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Cash Breeds Success:

The Role of Financing Constraints in Patent Races*

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Abstract

This paper studies the impact of cash constraints on equilibrium winning probabilities in a patent race between an incumbent and an entrant. We develop a model where cash-constrained firms finance their R&D expenditures with an investor who cannot verify their effort. In equilibrium, the incumbent faces better prospects of winning the race the less cash-constrained he is and the more cash-constrained the entrant is. We use NBER evidence from pharmaceutical patents awarded between 1975 and 1999 in the US, patent citations, and COMPUSTAT to measure the effect of the incumbent's and entrants' cash holdings on the equilibrium winning probabilities. The empirical findings support our theoretical predictions.

Keywords: Patent Race, incumbent, entrant, financial constraints, empirical estimation.

JEL Classification: G24, G32, L13

Do a firm's financing constraints affect its decisions to pursue innovation? Since Fazzari, Hubbard, and Petersen's (1988) seminal paper, economists have found that financing matters through various channels for total firm level investment in R&D. For example, Hall (1992) shows that the source of financing matters and Himmelberg and Petersen (1994) show that internal finance predicts R&D expenditures of small high tech firms. But do a firm's financing constraints also affect its rivals' decisions to pursue innovations?

To our surprise, the role of financing constraints in patent races hasn't been comprehensively studied in the literature. Theorists have studied extensively how firms' R&D effort depends on technological standing and market structure. Reinganum (1983) shows that incumbent firms have less incentives to innovate than entrants in a stochastic setup because additional investments in R&D speed up the cannibalization of their current monopoly profits. Opposing this view, Gilbert and Newbery (1982) show that incumbents can preempt entrants from racing for incremental innovations if the incumbent benefits more from persisting as a monopolist than the entrant from coexisting as a duopolist. In this paper, we incorporate financing constraints explicitly into the model of Reinganum (1983) and test the model's predictions empirically.

In our model, entrepreneurs will finance their R&D expenditures with internal and external funds. The probability of making the discovery at a point in time depends on the effort exerted by the entrepreneur, which cannot be verified by the investor. Thus, in equilibrium, finance is costly for the entrepreneur and the marginal cost of innovative activity is increasing in the fraction of outside funds to the total investment, very much following the logic proposed by Jensen and Meckling (1976). The increase in the marginal cost of innovating shifts a player's best response function in the patent race monotonically, which in turn results in a monotonic change in the equilibrium R&D expenditures. The practical upshot is that in a setting of strategic interactions, financial standing power is a source of comparative advantage. This prediction is testable and is at the core of our empirical investigation.

We face three major empirical challenges. First, we need data on financial standing *and* patent awards, but existing data sets typically contain information on *either* finance *or* patents only. Therefore, we construct a data set that combines both. We use the NBER

Patent Citations Data File developed by Hall, Jaffe and Trajtenberg (2002), which records all utility patents granted in the United States between 1963 and 1999 and links every patent granted after 1975 to all the patents it cites and to the CUSIP code of the assignee as it appears in COMPUSTAT. We merge the patent records with COMPUSTAT to obtain the winners' and losers' financial data before the patent was awarded.[1] Second, we need to identify in the data which firms were incumbents and which firms were entrants to every race. Since a patent must cite the prior technology it builds on, we consider the owners of the patents for the cited technologies as incumbents to the race. Third, we need to be sure that patents are a good measure of innovative success. Therefore, we focus on the drug industry, where patents are crucial to reap the returns to R&D investment (see Levin et al., 1987, and Cohen, Nelson and Walsh, 2000).[2]

Our model links the probability that the winner of the race is either an incumbent or an entrant to the underlying characteristics of the race, e.g., the firms' financial resources, the value of the prize and the value of prior innovations. The outcome is therefore jointly determined by the cash holdings and other characteristics of both players. To test our predictions we fit logistic regressions of the observed outcome of each race on these variables. We find that a firm's probability of winning a race is increasing -on average- in its stock of cash and decreasing in its rivals' stocks of cash. The predicted impacts are not only statistically significant but also economically meaningful: differences in stocks of cash imply large differences in the probability of winning. Our results are robust to different definitions of incumbency.

Our empirical analysis also makes a clear distinction between the effects of patenting experience and those of incumbency by counting separately the cited and non-cited patents the firm has accumulated before each race. Most previous studies use the total count to characterize the persistence of innovation and will therefore fail to identify one effect from the other. We observe that incumbents keep on innovating more often the more valuable are their cited patents younger than two years and the less valuable are their older cited patents. Therefore, it appears that the efficiency effect is replaced by the cannibalization effect after two years.

This paper is related to several strands of the literature but novel in its focus and comprehensiveness. The literature has devoted some attention to the commitment effects of financial structure on generic strategies in oligopolistic product market games. A capital structure choice that is observed by rivals can influence a firm's aggressiveness in the product market (see Brander and Lewis, 1986; Maksimovic, 1988, and Rotemberg and Scharfstein, 1990; Fudenberg and Tirole, 1986; and Bolton and Scharfstein, 1990). Chevalier (1995) and Jensen and Showalter (2004), among others, test these predictions empirically. We depart from this literature in two respects. First, we assume that financing choices are not observable to rivals, so that the commitment effects of financing choices play no role. We believe that our assumption is appropriate to analyze the interaction between large firms, where rivals find it difficult to disentangle the financing of individual projects from the overall financing of the concern. Second, we do not take the form of the contracts as given but work from first principles, i.e., we derive the equilibrium financing contracts for competitors given their financing gap. Thus, we focus on a different comparative statics exercise. Instead of varying the capital structure, we vary the financing *need* of firms.

Our empirical investigation explores a game theoretic setup with a comprehensive data base. Only few studies share these two features. Blundell, Griffith and Van Reenen (1999) study the relationship between market share and innovation using a panel of British pharmaceutical firms. They find that firms with more market dominance innovate more often, consistent with Gilbert and Newbery's "efficiency effect". In contrast to their study we incorporate financing explicitly into ours and show that financing matters even if we control for size effects.

Cockburn and Henderson (1994) address whether or not R&D investments are strategic. Gathering detailed data at the individual project level for ten of the largest firms in the pharmaceutical industry, they find that research investments are only weakly correlated across firms. However, as they acknowledge, their study may miss correlations between investments of smaller potential entrants and the large firms by focusing only on the large players.[3] Lacking R&D data at the project level, we identify strategic behavior from the outcome of and not the inputs to these projects. We are thus able to use a much more comprehensive data base and show that the winning probabilities of firms are significantly affected by other firms' characteristics. Moreover, we include measures of the player's financial wealth in the empirical analysis.

Lerner (1997) does find that strategic variables explain the decision of firms to innovate. Lerner finds that the leaders in the disk drive industry between 1971 and 1988 were less likely to improve their disk drive density than the laggards.[4] Lerner's approach owes much of its elegance to the fact that the distance to the maximum disk drive in the industry measures the strategic interaction appropriately. Also, he focuses on an industry where not only the first but any firm that innovates is awarded the prize so he can treat observation errors independently across firms. We cannot rely on such assumptions in the pharmaceutical industry and are forced to take a more detailed view. Our approach identifies strategic behavior from the outcome of races where the winner takes all and finds results consistent with Lerner's.[5]

Hellman and Puri (2000) also study empirically the relationship between product market strategies and finance. They find evidence that budding firms with innovative strategies are more likely to be funded by venture capitalists. Our results are consistent with theirs insofar as firms with a bigger expected probability of success at innovation are financed by outsiders at smaller costs. However, in our setup, the expected probability of success is not taken as given but determined endogenously in a Nash Equilibrium, conditional on the technological standing of firms, i.e., incumbent or entrant, and the availability of cash before the race.

