thus a greater probability of success.

Finally, it is also possible that licensing to a start-up firm occurs, even if expected profit is same for both types of firms, simply because the TTO's opportunity cost of searching for an established firm as a licensee is greater. This is an assumption of our model, of course, but it is consistent with the stylized facts. TTOs tend to focus their limited time on finding established firms as licensees for their most promising inventions, while essentially ignoring the others, which then typically are commercialized only if the inventors make the lion's share of the effort to find investors to assist them in forming start-ups. Again, this is consistent with Shane's (2002) argument that licensing to start-ups is a second-best solution for TTOs.

We summarize the implications of the model for our empirical analysis in terms of characteristics of the inventor, the invention, and the TTO. Obviously this approach is somewhat arbitrary, but it facilitates the analysis and discussion. The primary characteristic of an inventor is his (perceived) quality. Higher quality inventors disclose inventions which, *ceteris paribus*, have higher probabilities of success and lower TTO utility costs of searching for an established firm as a licensee.

The nature of the invention also is an important factor. For example, it is generally conceded that inventions that are the result of more applied research are "closer" to commercialization (i.e., in our model, they would need less additional development, if any). Such inventions would not only have higher probabilities of success, but also lower costs of the TTO's search for an established firm as a licensee. Thus, we expect higher quality inventions to be positively related to start-ups and licenses.

As is well known by now, TTOs are an important factor in university invention. First, they play a role as intermediaries between inventors and licensees, and as such have come to serve as guarantors of minimum quality levels (see Hoppe and Ozdenoren 2004 and Macho-Stadler, Perez-Castrillo, and Veugelers 2004). From this perspective, we expect fewer start-ups from more experienced and successful TTOs. Perhaps more importantly for our purposes, TTOs also rely on their experience and expertise in their search for firms to serve as partners in commercializing inventions. TTO experience and expertise should be positively related to start-up firm activity and overall licensing.

Finally, another important factor in whether licensing occurs to a start-up or an established firm is the potential difference between the costs of additional development and the attempt to commercialize borne by these firms. As noted above, there may be such differences because these types of firms typically have different investment opportunities, and so different opportunity costs. For example, in considering the cost of additional development, an established firm has alternatives that typically include development of new products or processes that closely fit or complement its current product line, whereas investors who fund start-ups have alternatives that typically include a broader array of options, but lower expected rates of return. For this reason we conclude that financial market conditions may matter significantly in the creations of start-ups from university inventions.

5 Data and Methodology

Data on start-ups and licenses were gathered using the Association of University Technology Managers (AUTM) surveys for the years 1993 through 2002. The sample for analysis is an unbalanced panel consisting of 110 universities. This sample includes 40 private universities and 67 universities with medical schools and 31 universities in the top 5 states that received venture capital investments. Start-ups are companies formed with the aid of the university technology licensing office to commercialize a faculty invention. The AUTM Licensing Survey 2002 states that start-up firms "are companies that were dependent upon licensing the institution's technology for initiation."[5] Our license data is licenses and options agreements executed to established firms. The universities in our sample generated 3047 start-ups, 79579 disclosures and 24352 licenses during this time period. Table 1.1 shows the descriptive statistics for the variables in our sample. The mean number of start-ups is 3 per year and universities generated on average 26 licenses to established firms. Technology transfer offices received

[5] Association of University Technology Mangaers Survey FY 2002, page 24.

roughly 83 new invention disclosures per year and had an average of 3 full time employees devoted to licensing activity.

We test our theoretical model in the form,

$$Y_{it} = \alpha_{it} + \beta_1 X_{1i} + \beta_2 X_{2it} + \beta_3 X_{3it} + \beta_4 X_{4it} + e_{it}. \tag{9}$$

In model 1 the dependent variable is start-ups at university i in year t as our dependent variable., and in model 2 it is licenses. The empirical models estimate the effect of university inventor, invention, and TTO characteristics such as age and size as well as venture capital spending on start-ups firm and licensing activity to established firms. The independent variables include our proxy measures of inventor quality X_{1i},TTO characteristics X_{2it}, invention characteristics X_{3it} and financial market conditions as well as venture capital sentiment X_{4it}.

Because we assume inventor quality affects both the probability of success and the utility cost of the TTO in searching for a licensee, for each university i, we use two measures of quality, engineering quality, $ENGQUAL_i$, and natural sciences quality, $SCIQUAL_i$, X_{1it}. We control for quality in these disciplines because most new inventions occur in these fields. We used data from the 1993 National Research Council's (NRC 1995) Survey of Ph.D. granting institutions. We construct a measure for each university by forming a weighted average of the engineering department quality scores, where the weights are faculty size.[6] The NRC rankings for each engineering department such as Aerospace Engineering or Biomedical Engineering, ranged from 0 to 5, where 5 indicates a distinguished department, so higher values of $ENGQUAL_i$, correspond to higher engineering quality. We also construct a measure for each university by forming a weighted average of the science department quality scores. These rankings also ranged from 0 - 5, for departments such as Chemistry, Physics and Biology. We expect a positive relationship between our measures for inventor quality and start-up activity as inventor quality positively affects the probability of success of commercialization of the invention and decreases the utility cost of the TTO's search efforts. We also expect a positive relationship between our measures for inventor quality and licenses and options executed to established firms. We also use a dummy variable to denote whether the university is private or public ($PRIVATE_i = 1$ if private, 0 otherwise). Public universities receive substantial federal funding and may be restricted in pursuing risky technologies. Also, private schools may have more flexibility in research options and more ties to established firms, which leads us to expect private universities

[6] We thank Jerry Thursby for providing his NRC data.

to generate fewer start-up firms. We expect private universities to generate more licenses to established firms.