The remainder of this article is organized as follows. The next Section of the paper develops the model. It derives the comparative statics on the probability that a given firm wins the race conditional on its financial resources. Section 2 outlines the econometric strategy to test the model's predictions. Section 3 describes the construction of our data set and summarizes it. Section 4 presents the estimation results and Section 5 sums up and interprets all our findings. The final section concludes briefly.

1 Theory

We consider the financing of research in a version of the Reinganum (1983) model . There are two firms: an incumbent, I, and an entrant, E. The incumbent produces and sells the "state-of-the-art" product. The firms can enter a research race for a higher quality product.

We model the uncertain success in this research race as the outcome of a Poisson process. The state-of-the-art product and the innovation are protected by patents of infinite length. The sales of the incumbent's product yield a flow profit of π to the incumbent. If the incumbent innovates, sales of the new (and possibly also of the old) product yield a profit $\overline{\pi}_I$ to him. If the entrant innovates, he obtains flow profits of $\overline{\pi}_E$ and the incumbent obtains flow profits $\underline{\pi}_I$. This formulation allows for drastic and non-drastic innovations.

If a firm enters the research race, it has to spend once and for all a fixed cost F. Once this cost is sunk it can exert a flow of effort a_h for $h = E, I$. If a firm spends a constant flow of effort a_h, then the conditional likelihood at any point in time to innovate within the next instant given that it has not innovated before is a_h^α, where $\alpha < 1$. The non-pecuniary cost of effort is equal to a_h. Firms have limited financial resources, W_h. If $W_h < F$ the firm needs outside funds to finance the fixed cost.[6]

We assume that many investors compete in Bertrand fashion for the right to finance a firm's investment. They make take-it-or-leave-it offers to firms and then firms decide whether or not to accept the contract. A firm with $W_h < F$ that rejects its contract cannot innovate, i.e., has probability of innovation equal to zero for all a_h. After the firm has accepted a contract, it chooses its research intensity a_h. Contracts between investors and a firm are not observable to other investors and the other firm.

We assume that contracts are not observable to third parties in order to rule out commitment effects of finance. That is, we adopt the simultaneous move assumption from Reinganum's paper and take Nash-Equilibrium as our equilibrium concept. We do not consider sequential (Stackelberg) games where one firm can observe the financing of the other firm before it chooses its research intensity. Our main results are not affected by this modeling choice.

We begin our analysis with the derivation of firms' best responses. We first discuss the entrants optimal choice of research intensity for a given research intensity of the incumbent. Afterwards, we repeat this analysis for the incumbent. In each of these discussions we begin with a characterization of optimal contracts. Then we characterize the firm's research intensity that results from accepting an optimal contract.

1.1 The entrants' optimal financing problem

The Poisson nature of research implies that there are two classes of positive probability events: either the incumbent innovates before the entrant or vice-versa. Within these classes, events differ only in the time of innovation. We consider stationary contracts where the repayment conditions depend on who wins the race but not on when he wins. Thus, the model has essentially two outcomes. We place no further restrictions on the form of contracts. Contracts with any arbitrarily complex time-dependent repayments (in the sense of the length of time elapsed since the arrival of the innovation) have a simple equivalent representation where the entrant commits to repay a constant share, s_E, of profits from the time of innovation to infinity. Since everybody is risk-neutral, all that matters is the present value of the repayment stream. We analyze our game of optimal contracting by backwards induction. First, we characterize the best contracts that can be offered to the entrant. Then, we discuss whether or not the entrant will accept such a contract.

If the incumbent wins the race the entrant's profits are zero. Therefore, the entrant can repay the finance he has obtained only if he wins the race. The initial payment of $F - W_E$ and the share of profits s_E completely describe all relevant information of financial contracts.

Let $V_E(W_E, a_I, s_E)$ denote the value of the entrant's claim of future profits for given values of wealth, the incumbent's research, and the investor's repayment shares. The entrant's problem is to accept or reject a contract offered by the investor and to choose his research effort conditional on accepting. We solve this problem by backward induction. The second stage of the entrant's problem can be described by the following asset equation:

$$rV_E(W_E, a_I, s_E)\,dt = \max_{a_E}\left\{a_E^{\alpha}\left((1-s_E)V_E^{+} - V_E(W_E, a_I, s_E)\right) - a_I^{\alpha}V_E(W_E, a_I, s_E) - a_E\right\}dt, \tag{1}$$

where r is the risk-free interest rate and $V_E^{+} \equiv \frac{\overline{\pi}_E}{r}$, i.e., the net present value of the perpetual flow of profits, $\overline{\pi}_E$, starting at the time of innovation. We assume that $V_E^{+} > F$. In a short interval of time between t and $t + dt$ the entrant innovates with probability $a_E^{\alpha}dt$ and the incumbent innovates with probability $a_I^{\alpha}dt$. In case the entrant innovates, he receives a share $(1 - s_E)$ of all future profits and thus a claim that is worth $(1 - s_E)V_E^{+}$ as of the time of innovation. If either the entrant or the incumbent innovates, the entrant loses the value of its current claim, $V_E(W_E, a_I, s_E)$. The flow cost of research during the small interval of time is $a_E dt$.

The maximization problem on the right hand side of (1) is strictly concave in a_E. Let $a_E(s_E)$ denote a solution to this problem. The first-order condition,

$$\alpha (a_E(s_E))^{\alpha-1} \left((1-s_E) V_E^+ - V_E(W_E, a_I, s_E)\right) = 1, \tag{2}$$

is necessary and sufficient for the unique optimal choice of $a_E(s_E)$ induced by the contract $\{F - W_E, s_E\}$.

We can multiply both sides of condition (2) by $a_E(s_E)$ and obtain the condition

$$\alpha (a_E(s_E))^{\alpha} \left((1-s_E) V_E^+ - V_E(W_E, a_I, s_E)\right) = a_E(s_E). \tag{3}$$

If we substitute condition (3) into the asset equation (1) we can solve for the value of the claim to the entrant

$$V_E(W_E, a_I, s_E) = (1-s_E) \frac{(1-\alpha)(a_E(s_E))^{\alpha} V_E^+}{(1-\alpha)(a_E(s_E))^{\alpha} + a_I^{\alpha} + r}. \tag{4}$$

With perfect competition in the investors market, the equilibrium contract maximizes $V_E(W_E, a_I, s_E)$ subject to the constraint that the investor breaks even, i.e.,

$$s_E \frac{(a_E(s_E))^{\alpha} V_E^+}{(a_E(s_E))^{\alpha} + a_I^{\alpha} + r} = F - W_E. \tag{5}$$

Let $\hat{a}_E$ denote level of research effort by the entrant as induced by a contract that satisfies incentive compatibility for the entrant and individual rationality for a financier. Substituting (4) and (5) into (2) we conclude that $\hat{a}_E$ must satisfy the condition

$$\alpha \left(\hat{a}_E^{\alpha} V_E^+ - (\hat{a}_E^{\alpha} + a_I^{\alpha} + r)(F - W_E)\right)(a_I^{\alpha} + r) - \hat{a}_E \left((1-\alpha)\hat{a}_E^{\alpha} + a_I^{\alpha} + r\right) = 0 \tag{6}$$

Observe that the left-hand side of (6) is strictly concave in $\hat{a}_E$. Hence (6) has at most two distinct solutions. Let a_E^* denote an effort level induced by an optimal contract. It is easy to see that a_E^* is the largest solution of (6). The reason is as follows. The investor just breaks even, so the entrant receives all of the surplus. The entrant's effort is distorted downwards (which can be seen from (2)). Hence, it is desirable to induce the highest possible effort level. Note also that this implies that the optimal contract is unique.