Because we assume in our theoretical model that TTO experience and expertise also affect the probability of success and the TTO's disutility of search we also include measures of TTO characteristics as independent variables, X_{2it}. As noted above, less experienced TTOs may be less able to identify inventions with commercial potential and less able to find appropriate potential partners, so we expect more start-ups from less experienced TTO. For each university i, in each year t, we use the number of disclosures DIS_{it}, the age of the technology transfer office, $TTOAGE_{it}$, the size of the technology transfer office $TTOSIZE_{it}$,and the log of gross royalties, $LNGROSS_{it}$, to measure the relevant characteristics of the TTO. Those TTOs that have more inventions disclosed to them are more likely to be successful in commercialization simply because they have more new inventions in their portfolio for either established firms or start-ups. Similarly we believe that TTOs that are older and larger have more experience and expertise. TTOs that have more full time professional technology employees may have an advantage in finding new inventions with commercial potential as they have more available specialists to review disclosures. These TTOs may also have more resources available to find commercial partners. We therefore expect a positive relationship between start-up firms, disclosures, TTO age and TTO size. We expect a negative relationship between the log of gross royalties and start-up firm activity as we believe TTOs with more gross royalties are more able to find established partners. In model 2 where our dependent variable is licenses, we expect a positive relationship between our dependent variable and our measures for TTO characteristics, the number of disclosures, TTO age and TTO size as in model 1. However, we expect positive relationship between the licenses and the log of gross royalties. TTOs with more gross royalties may be more adept in licensing in general and finding established partners.

We use two variables as proxies for the characteristics of the inventions, in terms of their commercial orientation, X_{3it}. The presence of a medical school at a university suggests more applied inventions, and may suggest a more commercial orientation on the part of the faculty. It should be easier to interest established firms in these types of inventions, so we expect that the presence of a medical school may negatively be related to start-up activity. We expect the presence of a medical school to be positively related to licenses. We use a dummy variable to measure the presence of a medical school ($MED_i = 1$ if medical school, 0 otherwise) We also include the ratio of industrial research support to federal research support, $INDFED_{it}$, as an invention characteristic. We expect inventions from universities with greater industrial funding relative to federal funding to be more applied in nature, and so apparently more suitable for commercialization. Universities with greater industrial funding relative to federal funding may be expected to generate more start-ups and licenses.

Finally, we include several measures of financial market and general business conditions to predict their effects on start-ups, X_{4it}. In model 1, we include independent variables measuring venture capital spending. Venture capital data is obtained from the National Venture Capital Association Yearbook 2004. We use the log of venture capital funding in each state for each university for fiscal years 1993 through 2002, $VCSTATE_{it}$. We also use a dummy variable to denote whether the university is located in one of the top six states[7] that received venture capital funding ($HIGHVCST_{it} = 1$ if located in a high venture capital state, 0 otherwise). We test the effects of our measures for quality, TTO, invention and inventor characteristics on licensing activity. Model 2 does not include our proxies measuring venture capital activity and market sentiment as we feel they may not play a significant role in licensing efforts to established firms.

Our theoretical model shows that licensing occurs to start-up firms when the cost of searching for a start-up firm by the TTO is low or when the disutility for the TTO is lower than if the TTO were to expend the same effort looking for an established firm as a commercial partner. It is less costly for TTOs with greater access to venture capital to find a start-up firm licensee. We expect a positive relationship between venture capital spending and start-up firm activity. We measure the rate of venture capital spending to proxy the decision making of the venture capitalist. Under the optimal contract when licensing to a start-up firm, the TTO earns greater net utility. This is more likely to occur when venture capital spending is more prevalent. Kortum and Lerner (2000) find that venture capital fundraising effects patenting rates. Venture capitalists play a unique role in start-up activity. We measure venture capital to proxy the TTO's general ability to tap into such funding because direct data on venture capital is hard to obtain for the universities in our sample due to legal issues.

If venture capital is a significant factor in patenting rates, then it may also help to explain start-up activity. University licensing, patenting and start-up activity should be related in some way to market conditions and availability of capital and credit. Another reason we include venture capital data in our empirical analysis is because our theoretical model shows that

[7] California, New York, Massachusetts, Connecticut, Maryland, and Texas.

we are more likely to observe commercialization of university inventions by start-up firms when start-up firms have a cost advantage in the development or commercialization of a new invention. Licensing to start-ups also may occur if the opportunity cost of searching for an established firm as a partner is high for the university TTO. Access to venture capital directly effects start-up firm costs, survival rate and probability that the invention will reach eventual success. As aforementioned inventor founded start-up firms may have a cost advantage over established firms when working with venture capitalists who specialize in embryonic inventions. Because greater inventor and firm effort are strategic compliments, more venture capital spending (on equipment for example) and greater inventor effort in the development stage increase the probability of success and greater expected profit for the start-up firm. This in turn raises the net utility for the TTO. We expect more start-ups when venture capital spending is high which suggests more venture capitalists are interested in new business ideas.

Previous literature on start-up activity has made little connection between university-industry technology transfer and general financial market conditions and sentiment. For each year t in the sample, we use the five year rolling averages of the Venture Capital Index, $RLAVEVC_t$ and the Standard and Poors 500 Index $RLAVESP_t$. We obtained this data from the the National Venture Capital Association Yearbook. We expect returns to venture capital to negatively affect start-up activity. This may be because venture capitalists may have other opportunities to afford their capital during healthy financial market and general business conditions. Venture capitalists may find embryonic inventions too risky when competing investments offer reasonable returns. We expect a positive relationship between start-up activity and returns to the S&P 500 because we believe more start-up activity occurs when business conditions are favorable. We also include the annual percentage change in the Federal Reserve's fed funds rate, $INTEREST_t$. Interest rate data is compiled from the St. Louis Federal Reserve Database (FREDII) and the U.S. Department of Labor, Bureau of Labor Statistics. Each of these affect the ability of a start-up firm to raise capital, and so the costs of development effort and commercialization. Our model predicts that there should be fewer start-ups in less favorable financial conditions.

6 Empirical Results

In general, our results provide evidence that inventor quality is positively related to both start-up activity and licensing. We contribute to the exiting empirical literature by using more detailed measures for inventor quality. In earlier versions of this paper, we followed previous authors by using a weighted average of the quality of faculty in all departments with doctoral programs, as measured by the National Research Council's (NRC 1995) Survey of Ph.D granting institutions. This measure included departments from the humanities and social sciences, which are not typically the driving forces behind university licensing and start-up activity. The estimated coefficients for our engineering and science quality variables are positive in our benchmark regression estimation and several others. The estimated coefficient for engineering quality is positive and significantly different from zero in each regression we estimated, while the estimated coefficient for science quality is positive and significantly different from zero in one. This result is similar to that of Di Gregoriao and Shane (2003), who find a positive relationship between start-up formation and faculty quality, as measured by the Gourman Report, for the period 1994-1998. This supports our theoretical result that inventions from high-quality faculty are more easily commercialized with established or start-up firms.