The existence of an optimal contract, s_E^*, depends on the aggressiveness of the rival firm. One can show that for all $W_E \geq 0$ and F there exists $\overline{a}_I$ such that a unique optimal contract exists if and only if $a_I \leq \overline{a}_I \left(V_E^+, W_E\right)$. $\overline{a}_I \left(V_E^+, W_E\right)$ is non-decreasing in both its arguments. It is strictly increasing in V_E^+ whenever $\overline{a}_I > 0$. It is strictly increasing in W_E whenever $F > W_E$ and $\overline{a}_I > 0$. For a formal proof of these statements, see our companion paper (Schroth and Szalay (2007)). We deliberately abstain from all technicalities in this paper to keep the exposition compact.

The intuition for these results is straightforward. The higher the research effort chosen by the incumbent, the smaller the expected value of the prize for a given effort level by the entrant. As a result, the value of the investor's claim is decreasing in a_I for fixed s_E, and the investor requires a larger share of profits the higher is a_I. But an increase in s_E decreases the entrant's incentive to provide effort. Eventually, that is for large enough a_I, these discouraging effects are so strong that an optimal contract ceases to exist. On the other hand, an increase in the value of the race, V_E^+, balances these effects, so that the higher is the value of the race, the larger the critical level of the incumbent's effort $\overline{a}_I$ that chokes off the entrant's innovative efforts. Likewise, the higher is the entrant's wealth, the smaller is the amount of money needed from the investor and the less discouraging is an increase in the incumbent's effort.

Consider now the entrant's decision whether or not to accept the contract. The entrant accepts the optimal contract if and only if the project generates a nonnegative net present value to him, accounting for agency costs due to asymmetric information, that is if

$$V_E\left(W_E, a_I, s_E^*\right) - \min\left\{F, W_E\right\} \geq 0. \tag{7}$$

where $\min\{F, W_E\} = W_E$ if and only if the entrant is financially constrained. Suppose V_E^+ is sufficiently large so that the entrant engages in research for $a_I = 0$. Then, one can show that for all $W_E \geq 0$ and F, there exists $\overline{\overline{a}}_I$ such that the entrant accepts the optimal contract if and only if $a_I \leq \overline{\overline{a}}_I \left(V_E^+, W_E\right)$. $\overline{\overline{a}}_I$ is non-decreasing in both its arguments. $\overline{\overline{a}}_I$ is strictly increasing in V_E^+ whenever $\overline{\overline{a}}_I > 0$, and strictly increasing in W_E whenever both $\overline{\overline{a}}_I > 0$ and $F > W_E$.

Again, the logic of the argument is rather simple. The value of the prize that goes to the entrant is a strictly decreasing function of the incumbent's level of research effort. As a result, the entrant is willing to engage in research if and only if the opponent's effort is not too high. Conversely, for a given a_I, the value of the entrant's claim is the higher the higher is V_E^+. As a result, the critical level of the incumbent's research effort that chokes off the entrant's research incentives is a non-decreasing function of V_E^+. Similarly, an increase in wealth increases the net value of the entrant's claim by reducing agency costs of contracting. Moreover, this reduction of agency costs outweighs the increase in the investment cost to the entrant. As a result, the critical level of incumbent effort that chokes off the entrant's incentive to enter the research race is again an increasing function of W_E.

For future reference, we define the function $b_E\left(a_I; W_E, V_E^+\right)$, which denotes the effort level induced by the optimal contract as a function of a_I, the incumbent's research effort, and the parameters of the entrant's contracting problem. We note that $b_E\left(a_I; W_E, V_E^+\right)$ is positive for all $a_I \leq \min\left\{\overline{a}_I, \overline{\overline{a}}_I\right\}$ and is equal to zero otherwise. From the implicit function theorem applied to condition (6), we find

$$\frac{da_E^*}{dW_E} = \frac{\alpha\left(a_E^{*\alpha} + a_I^\alpha + r\right)\left(a_I^\alpha + r\right)}{-\alpha^2 \frac{\left(a_I^\alpha + r\right)^2}{a_E^*}\left(F - W_E\right) + \left(1-\alpha\right)\left(a_E^{*\alpha} + a_I^\alpha + r\right)} > 0 \tag{8}$$

The denominator is positive because a_E^* is the larger one of the solutions to equation (6). Thus we have shown that whenever $b_E\left(a_I; W_E, V_E^+\right) > 0$ and $F > W_E$, then, $\frac{db_E\left(a_I; W_E, V_E^+\right)}{dW_E} > 0$.[7]

If $W_E \geq F$ then the financing constraints are slack and an increase in W_E has no effect whatsoever on the entrant's best response. The best-response function in this case coincides with the one in Reinganum's model. If $W_E < F$ then the financing constraints bind. The larger $F - W_E$, the larger the repayment share to the investor and the smaller the entrant's effort choice. Intuitively, an increase in $F - W_E$ increases the agency costs of finance and increases the entrant's marginal costs of innovative activity.

1.2 The incumbent's optimal financing problem

Consider now the incumbent's problem. Let $V_I^+ \equiv \frac{\overline{\pi}_I}{r}$ denote the net present value of the incumbent's firm if it wins the race and let $V_I^- \equiv \frac{\pi_I}{r} \geq 0$ denote the value of the incumbent firm if the entrant wins the race. If $V_I^- > 0$ then the innovation is non drastic. Finally, recall that π is the flow profit of the firm if it uses its current technology. As it is standard, we assume that $V_I^- \leq \frac{\pi}{r}$.

A contract between the incumbent firm and an investor specifies the initial investment $F - W_I$ and a repayment scheme. We again restrict attention to stationary contracts in the sense that the repayment scheme does not depend on the date of the innovation. Any contract of this type, whatever complex repayment structure it may have, can be written in equivalent form in terms of repayment shares in the different contingencies. Let these shares be $\left(s_I^-, s_I^+, s_I\right)$, corresponding to the investor's share in the profits when the entrant innovates, the incumbent innovates, and when no one innovates, respectively. Let $\mathbf{s_I} = \left(s_I^-, s_I^+, s_I\right)$ denote the vector of repayment shares, and let $V_I\left(a_E, W_I, \mathbf{s_I}\right)$ denote the value of the incumbent's claim to the ongoing firm before any innovation has occurred. For brevity we shall write $V_I\left(\cdot\right)$ for $V_I\left(a_E, W_I, \mathbf{s_I}\right)$.

To characterize optimal contracts we proceed again in two steps. First, we characterize the best contracts that can be offered to the incumbent conditional on engaging in research. Second, we investigate whether the incumbent will indeed find it optimal to engage in research.

With financing, the asset equation takes the form

$$rV_I\left(\cdot\right)dt = \max_{a_I}\left\{a_I^{\alpha}\left(\left(1-s_I^+\right)V_I^+ - V_I\left(\cdot\right)\right) + a_E^{\alpha}\left(\left(1-s_I^-\right)V_I^- - V_I\left(\cdot\right)\right) + \left(1-s_I\right)\pi - a_I\right\}dt. \tag{9}$$

The difference to the entrant's asset equation is that the incumbent receives flow profits π as long as no innovation occurs and that the value of the incumbent's firm if the entrant wins the race, V_I^-, may be positive. Since the right-hand-side of the asset equation is strictly concave in a_I, a solution to the incumbent's problem must satisfy the first-order condition

$$\alpha a_I\left(\mathbf{s_I}\right)^{\alpha-1}\left((1-s_I^+)V_I^+ - V_I\left(\cdot\right)\right) = 1. \tag{10}$$

Multiplying condition (10) on both sides by $a_I\left(\mathbf{s_I}\right)$ and substituting the resulting expression into (9) we solve for the value of the incumbents claim

$$V_I\left(a_E, W_I, \mathbf{s_I}\right) = \frac{\left(1-\alpha\right)a_I\left(\mathbf{s_I}\right)^{\alpha}\left(1-s_I^+\right)V_I^+ + a_E^{\alpha}\left(1-s_I^-\right)V_I^- + \left(1-s_I\right)\pi}{\left(1-\alpha\right)a_I\left(\mathbf{s_I}\right)^{\alpha} + a_E^{\alpha} + r}. \tag{11}$$

In addition, investors must break even. Formally, it must be true that

$$\frac{a_I\left(\mathbf{s_I}\right)^{\alpha} s_I^{+} V_I^{+} + a_E^{\alpha} s_I^{-} V_I^{-} + s_I \pi}{a_I\left(\mathbf{s_I}\right)^{\alpha} + a_E^{\alpha} + r} = F - W_I. \tag{12}$$

An optimal contract maximizes (11) subject to (12) and (10). It is interesting to note that financing does not always involve a loss of efficiency for the incumbent. It is sometimes possible to implement the first-best outcome even if the incumbent needs to raise cash from outside investors, i.e., even if $W_I < F$.

Proposition 1 *i) There exists* $\overline{a}_E^{FB} \equiv \overline{a}_E^{FB}\left(V_I^{-}, W_I, \pi\right)$ *such that a contract that implements the first-best outcome exists if and only if* $a_E \leq \overline{a}_E^{FB}$. $\overline{a}_E^{FB}$ *is strictly positive for* $\frac{\pi}{r} > F - W_I$ *and bounded for* $F - W_I > V_I^{-}$. $F - W_I \in \left(V_I^{-}, \frac{\pi}{r}\right)$, $\overline{a}_E^{FB}$ *weakly increasing in its arguments, and strictly increasing whenever* $\overline{a}_E^{FB} > 0$.
ii) For $a_E > \overline{a}_E^{FB}$, *a second best optimal contract takes the form* $\mathbf{s_I} = \left(1, 1, s_I^{+}\right)$ *where* s_I^{+} *solves the system of equations* (10), (11), *and* (12).

The incumbent firm can pledge its current profits to finance its current research expenditures. If the current profits are relatively large relative to the size of the investment, then a first-best financing contract is feasible for low research efforts of the entrant. The exact condition that we derive in the appendix states that the first-best outcome is implementable if and only if $W_I + \frac{a_E^{\alpha} V_I^{-} + \pi}{a_E^{\alpha} + r} \geq F$. $\frac{a_E^{\alpha} V_I^{-}}{a_E^{\alpha} + r}$ is the expected present value of the incumbent's firm if the entrant innovates and $\frac{\pi}{a_E^{\alpha} + r}$ is the net present value of the incumbent's current stream of profits. These values are independent of the incumbent's own effort. As a result, these values can be pledged without creating any moral hazard problems with respect to the choice of effort. The higher the research activity of the entrant, the higher the likelihood that the incumbent loses his current profits, and thus the smaller the value of pledgeable profits. As a result, first-best financing becomes eventually impossible for a large enough research activity of the entrant.

While it is interesting to note that the incumbent's contracting problem is somewhat richer than the entrant's, the case where first-best financing is feasible is somewhat less interesting from a comparative statics perspective. By definition, the level of W_I does not influence the incumbent's choice of research effort in the first-best. Therefore, we will restrict attention to the case where the first-best is not implementable in what follows. In that respect, statement $ii)$ in the proposition is more relevant to what we exploit below, in that it characterizes the structure of optimal contracts. The incumbent pledges profits in the state where he loses the race or when no innovation has been made to the point where all these profits are exhausted. From then on, the incumbent's asset equation takes exactly the same form as the one for the entrant does. Hence, in the second best, the solutions to the contracting problems have exactly the same properties.

Formally, combining equations (10), (11), and (12), we can eliminate the share s_I^+ and obtain a condition for the effort level that is induced by a contract that satisfies incentive compatibility for the incumbent and individual rationality for the financier:

$$\alpha\left(\hat{a}_I^\alpha V_I^+ - \left(\hat{a}_I^\alpha + a_E^\alpha + r\right)\left(F - W_I\right)\right)\left(a_E^\alpha + r\right) - \hat{a}_I\left(\left(1-\alpha\right)\hat{a}_I^\alpha + a_E^\alpha + r\right) = 0 \tag{13}$$

Again, one can show that for all $W_I \geq 0$ and F there exists $\overline{a}_E \equiv \overline{a}_E\left(V_I^+, W_I, V_I^-, \pi\right)$ such that a unique optimal contract exists if and only if $a_E \leq \overline{a}_E$. $\overline{a}_E$ is non-decreasing in all its arguments. It is strictly increasing in V_I^+, V_I^-, and π whenever $\overline{a}_E > 0$. It is strictly increasing in W_I whenever $F > W_I$ and $\overline{a}_E > 0$. Moreover, if V_I^+ is sufficiently large so that the incumbent engages in research for $a_E = 0$, then, for all $W_I \geq 0$ and F, there exists $\overline{\overline{a}}_E > 0$ such that the entrant accepts the optimal contract if and only if $a_E \leq \overline{\overline{a}}_E\left(V_I^+, W_I; \cdot\right)$. $\overline{\overline{a}}_I$ is non-decreasing in V_I^+ and W_I. $\overline{\overline{a}}_I$ is strictly increasing in V_E^+ and strictly increasing in W_I whenever $F > W_I + \frac{a_E^\alpha V_I^- + \pi}{a_E^\alpha + r}$.

The research effort induced by the unique, optimal contract is the larger of the solutions to equation (13). We define the function $b_I\left(a_E; W_I, V_I^+\right)$, which denotes the effort level induced by the optimal contract as a function of a_E and the parameters of the incumbent's contracting problem. $b_I\left(a_E; W_I, V_I^+\right)$ is positive for all $a_E \leq \min\left\{\overline{a}_E, \overline{\overline{a}}_E\right\}$, and is equal to zero otherwise; and whenever $b_I\left(a_E; W_I, V_I^+\right) > 0$ and $F > W_I + \frac{a_E^\alpha V_I^- + \pi}{a_E^\alpha + r}$, then, $\frac{db_I\left(a_E; W_I, V_I^+\right)}{dW_I} > 0$.

1.3 Comparative statics of Equilibrium Research

Our game admits two kinds of equilibria for different parameter constellations. First, equilibria where both firms are active and the equilibrium research efforts, a_I^* and a_E^* are both positive. Second, equilibria where only one firm enters the research race and the other firm stays out. When the prizes the firms can win, V_I^+ and V_E^+ are sufficiently large relative to the cost of entering the race, F, then any equilibrium must be of the first kind, that is, both firms are active. Whenever such an equilibrium exists, it has the following properties:

Proposition 2 *Consider a stable, interior equilibrium. Formally, suppose that* $(a_I^*, a_E^*) >> 0$, $\left|\frac{db_I\left(a_E; W_I, V_I^+\right)}{da_E}\right| < 1$ *and* $\left|\frac{db_E\left(a_I; W_E, V_E^+\right)}{da_I}\right| < 1$ *around* (a_I^*, a_E^*). *If in addition*
i) $F > \max\left\{W_E, W_I + \frac{a_E^{*\alpha} V_I^- + \pi}{a_E^{*\alpha} + r}\right\}$, *then* $\frac{da_I^*}{dW_I} > 0$ *and* $\frac{da_E^*}{dW_E} > 0$; *moreover,* $\frac{da_I^*}{dW_I} > \frac{da_E^*}{dW_I}$ *and* $\frac{da_E^*}{dW_E} > \frac{da_I^*}{dW_E}$.
ii) $F < W_E$, *then* a_I^* *and* a_E^* *are independent of* W_E.
iii) $F < W_I + \frac{a_E^{*\alpha} V_I^- + \pi}{a_E^{*\alpha} + r}$, *then* a_I^* *and* a_E^* *are independent of* W_E.