This is also consistent with the finding of Jensen, Thursby and Thursby (2003) that higher quality faculty disclose inventions at earlier stages of development, and the findings of Lach and Shankerman (2002) that higher quality faculty disclose more inventions and higher value inventions. Thursby and Thursby (1998) find that faculty are critical in the licensing process. Jensen and Thursby (2001) focus on inventor behavior in examining licensing agreements. Jensen, Thursby and Thursby (2003) find that quality is negatively related to the share of license income allotted to faculty. Our results contribute to these findings as we evaluate faculty quality and start-up activity in the context of licensing in general. Engineering faculty quality and science faculty quality are positively related to licensing to established firms, and engineering department quality is positively related to the number of start-ups (the estimated coefficient for engineering quality is positive and significantly different from zero in model 2, Table 1.2). We also analyzed the data using the original, over-all quality measure. The coefficients for science quality and engineering quality, when added together, are larger than our original, less robust quality measure that included all departments in the NRC Survey (see Tables 1.2, 1.3, 1.4). We checked this result using several estimation techniques as robustness checks and found similar results. We believe these results show that our more detailed measures for faculty quality have more explanatory power.

We find no evidence that our dummy variable for the whether the university is private helped to predict start-up firm activity or licensing. In several models where we use start-ups as our dependent variable, the estimated coefficient for this indicator variable is ambiguous and never significantly different from zero in any equation estimated. The same result occurs when our dependent variable is licenses. We believe this may indicate that whether a university is private is simply a proxy for inventor quality. That is, if a university is private, this is in effect a reflection of the quality of the potential inventors that the university employs.

The presence of a medical school also did not seem to significantly affect start-up activity or licensing activity. In Table 1.2, model 1, using start-ups as the dependent variable, the coefficient for medical schools is negative but not significantly different from zero in several of the equations we estimated. However, in model 2, where licenses is the dependent variable, the coefficient for medical schools is positive but not significantly different from zero in any equation estimated. This may indicate that universities with medical schools generate less start-up activity, and support our theory that inventors from medical schools may be more commercially oriented, so it is easier to license their inventions to established firms. It is also consistent with the finding of Jensen, Thursby and Thursby (2003) that universities with higher fractions of their inventions from medical schools have more inventions disclosed at an early stage of development. The estimated coefficient for private schools is positive, but not significant in any equation estimated. This also may help to explain university variations in start-up firm activity. Shane and Stuart (2002) find that intellectual eminence is positively related to start-up activity.

The number of invention disclosures to the TTO is significantly related to both start-up and licensing activity. In our benchmark regressions and several other estimations, the estimated coefficients for disclosures are positive and significantly different from zero. Universities with larger pools of disclosures are have a significantly larger number of licenses to both established firms and start-up firms. Although a larger pool of disclosures may increase the TTO's opportunity cost of searching fro a licensee for any one of them, it also increases the number of commercially viable disclosures and results in more licensing. This reflects the now well-known fact that it is important for TTOs to solicit new disclosures from faculty.

The log of gross licensing royalties negatively affects start-up activity. Larger gross licensing royalties are a measure of greater past TTO success in licensing, which our model predicts leads to not only higher estimates of the probability of success for current disclosures, but also lower TTO costs of searching for established firms as licensees. Such TTOs should have less need to fall back on the second-best option of start-ups. This, however, differs from our results when licenses are used as a dependent variable in model 2. In our benchmark equation, Table 1.1, when we regress the log of gross licensing royalties on our dependent variable, the estimated coefficient is positive and significantly different from zero except when we use the fixed effects specification. Those universities that are able to generate many start-ups may not be the same universities that also have large royalty incomes. Thus, greater gross royalties are negatively related to start-up activity, but positively related to licensing to established firms. This is consistent with the stylized fact that the majority of "royalty rich" TTOs obtain their revenue from established firms, not start-up firms.

We also find evidence that the age of the TTO positively affects start-up activity. In each regression specification, the coefficient for TTO age is positive and significantly different from zero. The older the technology licensing office, the more likely the TTO is to license an invention to a start-up firm. However, we also find that TTO age has a positive effect on licensing to established firms. When licenses is the dependent variable, the coefficient for TTO age is again positive and significantly different from zero. This is consistent with the results of Lach and Schankerman (2002), who find that disclosures and their average values increase with TTO age, and with the results of Franklin, Wright, and Lockett (2001), who find that older universities are more successful in launching new startups. Feldman Feller, Bercovitz and Burton (2002) similarly find that the greater the amount of experience with technology transfer, the more likely the university will accept equity-based technology transfer mechanisms. Older, experienced TTOs are more effective in commercializing inventions, in general. Thus, although increases in TTO age increase both the probability of success of a given disclosure and the cost of TTO search for an established firm as a partner in our theory, it appears that the former effect outweighs the latter in this data.

It is somewhat surprising that the size of the TTO did not have a significant impact on start-up activity. The sign for this coefficient was positive and significantly different from zero in only one estimation, and was ambiguous and insignificant in several other regressions. However, TTO size did have a significant impact on licensing. In almost all our models, the coefficient for TTO size is positive and significantly different from zero. This suggests that TTO size has a significant effect on licensing to established firms, but not start-up firms. This is consistent with our theoretical model's assumption that start-ups are usually a second-best alternative, especially at higher quality universities.

We find some evidence that the ratio of industrial to federal research support significantly predicts start-up activity and licensing. In our benchmark models 1 and 2, Table 1.1, the sign for this estimated coefficient is positive, as expected, in both, but only significantly different from zero in our estimation using licenses as the dependent variable. However, this result did not hold when we used alternative estimations. The sign for the ratio of industrial to federal research support was ambiguous and never significantly different from zero in both models in our robustness checks. This is perhaps not surprising as Jensen, Thursby and Thursby (2003) find this variable does not help to predict the stage of development at which inventions are disclosed. Following Di Gregoriao and Shane (2003), we also used the ratio of industrial support to total research support in an attempt to capture the applied nature of research, but found no significance with this variable either.