Proposition 3 *In a stable, interior equilibrium, the probability that the incumbent wins the race is*
i) nondecreasing in W_I *and strictly increasing in* W_I *if* $F > W_I + \frac{a_E^{*\alpha} V_I^- + \pi}{a_E^{*\alpha} + r}$; *and*
ii) nonincreasing in W_E *and strictly decreasing in* W_E *if* $F > W_E$.

The intuition for the results is quite simple. An increase in the incumbent's wealth improves the contracts that can be offered to the incumbent and hence increase the research effort induced by an optimal financing contract. In other words, the best reply of the incumbent to any given research effort of the entrant is increased. The entrant's research effort adjusts to this change by a move on the entrant's best reply function. While the former effect tends to increase the probability that the incumbent wins the race, the latter effect tends to reduce the same probability. However, in a stable equilibrium, the former effect always dominates the latter. Hence, improved financing conditions improve the incumbent's strategic position, and it becomes more likely that the incumbent wins the race.

The effects of the remaining parameters on the equilibrium research efforts are ambiguous. Anything that causes $\overline{\pi}_E$ to increase (say an increase in demand) will also increase $\overline{\pi}_I$. As a result both reaction functions are shifted upwards by an increase in the value of the patent race as measured by V_E^+ and V_I^+ and the effect on the equilibrium efforts is unclear. Increases in $\underline{\pi}_I$ and π have two effects. On the one hand it may become feasible to write first-best contracts so that the incumbent's best response function shifts up. On the other hand, an increase in operating profits makes the incumbent reluctant to destroy these profits, so that he reduces his research efforts and his best response function shifts downwards.

We now proceed to investigate whether the predictions of our game are verified empirically.

2 The econometric approach

2.1 Nash Equilibrium winning probabilities

Let λ^*_{ih} denote the Nash Equilibrium hazard rate of firm $h \in \{E, I\}$ in race i. The Nash Equilibrium can be written as

$$\begin{aligned}
\lambda^*_{iI} &= \lambda^*_I(W_{iI}, W_{iE}, V^+_{iE}, V^+_{iI}, \pi_i, S_{iI}, S_{iE}) = \lambda^*_I(\mathbf{X}_{iI}, \mathbf{X}_{iE}; \boldsymbol{\beta}_I) = \lambda^*_I(\mathbf{X}_i; \boldsymbol{\beta}_I), \\
\lambda^*_{iE} &= \lambda^*_E(W_{iI}, W_{iE}, V^+_{iE}, V^+_{iI}, \pi_i, S_{iI}, S_{iE}) = \lambda^*_E(\mathbf{X}_{iI}, \mathbf{X}_{iE}; \boldsymbol{\beta}_E) = \lambda^*_E(\mathbf{X}_i; \boldsymbol{\beta}_E),
\end{aligned}$$

where W_{iI} and W_{iE} are measures of financial wealth, V^+_E and V^+_I measure the values of the new patent to the winner, π_i measures the value of the patent that is replaced, and S_{iI} and S_{iE} are vectors of other variables we us as empirical controls. $\boldsymbol{\beta}_I$ and $\boldsymbol{\beta}_E$ are the parameter vectors associated to the exogenous variables. The incumbent's equilibrium winning probability is

$$\begin{aligned}
\Pr(\text{race } i \text{ is won by the incumbent}) &= \int_0^\infty e^{-(\lambda^*_{iI}+\lambda^*_{iE})t}\lambda^*_{iI}dt \\
&= \frac{\lambda^*_{iI}(\mathbf{X}_i)}{\lambda^*_{iI}(\mathbf{X}_i)+\lambda^*_{iE}(\mathbf{X}_i)} = \frac{\frac{\lambda^*_I(\mathbf{X}_i)}{\lambda^*_E(\mathbf{X}_i)}}{\frac{\lambda^*_I(\mathbf{X}_i)}{\lambda^*_E(\mathbf{X}_i)}+1}
\end{aligned}$$

With an exponential function approximation of the hazard rates, i.e. if $\lambda_{ih} \approx \exp(\mathbf{X}_i\boldsymbol{\beta}_h)$, we we can write $\frac{\lambda^*_{iI}}{\lambda^*_{iE}} \approx \exp(\mathbf{X}_i\boldsymbol{\beta}_I - \mathbf{X}_i\boldsymbol{\beta}_E) = \exp(\mathbf{X}_i\boldsymbol{\beta})$ for $\boldsymbol{\beta}_I - \boldsymbol{\beta}_E \equiv \boldsymbol{\beta}$. The incumbent's equilibrium winning probability simplifies to

$$\Pr(\text{race } i \text{ won by the incumbent}) = \frac{\exp(\mathbf{X}_i\boldsymbol{\beta})}{1+\exp(\mathbf{X}_i\boldsymbol{\beta})}, \tag{14}$$

which is the well known logit formula.

2.2 The empirical winning probabilities

A patent is won either by the incumbent or the entrant, and the randomness in the outcome comes from the uncertainty of the R&D effort. The empirical interpretation of how the data is generated is therefore that firms "submit" their exogenous variables at the beginning of the race and "nature" picks the incumbent with probability

$$\Pr(I_i = 1) = \Pr(\beta_0 + \beta_1 W_I + \beta_2 W_E + \mathbf{c}\boldsymbol{\alpha} + \varepsilon_i \geq 0), \tag{15}$$

where $I_i = 1$ if the winner of patent i is an incumbent, and 0 otherwise. W_I and W_E are measures of the incumbent's and entrant's financial resources, respectively, the vector $\mathbf{c}$ includes the control variables $V_{iE}^{+}, V_{iI}^{+}, \pi_i, S_{iI}, S_{iE}$, and $\boldsymbol{\alpha}$ is the vector of their associated parameters. If the error term, ε_i, which represents the randomness in the choice of nature, has the extreme value distribution then conditions (15) and (14) become equivalent.[8] Hence, we can test our model with a logit regression.

2.3 Hypothesis testing

2.3.1 The basic specification

The main comparative statics of the Nash equilibrium of our model is that an increase in any player's cash holdings should be positively associated with that player's winning probability. Therefore, the estimate of β_1 should be significantly different from zero and positive, while that of β_2 should be significantly different from zero and negative.

The specification above also allows us to test the role of strategic interactions of this game through the regressors included in $\mathbf{c}$. Our specification captures the effect of the patent race characteristics, e.g., the value of the race, the incumbency value, on the Nash equilibrium winning probabilities. For example, we can estimate the net effect of the incumbency values and measure whether the cannibalization effect overpowers the efficiency effect.

2.3.2 Variable cash sensitivity

We enrich our basic specification with interactions between cash holdings and the value of the patent. The model

$$\Pr(I_i = 1) = \Pr(\beta_0 + \beta_1 W_I + \beta_2 W_E + \beta_3 \overline{\pi} \times W_I + \beta_4 \overline{\pi} \times W_E + \mathbf{c}\boldsymbol{\alpha} + \varepsilon_i \geq 0), \tag{16}$$

allows to test whether or not financing constraints bind less in more valuable races. Cash may matter less in more valuable races for two reasons. First, the payoffs in case of success increase and the cost of finance decreases in the values of the race. Thus, the firm is closer to implementing first-best R&D effort. Second, the firm would spend any additional available cash in the most profitable races so as to equate the marginal profit in every race. Thus, the firm would be less cash constrained in more profitable races and the probability of success would be less sensitive to cash. Both effects together predict β_3 to be negative and β_4 to be positive.