Our results provide evidence that access to venture capital greatly affects start-up activity. The estimated coefficient for the log of venture capital funding is positive and significant. This supports our theoretical result that access to venture capital is a significant reason why some universities are morel likely to license to start-up firms than to established firms. Our analysis shows that those universities that have significant venture capital spending in their state are more likely to license inventions to start-up firms. The estimated coefficient for whether the university is located in one of the six states with the most venture capital funding is positive in four of five equations estimated, but was not significantly different from zero in any of them.

Although start-ups often do pay (typically small) fixed fees, and commit to pay some royalties if the invention succeeds, it is perhaps more common for both inventors and universities to take equity positions in start-ups. When returns to venture capital are high, venture capitalists may ask for a bigger share of available equity which decreases utility for the inventor and the TTO. Our results provide evidence that this would decrease start-up firm activity. As venture capitalists have more alternatives, more risky investments such a start-ups are shelved or they require a bigger share of profits to induce their participation.

We find evidence that interest rate changes significantly impacts start-up activity. The estimated coefficient for interest rate percentage change is negative and significantly different from zero in each regression estimation specified. As interest rates rise, available capital for start-up formation decreases. We also find evidence that the rate of growth in the S&P 500 index is positively related to start-up activity. Changes in the S&P 500 help to predict start-up activity. We expected a positive relationship between changes in the S&P 500 index and start-up activity. This result lends further support to our view that economic indicators and overall business sentiment also affect start-up activity.

In alternative estimates we use the log of cashed-in-equity to measure the past success of the TTO, especially with regard to past start-ups, as equity is often used in these cases. We also regress the log of cashed-in-equity on the dependent variable licenses. In model 1, this coefficient is positive and significantly different from zero in all of our estimated equations. The log of cashed-in-equity is negatively related to licenses. This coefficient is negative but not significantly different from zero in model 2. This provides some evidence that TTOs that accept equity as payments in the technology transfer process may also license technologies to more start-ups. Feldman, Feller, Bercovitz and Burton (2002) find an increase in the use of cashed-in-equity in licensing agreements involving startup firms and some established firms. They also note the rise in securities prices in the 1990's that may have contributed to TTO perceptions of equity deals. Our results suggest that many licensing agreements using cashed-in-equity involve start-up firms as opposed to established firms.

7 Robustness Checks

We checked our results using several tests for robustness. We also include seemingly unrelated regression estimation in our empirical analysis. Here, we examine if, contemporaneous cross-equation error correlation exists. It is possible that model 1 and model 2 are related through the correlation in the error terms. We cointegrated these regressions to obtain efficient estimates. We found no correlation in error terms (these results are included in the appendix). Estimating these two equations separately seems to lend explanatory power to our findings above. We used the number of licenses in the prior year as an instrumented variable and generalized two stage least squares in estimating the cross effects of start-up activity and licensing activity in general. These results did not help to predict start-up activity and licensing.[8]

We also empirically tested our theoretical model using random effects models. We analyzed our universities for inter-university dependence and correlation in the variance of error terms. We utilize this estimation technique to account any unobserved inter-university differences or clustering effects that may exist. This design allows for additional sources of varia-

[8] These results are available upon request. by contacting the authors

tion in the model to examine variance of error terms across universities for contemporaneous correlation between cross-sections. We estimated a model using a random effects specification that allowed for in-state dependence between universities but assumed no dependence between universities across states. These results in Table 1.4 were largely similar to those in Table 1.1, our benchmark model and the standard errors were very similar. It does not appear that university inter-dependence or cross-sectional effects significantly impact our findings. We found no need to conduct cross-section weighted estimations.

Table 1.5 shows the results of an alternative model using fixed-effects models. We check for any unmodeled heterogeneity and assume that individual specific time invariant effects may exist. We added a time trend to further examine the positive relationship between our proxies for cost, venture capital spending and start-up firm activity and licensing to established firms. This model excludes our quality measures and indicator variables for whether the university has a medical school or is public or private. The results in Table 1.5 are also largely similar to those in Table 1.1 our benchmark model. They show that the rate of interest is negatively related to start-up firm activity. In model 1, this estimated coefficient is negative and significantly different from zero. The rate of venture capital spending and equity markets are positively related to start-up firm activity. The estimated coefficient for the S&P 500 is coefficient is positive and significantly different from zero which supports our earlier findings.

8 Conclusion

We have developed a theoretical model to explain why commercialization of university research occurs in start-up firms rather than established firms. Several empirical implications follow immediately from the theory. Essentially, we are more likely to observe commercialization of university inventions by start-up firms in situations in which start-ups are more likely to have a cost advantage in the development or commercialization, or in which the opportunity cost of TTOs in searching for an established firm as a partner is higher. We summarize these in terms of characteristics of the inventor, the TTO, the invention, and financial market conditions such as venture capital spending.

We tested the implications of the model in terms of characteristics of the inventor, the invention, and the TTO, and financial market conditions using AUTM data for 1993-2001 and the National Venture Capital Association

Yearbook 2004. We estimated negative binomial, ordinary least squares, fixed effects and random effects models using the annual number of start-ups and licenses per university. Our results provide evidence that inventor quality has a positive impact on start-up activity and licensing in general. Universities with higher quality faculty are more able to commercialize their inventions through start-ups or established firms. We also find that disclosures, the age of the TTO, and venture capital spending at the state level have positive affects on start-up activity, but interest rate levels and gross licensing royalties have a negative affect on start-up activity. We find little evidence that TTO size, the presence of a medical school and whether the university is public or private affects start-up firm activity. We find that the number of disclosures, the age of the TTO and TTO size have positive affects on overall licensing.

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10 Appendix: Proof of Theorem 1.

Existence of at least one Nash equilibrium follows immediately from the fact that the payoffs are continuous and defined on compact strategy spaces. As noted in the text, for each $j = F, S$, the continuity and strict concavity of P_I guarantees that it is maximized at some $e_j \in [0, \hat{e}]$, and so there exists an inventor best-reply function $b_I(E_j)$. If $\frac{\partial P_I(0,\hat{E}_j)}{\partial e_j} \leq 0$, then $\frac{\partial^2 p}{\partial e \partial E} > 0$ implies $\frac{\partial P_I(0,E_j)}{\partial e_j} < 0$ for all $E_j \in [0, \hat{E}_j)$, so P_I has its maximum at $e_j = 0$, and $b_I(E_j) = 0$ for all $E_j \in [0, \hat{E}_j]$. Similarly, the continuity and strict concavity of each P_j guarantees that it is maximized at some $E_j \in [0, \hat{E}_j]$, and so there exists a firm j best-reply function $b_j(e_j)$. If $\frac{\partial P_j(\hat{e},0)}{\partial e_j} \leq 0$, then $\frac{\partial^2 p}{\partial e \partial E} > 0$ implies $\frac{\partial P_j(e_j,0)}{\partial E_j} < 0$ for all $e_j \in [0, \hat{e})$, so P_j has its maximum at $E_j = 0$, and $b_j(e_j) = 0$ for all $e_j \in [0, \hat{e}]$. This proves statement (i). Conversely, if

$\frac{\partial P_j(0,0)}{\partial E_j} > 0$, then $\frac{\partial^2 p}{\partial e \partial E} > 0$ implies $\frac{\partial P_j(e_j,0)}{\partial E_j} > 0$, and so $b_j(e_j) > 0$, for all $e_j > 0$; and if $\frac{\partial P_I(0,0)}{\partial e_j} > 0$, then $\frac{\partial^2 p}{\partial e \partial E} > 0$ implies $\frac{\partial P_I(0,E_j)}{\partial e_j} > 0$, and so $b_I(e_j) > 0$, for all $E_j > 0$. This proves statement (ii). Statement (iii) then follows from the definition of uniqueness and locally stability. Q.E.D.

Table 1.1 Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Start-up Companies Formed	951	3.203996	5.624048	0	64
Licenses and Options Executed	951	25.60673	35.73951	0	313
Inventor Characteristics					
NRC overall Quality Engineering Ranking weighted by department	830	2.867632	0.817586	1.24	4.631456
NRC overall Quality Sciences Ranking weighted by department	1080	2.974425	0.832695	0.717059	4.746132
NRC overall Quality Ranking weighted by department	1100	2.923386	0.798214	1.203704	4.697401
University is private (yes = 1)	1100	0.355455	0.478869	0	1
TTO Characteristics					
Licensing FTE's in Technology Transfer Offices	951	3.259474	5.026659	0	62
TTO Age - Program Year Technology Transfer Office Began	971	14.19773	12.27503	0	77
Invention Disclosures Received	956	83.24163	100.1542	0	973
Gross License Income Received	950	13.88279	1.977126	6.60665	19.40562
Invention Characteristics					
University has Medical School (yes = 1)	1100	0.592727	0.49155	0	1
Industrial/Federal Research Expenditure	951	0.176505	0.182519	0	1.610801
Financial/Market Conditions					
Interest Rate Level	1100	2.073583	1.246248	0.0225	3.753333
Log of Venture Capital Expenditure per State	1100	18.87763	2.964445	0	24.4911
University is located in a High Venture Capital Expenditure State (yes = 1)	1100	0.273636	0.446027	0	1
Returns to Venture Capital	1100	27.78	12.47522	11.2	48.6
Returns to the S & P 500 index	1100	13.06	7.591099	-1.9	26.2
License Income Received:Cashed-In Equity	625	2.860903	5.477156	0	18.02734

Table 1.2 Negative Binomial Regressions Predicting the Effect of Inventor Quality, TTO Experience, and Financial Market and Venture Capital Conditions on Start-up Activity and Licensing to Established Firms

Dependent Variable	Model 1 Start-ups	Model 2 Licenses	Model 3 Start-ups	Model 4 Licenses	Model 5 Start-ups	Model 6 Licenses
Inventor Characteristics						
ENGQUAL	0.447	0.464	0.528	0.498		
	(0.141)**	(0.130)**	(0.134)**	(0.153)**		
SCIQUAL	0.063	0.083	0.131	0.182		
	(-0.155)	(-0.136)	(-0.149)	-0.167		
QUAL					0.456	0.471
					(0.091)**	(0.073)**
PRIVATE	-0.11	-0.182	-0.348	-0.26	-0.155	-0.11
	(-0.138)	(-0.117)	(0.132)**	(-0.146)	(-0.124)	(-0.106)
TTO Characteristics						
TTOSIZE	0.003	-0.003	-0.012	-0.005	0.001	-0.004
	(-0.008)	(-0.004)	-0.008	(-0.004)	(-0.008)	(-0.004)
TTOAGE	0.009	0.014	0.01	0.018	0.009	0.012
	(0.004)*	(0.004)**	(0.004)**	(0.005)**	(0.004)*	(0.004)**
DIS	0.002	0.002	0.002	0.002	0.002	0.002
	(0.001)**	(0.000)**	(0.001)**	(0.000)**	(0.001)**	(0.000)**
LNGROSS	0.058	0.122	0.053	0.105	0.076	0.136
	(-0.035)	(0.022)**	-0.037	(0.028)**	(0.030)*	(0.018)**
Invention Characteristics						
MED	0.171	0.135	0.093	0.179	-0.12	-0.045
	(-0.121)	(-0.11)	-0.113	(-0.132)	(-0.107)	(-0.097)
INDFED	0.731	0.485	0.775	0.367	0.463	0.37
	(0.257)**	(0.163)**	(0.259)**	(-0.194)	(-0.247)	(0.150)*
Financial/Market Conditions						
INTEREST	-0.472		-0.05		-0.488	
	(0.034)**		(-0.067)		(0.031)**	
LNVCSTAT	0.028		0.091		0.043	
	(-0.02)		(0.037)*		(0.020)*	
HIGHVCST	0.13		0.177		-0.06	
	(-0.152)		(-0.151)		(-0.134)	
RLAVEVC	-0.011		0.004		-0.016	
	(0.003)**		(-0.005)		(0.003)**	
RLAVESP	0.061		-0.007		0.064	
	(0.006)**		(-0.01)		(0.006)**	
LNCAINE			0.01	-0.002		
			(-0.007)	(-0.004)		
Constant	-1.927	-1.918	-2.522	-1.803	-2.076	-1.722
	(0.544)**	(0.359)**	(0.835)**	(0.431)**	(0.501)**	(0.291)**
Observations	655	659	443	443	845	847
Log likelihood	-1344.292	-2355.887	-817.7383	-1575.923	-1675.346	-2942.5