3 The data

3.1 Data set construction

We use two sources of data. The first is the NBER Patent Citations Data File developed by Hall, Jaffe and Trajtenberg (2002). This data set comprises all utility patents granted in the United States between 1963 and 1999 and records their technological category, the dates of award and their assignees. Each patent awarded after 1975 is linked to all the patents it cites and the assignee names in the patent records are matched to the name of the company as it appears in COMPUSTAT. From COMPUSTAT we get the financial information of the patent assignees whose stock is publicly traded in the U.S.

The NBER Patent Citations Data File is useful to identify racing behavior only in industries that rely heavily on patent protection to appropriate the returns of R&D. It is well recognized that patenting is crucial to protect R&D in the pharmaceutical industry (see the survey conducted by Levin, Klevorick, Nelson and Winter (1987), and its follow-up by Cohen, Nelson, and Walsh (2000)).[9]

The pharmaceutical industry also belongs to Cohen et al.'s (2000) 'discrete technology' category. Discrete innovations comprise single patents that are used for their original purpose, that is, to block imitation. Firms that develop 'complex technologies' (software, electrical equipment) accumulate bundles of patents to induce rivals to negotiate property rights over complementary technologies (Hall, 2004). Thus, we restrict our sample to patents in the technological category 3, i.e., Drugs and Medical, and the subcategories 31, 33 and 39:

Drugs, Biotechnology, and Miscellaneous Drugs, respectively. We treat each patent in these categories as the outcome of a race.

3.2 Classification of players

We classify patent assignees as either incumbents or entrants to the race.[10] To do so, we match every pharmaceutical patent in the data to all its citations and record the dates and the assignees of the cited patents. A patent is won by an incumbent whenever its assignee also owned at least one of the cited patent provided that the citation is not "too old".

By "too old" we mean that some patents might not have value any more to the holder and thus not be relevant for his decision to innovate again or not. Whether a patent of a given age has an incumbency value anymore is an empirical issue. To address this issue we classify our patents using several definitions of incumbency and conduct our estimations for all of them. We allow the maximum age to count incumbency to be one year old, or 2, or 3, 4, 5, 10 or up to 20. The last is the most generous possible definition of an incumbent, since property rights extend for 20 years at most.[11]

Citations have been shown to be good measures of the previously existing technology over which the citing patent is built because it is the legal obligation of the applicant to cite all the prior art of the innovations he claims. In fact, the patent examiner, who must be a specialist in the field, examines these citations and decides which ones to be included finally in the award.

Note that this classification defines entrants as firms without ownership of the building technology and not newcomers in the industry. As in the model, a firm may be large and have a successful record of innovation but still be an entrant to a given sequence of innovations. It is important to respect this definition empirically in order to identify the cannibalization and efficiency effects and distinguish them from the effects of age and size.

3.3 Data description

The NBER data set has 121,204 patents in the subcategories 31, 33 and 39 between 1975 and 1999. We are able to classify 91,656 of these. The remaining patents are lost using our definition of incumbency due to missing observations in the assignee names of citing or cited patents.

3.3.1 Winning intensities of incumbents and entrants

Table 1 summarizes the results of applying our definition of incumbency. Under the most generous definition, a patent is won by an entrant if the assignee owns none of the citations or only citations that are older than 20 years. In that case, 65.11% of all classifiable patents between 1975 and 1999 were awarded to entrants. A more restrictive definition of an incumbent, e.g., where the self-citations cannot be older than 5 years, implies a larger percentage of patents won by entrants: 73.81%. Not surprisingly, the percentage of entrant-won patents decreases in time. To a large extent this is due to the fact that we expect to have lost proportionally more incumbent won patents in the earlier years: entrant won patents with few young citations can always be classified. Moreover, even using the most generous definition of incumbency, almost two thirds of the patents are won by entrants.[12]

3.3.2 Incumbent and entrant-won patents

Table 2 compares the number of citations received by patents won by entrants and incumbents. We use all the possible definitions of incumbency for the comparison. Patents won by incumbents receive more citations than patents won by entrants, but the difference is small. Since the propensity to patent may exhibit significant time variation, we deflate patent counts using the re-scaling factors provided by Hall, et al., (2002). On average, for all definitions of incumbency, incumbents win the races for patents that are cited more.

3.4 Specification

The merger of the NBER data with COMPUSTAT results in 5,143 usable patents. Table 3 summarizes the characteristics of the patents in the NBER universe and the matched sample. Table 4 summarizes the characteristics of winners and losers of the races in our sample that are included in the empirical specification of that are specified in (15) and (16).

3.4.1 The market value of the patent: V_E^+ and V_I^+

Our model does not give an unambiguous prediction of the effects of V_E^+ and V_I^+. However, the outcome of the race depends on them measures and they are necessary controls. Hall, Jaffe and Trajtenberg (2005) have shown recently that the market value of a patent can be measured well by the number of citations it receives. While it has been used traditionally as a measure of the *social* value of a patent (e.g., Trajtenberg 1990), the number of citations has been shown to be a good measure of the private value by Hall et al. (2005: an extra citation per patent boosts the firm's market value by 3% on average. Therefore, we use the number of citations that a patent received in its whole lifetime to measure V_E^+ and V_I^+. While incumbents and entrants may derive different levels of profit from a given patent, the number of citations is a good measure for both V_E^+ and V_I^+ at the margin.

Table 3 shows that the average value of drugs and medical by publicly owned firms is almost the same as the average value of the drugs and medical patent universe. The value distribution is less skewed, and the value difference between incumbent and entrant won patents is very small (t-statistic of 1.303).

3.4.2 The market value of cited patents: π

Our measure for π is the average number of citations received by the cited patents. We distinguish between cited patents that are less than one year old, between 1 and 2 years old, 2 and 3, and so forth, up to between 10 and 20 year-old citations. In all cases, we re-scale these counts by the average number of citations received in the technological group in the particular grant year. As discussed above, the theoretical effect of π is ambiguous. Thus, the net effect of π on the probability that the incumbent wins is an empirical issue.

By grouping the citations into ages we can assess the incumbency effects of different vintages. We expect older vintages to have little residual value to the holder and thus carry no cannibalization effect. Table 3 compares the incumbency values in the patent universe to the estimation sample. The patents won by publicly traded firms have smaller incumbency values, i.e., its citations are cited much less often. However, the population average is strongly affected by extreme values. In fact, the median of the sample is not very different from the population. Also, the proportion of patents won by entrants in the sample is 0.5 using the 20 years definition, whereas in the universe it is 0.65. Hence, the sample of patents owned by publicly traded firms excludes incumbent won patents with extreme numbers of self citations.

3.4.3 Patenting experience

We include the average number of patents accumulated by the incumbents and the entrants to the date of the award of the patent, in the same patent class, to control for the effectiveness of the player's obtaining patents. We would expect that players who have accumulated more patents in the past in the same class would be more experienced in the patenting process and thus be more likely to obtain a new patent, *ceteris paribus*. Table 4 summarizes the patenting experience of winning and losing incumbents and entrants by the time they obtained a new one.

Table 4 clarifies what our model and data refer to as entrants. Entrants are not new firms in the industry, but rather firms that have been lagging in a given sequence of innovations. Winning entrants have not been cited by a patent and hence have no incumbency value in that race, but on average they have accumulated as much patents or more in the same patent class as the incumbents they defeat.

3.4.4 Cash: W_E and W_I

We use the level of the firm's cash holdings (COMPUSTAT item 36) to measure the financial wealth, W. The firm can use its cash to finance R&D without requiring costly external finance. For robustness, we will conduct our estimations for one, two and three-year lags of the amount of cash before the award of the patent. Longer lags are more likely to capture the given value of cash holdings before the R&D effort is chosen, as in the game.