* significant at 5%; ** significant at 1%
Standard errors in parentheses

Table 1.3 Poisson Regressions Predicting the Effect of Inventor Quality, TTO Experience, and Financial Market and Venture Capital Conditions on Start-up Activity and Licensing to Established Firms

Dependent Variable	Model 1 Start-ups	Model 2 Licenses	Model 3 Start-ups	Model 4 Licenses	Model 5 Start-ups	Model 6 Licenses
Inventor Characteristics						
ENGQUAL	0.527	0.341	0.486	9.335		
	(0.151)**	(-0.196)	(-0.321)	(3.424)**		
SCIQUAL	0.066	0.566	0.004	1.594		
	(-0.161)	(0.208)**	(-0.336)	(-3.566)		
QUAL					0.573	0.802
					(0.098)**	(0.087)**
PRIVATE	-0.091	-0.452	-0.161	-3.656	-0.048	-0.413
	(-0.138)	(0.158)**	(-0.31)	(-3.087)	(-0.134)	(0.132)**
TTO Characteristics						
TTOSIZE	0.001	-0.009	-0.125	2.282	0.005	-0.01
	(-0.007)	(0.002)**	(0.037)**	(0.398)**	(-0.007)	(0.002)**
TTOAGE	0.008	0.062	0.025	0.955	0.01	0.054
	(-0.005)	(0.004)**	(0.009)*	(0.101)**	(0.005)*	(0.003)**
DIS	0.002	0.001	0.026	0.093	0.002	0.001
	(0.000)**	(0.000)**	(0.002)**	(0.024)**	(0.000)**	(0.000)**
LNGROSS	0.046	0.052	-0.014	1.439	0.072	0.088
	(-0.03)	(0.013)**	(-0.092)	(-0.982)	(0.027)**	(0.011)**
Invention Characteristics						
MED	0.192	0.091	-0.446	0.643	-0.107	-0.04
	(-0.124)	(-0.161)	(-0.267)	(-2.808)	(-0.117)	(-0.128)
INDFED	0.823	0.583	1.518	3.911	0.526	0.466
	(0.197)**	(0.100)**	(0.671)*	(-7.025)	(0.191)**	(0.093)**
Financial/Market Conditions						
INTEREST	-0.53		-0.072		-0.538	
	(0.023)**		(-0.261)		(0.021)**	
LNVCSTAT	0.031		0.069		0.04	
	(0.015)*		(-0.067)		(0.014)**	
HIGHVCST	0.042		0.899		-0.075	
	(-0.153)		(0.368)*		(-0.146)	
RLAVEVC	-0.014		0.022		-0.017	
	(0.003)**		(-0.016)		(0.003)**	
RLAVESP	0.069		-0.031		0.068	
	(0.004)**		(-0.04)		(0.004)**	
LNCAINE			0.106	-0.328		
			(0.024)**	(-0.254)		
Constant	-1.995	-1.417	-2.574	-53.621	-2.25	-1.45
	(0.462)**	(0.371)**	(-1.542)	(12.364)**	(0.429)**	(0.284)**
Observations	655	659	442	443	845	847
Log likelihood	-1431.0948	-2821.9427	-1.542	(12.364)**	-1809.517	-3470.515

Standard errors in parentheses
* significant at 5%; ** significant at 1%

Table 1.4 OLS Regressions Predicting the Effect of Inventor Quality, TTO Experience, and Financial Market and Venture Capital Conditions on Start-up Activity and Licensing to Established Firms

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Dependent Variable	Start-ups	Licenses	Start-ups	Licenses	Start-ups	Licenses
Inventor Characteristics						
ENGQUAL	1.018	8.673	0.486	9.335		
	(0.477)*	(2.511)**	(-0.321)	(3.424)**		
SCIQUAL	0.088	1.116	0.004	1.594		
	(-0.497)	(-2.614)	(-0.336)	(-3.566)		
QUAL					0.819	6.646
					(0.292)**	(1.429)**
PRIVATE	0.111	-2.831	-0.161	-3.656	0.126	-2.752
	(-0.464)	(-2.245)	(-0.31)	(-3.087)	(-0.392)	(-1.926)
TTO Characteristics						
TTOSIZE	-0.054	2.454	-0.125	2.282	0.042	0.716
	(-0.058)	(0.307)**	(0.037)**	(0.398)**	(0.014)**	(0.067)**
TTOAGE	0.044	0.767	0.025	0.955	-0.036	2.102
	(0.014)**	(0.076)**	(0.009)*	(0.101)**	(-0.054)	(0.265)**
DIS	0.025	0.08	0.026	0.093	0.024	0.115
	(0.003)**	(0.018)**	(0.002)**	(0.024)**	(0.003)**	(0.015)**
LNGROSS	-0.03	1.474	-0.014	1.439	0.042	1.518
	(-0.136)	(0.708)*	(-0.092)	(-0.982)	(-0.108)	(0.528)**
Invention Characteristics						
MED	-0.314	0.93	-0.446	0.643	-0.813	-0.16
	(-0.405)	(-2.096)	(-0.267)	(-2.808)	(0.338)*	(-4.645)
INDFED	2.191	3.899	1.518	3.911	1.353	-2.705
	(1.064)*	(-5.587)	(0.671)*	(-7.025)	(-0.945)	(-1.66)
Financial/Market Conditions						
INTEREST	-2.465		-0.072		-2.351	0.895
	(0.218)**		(-0.261)		(0.195)**	(-0.956)
LNVCSTAT	0.011		0.069		0.049	-0.394
	(-0.074)		(-0.067)		(-0.062)	(-0.306)
HIGHVCST	0.26		0.899		0.262	-0.963
	(-0.539)		(0.368)*		(-0.442)	(-2.177)
RLAVEVC	-0.085		0.022		-0.087	0.064
	(0.018)**		(-0.016)		(0.016)**	(-0.076)
RLAVESP	0.343		-0.031		0.314	0.102
	(0.039)**		(-0.04)		(0.035)**	(-0.17)
LNCAINE			0.106	-0.328		
			(0.024)**	(-0.254)		
Constant	0.478	-48.271	-2.574	-53.621	0.252	-36.431
	(-1.898)	(8.862)**	(-1.542)	(12.364)**	(-1.59)	(7.800)**
Observations	655	659	442	443	845	847
R-squared	0.46	0.67	0.7	0.68	0.4191	0.67

Standard errors in parentheses
* significant at 5%; ** significant at 1%

Table 1.5 Random Effects RegressionsPredicting the Effect of Inventor Quality, TTO Experience, and Financial Market and Venture Capital Conditions on Start-up Activity and Licensing to Established Firms

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Dependent Variable	Start-ups	Licenses	Start-ups	Licenses	Start-ups	Licenses
Inventor Characteristics						
ENGQUAL	1.149	5.095	0.704	5.199		
	-0.646	-5.088	-0.436	-6.573		
SCIQUAL	0.06	2.67	-0.057	6.835		
	-0.681	-5.358	-0.461	-6.98		
QUAL					0.859	5.976
					(0.348)*	(2.429)*
PRIVATE	0.215	-4.287	-0.177	-8.746	0.174	-4.374
	(-0.637)	(-4.46)	(-0.427)	(-5.966)	(-0.48)	(-3.568)
TTO Characteristics						
TTOSIZE	0.015	0.334	-0.104	-0.172	0.013	0.224
	(-0.068)	(-0.34)	(0.043)*	(-0.381)	(-0.06)	(-0.29)
TTOAGE	0.047	0.763	0.027	0.813	0.044	0.731
	(0.020)*	(0.144)**	(0.013)*	(0.188)**	(0.017)**	(0.124)**
DIS	0.021	0.183	0.025	0.173	0.022	0.189
	(0.004)**	(0.020)**	(0.003)**	(0.024)**	(0.003)**	(0.017)**
LNGROSS	-0.049	1.016	-0.006	1.921	0.028	1.011
	(-0.166)	(-0.855)	(-0.113)	(-1.163)	(-0.123)	(-0.624)
Invention Characteristics						
MED	-0.262	1.553	-0.431	2.81	-0.802	-0.726
	(-0.552)	(-4.214)	(-0.367)	(-5.537)	(-0.411)	(-3.276)
INDFED	1.913	8.571	1.494	7.252	1.14	6.721
	(-1.171)	(-5.387)	(0.743)*	(-6.265)	(-1.018)	(-4.496)
Financial/Market Conditions						
INTEREST	-2.472		-0.026		-2.36	
	(0.205)**		(-0.238)		(0.187)**	
LNVCSTAT	0.031		0.071		0.053	
	(-0.078)		(-0.074)		(-0.066)	
HIGHVCST	0.087		0.79		0.127	
	(-0.715)		(-0.487)		(-0.531)	
RLAVEVC	-0.086		0.024		-0.088	
	(0.017)**		(-0.015)		(0.015)**	
RLAVESP	0.348		-0.033		0.318	
	(0.037)**		(-0.037)		(0.034)**	
LNCAINE			0.079	0.028		
			(-3.22)	(-0.187)		
Constant	0.183	-38.883	-1.791	-61.337	0.316	-31.691
	(-2.268)	(12.558)**	(0.544)**	(16.766)**	(-1.769)	(9.327)**
sigma_u	1.506104	15.64351	1.008894	19.96341	1.1167678	14.251912
sigma_e	4.036787	16.05907	2.104164	15.21221	4.0828955	14.671985
rho	0.122191	0.486894	0.186923	0.632651	0.0696074	0.4854797
R-sq: within	0.2218	0.2468	0.1792	0.1449	0.1969	0.247
R-sq: between	0.723	0.7354	0.8541	0.7069	0.7052	0.7411
R-sq: overall	0.4536	0.641	0.7025	0.6387	0.4184	0.6467
Observations	655	659	442	443	845	847

Standard errors in parentheses

* significant at 5%; ** significant at 1%

Table 1.6 Fixed Effects Regressions Predicting the Effect of Inventor Quality, TTO Experience, and Financial Market and Venture Capital Conditions on Start-up Activity and Licensing to Established Firms

Dependent Variable	Model 1. Start-ups	Model 2 Licenses	Model 1 Start-ups	Model 2 Licenses
TTO Characteristics				
TTOSIZE	0.239	-0.638	0.013	-1.148
	(0.095)*	(-0.335)	(-0.077)	(0.368)**
TTOAGE	-0.124	1.303	0.274	1.332
	-0.123	(0.251)**	(0.139)*	(0.374)**
DIS	0.015	0.191	0.023	0.152
	(0.005)**	(0.019)**	(0.005)**	(0.025)**
LNGROSS	0.06	0.264	-0.046	1.153
	(-0.215)	(-0.215)	(-0.204)	(-1)
Invention Characteristics				
INDFED	0.556	8.888	0.609	7.487
	(-1.329)	(-4.736)	(-1.105)	(-5.397)
Financial/Market Conditions				
INTEREST	-2.325		0.157	
	(0.189)**		(-0.289)	
LNVCSTAT	0.06		0.038	
	(-0.081)		(-0.091)	
RLAVEVC	-0.06		-0.008	
	(0.029)*		(-0.024)	
RLAVESP	0.297		-0.013	
	(0.042)**		(-0.046)	
LNCAINE			0.05	0.219
			(-0.032)	(-0.154)
Constant	3.685	-11.564	-3.764	-19.912
	(-3.014)	(-9.41)	(-3.251)	(-12.893)
sigma_u	3.194713	19.47604	3.331915	24.87316
sigma_e	4.089992	14.69187	2.819118	13.87321
rho	0.37893	0.637327	0.582792	0.762722
R-sq: within	0.2058	0.253	0.1169	0.167
Observations	845	847	581	581

Standard errors in parentheses
* significant at 5%; ** significant at 1%

Table 1.7 Seemingly Unrelated RegressionsPredicting the Effect of Inventor Quality, TTO Experience, and Financial Market and Venture Capital Conditions on Start-up Activity and Licensing to Established Firms