We normalize the value of cash holdings by the amount of total assets to rule out spurious correlation due to the fact that larger tend to accumulate more patents. Thus, the proportion of cash to assets approximates the cash allocated per race. The model with interactions between cash and patent value tests this approximation by checking that firms choose to be less constrained, i.e., less sensitive to cash holdings in more valuable races.

Note that we observe W_E in COMPUSTAT whenever the entrant wins but not when she loses. We assume that any non-cited firm that is in the same industry is also a potential entrant. We use the average cash holdings to assets in the same year of observation over all the non-cited firms in the same four-digit Standard Industry Classification Code (SIC) to approximate W_E for incumbent won patents.

Table 4 compares the cash holdings of winning and losing entrants. Winning entrants hold about twice more cash but are also bigger. The cash to assets ratios are similar, but entrants who win hold slightly more cash. Note too that our assumed average losing entrant in COMPUSTAT has some patenting experience, fitting our definition that the entrant is not a newcomer.

The losing incumbents are included in the list of citations of every patent. Therefore, for entrant-won patents W_I is computed from the average cash holdings and total assets of the cited losers that are matched to COMPUSTAT. Whenever we cannot match any incumbent to COMPUSTAT we approximate W_I with the maximum value of cash holdings to total assets in the same SIC code in the same period. This will bias our estimate of the incumbent's sensitivity to cash downwards, i.e., against our hypothesis. Intuitively, the maximum-likelihood estimator of β_1 would have a downward bias because the data associates failure to win the race by an incumbent with cash levels that are, by definition, higher than the true ones.[13] In deed, our hypothesis is that β_1 should be significantly different from zero and positive. If the downward-biased estimate is still significantly different from zero and positive then so should also be an unbiased estimate.

Note that we rely less on the accuracy of the proxy for losing incumbent's W_I as we use more generous definitions of incumbency. As we allow older citations to count in the incumbency list, more firms can be matched. Thus, we also analyze how our estimate of β_1 changes across definitions of incumbency.

Table 4 shows that the winning incumbents hold a large proportion of their assets in cash when compared to those who proportionally hold the most cash in the industry. In fact, the cash ratios of the winners are close to the maximum cash ratios in the industry.

3.4.5 Patenting experience and firm size

Our specifications include also controls for the size of the incumbents and entrants. We expect the size to capture other unobservable variables, and that larger firms would be more likely to win given races all other things constant. For example, size might capture some variation in the effectiveness of R&D, that is not accounted for by the previous patenting experience of the firm.

Finally, all specifications include year dummies as controls. Year dummies capture exogenous aggregate changes in financing conditions or additional changes in procedures in the US Patent Office.

3.4.6 The Error term

As we work with a large cross-section of patents, the error term, ε, could be heteroskedastic. For every specification we compute the maximum likelihood estimates of the logit under the assumption that the error is homoskedastic. We use these estimates to perform the BRMR specification test suggested by Davidson and MacKinnon (2004), where the alternative hypothesis is that $Var(\varepsilon_i) = \exp(\mathbf{Z}_i\boldsymbol{\theta})$. In $\mathbf{Z}_i$ we include all the exogenous characteristics that describe the race i : the citations received by the patent and the average number of citations received by all the patents cited by patent i.[14]

3.5 Summary

A first look at our data set shows that our classification of incumbents and entrants captures the essential difference between incumbents and entrants in the model: they differ in terms of their ownership of the building technology for the next innovation and not in terms of their age or timing of entry into the industry. The match between COMPUSTAT and the NBER database keeps patents with the same value on average as the population but excludes patents with extreme values. In our estimation sample, winners seem to have more experience whether they are incumbents or entrants. Entrants that hold proportionately more of their assets as cash win more often than the average firm in their same industrial classification. Winning incumbents are among the firms with the highest ratios of cash holdings in the same industrial classification.

We proceed now to estimate the effects of cash holdings in the winning probability and test formally the comparative statics of the model.

4 Results

We estimate the parameters of (15) when we use one, two or three year lags of the value of cash holdings normalized by total assets. Table 5 shows these estimates using data of the balance sheet two years before the award of the patent. Tables ii and iii in the Web Supplement show the estimates for one and three year lags. Each column in these tables corresponds to each definitions of an incumbent.

4.1 Base Specification

The results shown in the first column of Table 5 are fully consistent with the predictions of the model. The first column corresponds to the estimates when we use the 20 year-old definition of incumbency. We see that:

4.1.1 Cash

The estimates of β_1 and β_2 are highly statistically significant and have the sign predicted by our model: the incumbent's cash to total assets ratio parameter has a positive sign and the entrant's cash to total assets ratio parameter has a negative sign. We interpret the value and discuss the economic significance of these estimates and most others in Section 4.3 below.

4.1.2 Size

The size of incumbents, measured by the total book value of assets one year before the race has a positive sign, whereas the size of entrants has a negative sign. Both estimates are significantly different from zero. All other things constant, larger entrants or incumbents are more likely to win than smaller ones.[15]

4.1.3 Number of patents

As expected, the more patents either player has accumulated, the more likely it is that it wins the race (a positive and significant estimate). The estimate is larger in the case of entrants, implying that, in equilibrium, the experience of the entrants matters more at the margin than the experience of the incumbent.

4.1.4 Value of the race

The estimate of the parameter associated to the market value of the patent raced for, as proxied by the number of citations it receives is positive and significantly different from zero in the first column. While a higher patent value shifts both best-response functions to the right, incumbents appear to have an advantage in more valuable races.

4.1.5 Age of cited patents

Table 5 shows also the role of old cited patents on the incumbent's incentives to innovate. In the case of cited patents that are between 3 and 20 years old, the higher π the smaller the probability that the winner is an incumbent. All of the associated coefficients are negative and significantly different from zero, to the 0.01 level. However, the cited patents that are less than two years old *increase* the probability that the winner is an incumbent the more valuable they are. Thus, incumbents with recent patents of high value are able to patent more within the next two years of these awards. This may happen because subsequent related innovations follow more easily from a race won recently by the same firm. The more valuable the patent, the more incentives the incumbent will have to obtain similar patents soon. After two years this effect seems to disappear and the value of cited patents operates through the replacement effect of innovation.

4.1.6 Further tests

As we showed, the merge with COMPUSTAT includes 5,143 usable patents of the total 91,656. The proportion of entrant-won races in the sample used for estimation (0.49) is not far from the population proportion (0.65). Finally, note that homoskedasticity cannot be rejected.

4.1.7 Definition of incumbency

It is interesting to compare the estimates across columns in Table 5. From left to right, we report the estimates for narrower definitions of incumbency. If incumbency is defined as the winner also having cited patents that are up to 5, or 10 years old then we also have a fit fully consistent with the theory and with the results in column 1. The estimates for β_1 and β_2 are robust to narrowing down the definition of incumbency to 10, 5 or even 4 years. As predicted by the model, the richer in cash is the incumbent (entrant), the more likely it is that the incumbent (entrant) wins the race, in all cases. The estimates decrease in absolute value from left to right. This is clear for β_1 because broader definitions of incumbency require us to proxy less frequently the cash ratio with that of the richest firm in the industry. Our results are robust even to the proxy with the largest bias against our theory.

The estimate of β_2 is also robust to all definitions. It is strongest also when we account for the effect of 10 year-old or 20 year-old citations, predicting a more powerful effect of cash balances on the chances of winning the race.

In the second and third columns the estimated effect of total assets value in the probability of winning is similar to the first column. As before, more experience in patenting makes either type significantly more likely to win.