	Model 1		Model 2		Model 3	
Dependent Variable	Start-ups	Licenses	Start-ups	Licenses	Start-ups	Licenses
Inventor Characteristics						
ENGQUAL	1.018	9.507	0.985			8.627
	(0.472)*	(2.506)**	(0.471)*			(2.498)**
SCIQUAL	0.088	1.036	0.107			0.898
	(-0.491)	(-2.609)	(-0.491)			(-2.605)
QUAL				9.145	0.987	
				(1.818)**	(0.340)**	
PRIVATE	0.111	-1.157	0.113	-0.964	0.112	-2.629
	(-0.458)	(-2.436)	(-0.458)	(-2.421)	(-0.453)	(-2.234)
TTO Characteristics						
TTOSIZE	-0.054	2.542	-0.055	2.441	-0.064	2.454
	(-0.058)	(0.306)**	(-0.058)	(0.307)**	(-0.057)	(0.304)**
TTOAGE	0.044	0.762	0.044	0.738	0.042	0.771
	(0.014)**	(0.076)**	(0.014)**	(0.076)**	(0.014)**	(0.075)**
DIS	0.025	0.081	0.025	0.093	0.026	0.08
	(0.003)**	(0.018)**	(0.003)**	(0.018)**	(0.003)**	(0.018)**
LNGROSS	-0.03	1.174	-0.028	1.439	-0.004	1.458
	(-0.135)	(-0.717)	(-0.135)	(0.702)*	(-0.131)	(0.707)*
Invention Characteristics						
MED	-0.314	1.085	-0.323	-2.384	-0.685	0.755
	(-0.4)	(-2.127)	(-0.4)	(-2.018)	(-0.378)	(-2.085)
INDFED	2.191	3.247	2.182	0.268	1.901	3.836
	(1.052)*	(-5.588)	(1.052)*	(-5.526)	(-1.035)	(-5.539)
Financial/Market Conditions						
INTEREST	-2.465	1.296	-2.466	1.222	-2.48	
	(0.216)**	(-1.146)	(0.216)**	(-1.154)	(0.216)**	
LNVCSTAT	0.011	-0.406	0.011	-0.241	0.03	
	(-0.073)	(-0.39)	(-0.073)	(-0.39)	(-0.073)	
HIGHVCST	0.26	-2.922	0.26	-3.617	0.199	
	(-0.532)	(-2.828)	(-0.532)	(-2.857)	(-0.535)	
RLAVEVC	-0.085	0.149	-0.085	0.126	-0.088	
	(0.017)**	(-0.093)	(0.017)**	(-0.093)	(0.017)**	
RLAVESP	0.343	0.04		0.044	0.343	
	(0.039)**	(-0.206)	(0.039)**	(-0.207)	(0.039)**	
Constant	0.478	-46.355		-46.912	0.387	-47.382
	(-1.876)	(9.966)**	(-1.876)	(10.087)**	(-1.888)	(8.861)**
Observations	655	655	655	655	655	
R-squared	0.4551	0.6742	0.4551	0.6693		

Standard errors in parentheses
* significant at 5%; ** significant at 1%

	Model 1	Model 2	Model 3
Breusch-Pagan test of independence: chi2(1) =	0.682, Pr = 0.4091	0.594, Pr = 0.4411	0.648, Pr = 0.4209

Figure 1

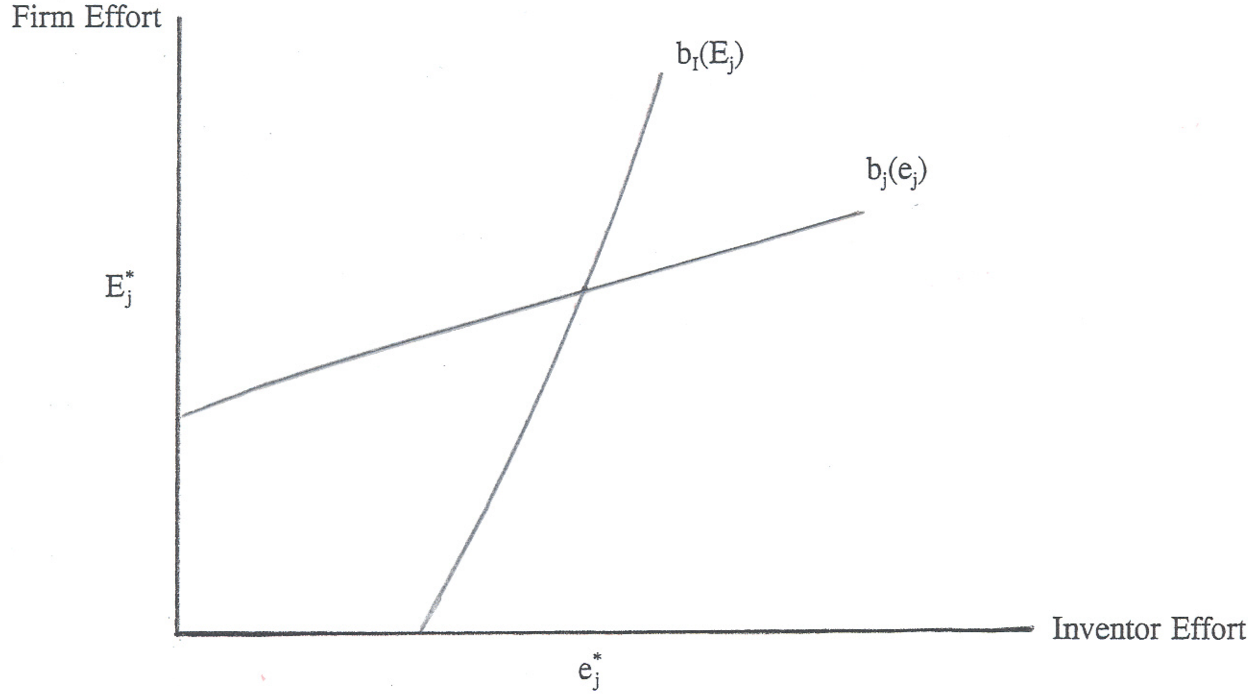

Figure 2