As we narrow further the incumbency definition to 2 years the estimate for the incumbents assets suggests that smaller incumbents are more likely to win *ceteris paribus*. While its possible that this estimate may be also bias downward, it may also suggest that the correct definition of incumbency is between 4 and 20 years. Similarly, the estimated effect of patenting experiences by the entrant weakens also for narrower definitions.

Note that in the last two columns we can only include as controls the average number of citations of patents cited that are at most three or two years old. This may explain why the effect of cash is smaller in these columns too, although the estimates remain consistent with the theory.

4.2 Other lags for cash holdings

When we use one-year or three-year rather than two-year lags for the cash ratio and the size of the firm the estimates tell the same story, qualitatively (see Tables ii and iii in the Web Supplement). The three-year lag case provides a consistent set of results with the 5, 10 or 20-year-old definitions of incumbency. Again, cash constraints have the effect predicted by our theory: a cash-richer player is more likely to win. The magnitude of the cash coefficients is very similar with three-year lags, and smaller in absolute value when using one-year lags. With three-year lags the coefficients of accumulated patents by entrants or incumbent are still close to each other, and the effect of changes in the value of cited patents is as larger than before.

Our sample is larger for the case of one-year lags because we are able to match more patents with COMPUSTAT. This inclusion adds more entrant-won patents but increases the downward bias on the coefficients of the incumbent's cash ratio. The Pseudo R-Squared coefficients are smallest for this case and the last two columns show that more experience by the entrants is associated on average with a smaller probability of winning. The poorer fit in this case suggests that cash ratios explain well racing behavior for patents awarded two and three years after lagged but nor earlier.

We conclude from this analysis that the empirical model is correctly specified when we use a definition of incumbency between 5 and 20 years. The results are generally robust, but most consistent with the theory when we use two or three year lags of balance sheet data.

4.3 Discussion of Economic Significance

We have shown above that the cash availability of an incumbent or an entrant between two and three years before a patent is awarded has a statistically significant effect on the outcome of the race. To see whether or not this effect is also economically significant we compute the average expected change in the probability that the incumbent wins with respect to a change in the value of cash by US$1 million when all other variables are set to their sample median and held constant. We use the coefficients for the benchmark specifications (Table 5 below, and Table iii in the Web Supplement). The results are reported in Table 6. An increase (decrease) in the probability that the entrant (incumbent) wins the race is on average between 0.00128 and 0.00214. To have a better sense of this estimate in the sample of firms used here we compute the difference between the predicted probabilities that the winner is an incumbent in a race where the entrant firm is in the 9th and in the 1st deciles of the sample distribution of cash divided by assets. We call this difference $\Delta P_{1\to 9}$. We find that cash has an economically significant effect: *ceteris paribus*, an entrant firm in the 9th decile of the cash to assets distribution is more likely to win the race than one in the 1st decile by a difference in probability between 0.29 and almost 0.4.

The marginal effect for incumbents' wealth is smaller for two reasons: (i) β_1 is biased downward, and (ii) first-best contracting is feasible for the incumbents. Nevertheless, the difference in the predicted probabilities of an incumbent winner at the 9th and 1st deciles of cash is significant, i.e., $\Delta P_{1\to 9}$ is between 0.45 and 0.54.

Table 6 shows too that each accumulated patent matters much more to entrants than to incumbents. Having an additional patent increases on average the probability that the incumbent wins by 0.002, whereas it increases the probability that the entrant wins by at least 0.021. Since incumbents on average have about twice more patents than entrants in this sample, this result may be indicative of diminishing returns in patenting experience. In this table we see too that the largest effect of the won citations on the probability that an incumbent wins is by those that are at most one year old.

4.4 Interactions

Table 7 shows the estimates of the parameters in (16). For parsimony, we report here only the estimates using cash and assets lagged two or three years and for the three broadest definitions of incumbency (20, 10 or 5 years). These cases are where the benchmark model fit best.

When cash and assets are lagged two years (first three columns) the estimates are similar to the benchmark case. The estimates for $\beta_1, \beta_2, \beta_3$, and β_4 have the expected sign in all columns. The estimate for β_4 is not significant at the 95% level for the 20-year definition of incumbency but all others are at the 99% level. Note that by augmenting the specification to allow for interactions, the estimated direct effect of cash appears to be bigger as the absolute values of $\widehat{\beta}_1$ and $\widehat{\beta}_2$ have increased. In the next section we interpret these values in terms of their effect in the probabilities of winning the race.

The estimates associated to patent counts are smaller than the benchmark case, in absolute values. The average number of patents accumulated by entrants is still statistically different from zero and it increases on average the probability that an entrant wins. The last three columns show the estimates using the three-year lags for the balance sheet variables and show basically similar results as the previous specification, but with smaller estimates for the patent counts.

Panel B shows the marginal effects and $\Delta P_{1\to 9}$ for the model with interactions between cash and $\overline{\pi}$. Here the effect of cash is economically significant too, as $\Delta P_{1\to 9}$ is between 0.46 and 0.62 for the entrant, and between 0.4 and 0.6 for the incumbent.

4.5 Further Robustness Checks

4.5.1 Patents of low value

We showed that changes in the player's cash availability have unambiguous effects on the equilibrium probabilities of winning the race, and are thus testable, provided that the value of the race is high enough. It remains to be checked that most of the data satisfy these conditions. We cannot tell ex-ante what are the value boundaries under which one player cannot be financed and is effectively out of the race. To see if there is a reason for concern, we estimated our model with the patents with more citations than the median. The results with the upper half of the sample are qualitatively and quantitatively similar than for the whole sample. These results are available to the interested reader upon request.

4.5.2 Correct definition of incumbency

We also estimated our model defining incumbency with patents up to 25 or 30 years old. In these cases, the fit was very poor. We take this as positive news because patents *expire* after 20 years. Thus, there is little room for concern that our incumbency index is capturing something else.

4.5.3 Other entrant definitions

We chose to define the entrant as an average firm in the same industrial segment (4 digit SIC code) as the incumbent in cases when the winner of the race was the incumbent. As an alternative, we defined an entrant as any firm that had also patented in the same subclasses as the patent raced for but with no citations by it. Under this definition, any firm that has patented in the same subclass in the past, but is not necessarily in the same industry, is assumed to have raced for any new patents in that subclass. This approach resulted unfeasible: for most patents, the set of firms that had obtained patents in the same subclass that were not cited was either small or often empty. Moreover, very few of these could be matched with COMPUSTAT to obtain their financial information.

4.5.4 Cash levels

All of our results above show that the model's predictions are consistent with the data when we measure W with the proportion of cash to assets. We have also computed the estimates of the parameters of the model with interactions (equation (16)), using the total *level* of cash (see Table iv, Web Supplement). We argued previously that the cash level fails to control for the fact that larger firms have larger balances of cash and are involved in more races. As we expected, several estimates are no longer consistent with the theoretical predictions. The total number of patents accumulated by entrants have now a positive effect on the probability that the incumbent wins and the incumbent's size has a negative effect. The signs of the estimates of β_2 and β_4 are the opposite too.

5 Discussion

The empirical analysis above has shown that the cross-sectional variation in the ratio of cash holdings to total assets of publicly traded firms is a powerful determinant of the cross-sectional variation in the probability of winning drugs and medical patents. We have identified this effect through the comparison of success rates across races and across incumbents and entrants to these races. Therefore, innovative success depends on how much more cash the firm has relative to its rivals.

This estimated relationship is robust to several definitions of incumbency through a long time period: 1975 and 2002. The theoretical relationship tested by this data is itself very robust. Indeed, the empirical specification is derived directly from a Nash equilibrium where firms are optimally financed at any point in their best-response function. This approach is more robust than approaches in the literature that analyze best-response behavior keeping the financing contract fixed as the financing needs of the firm change (e.g., Chevalier, 1995; Jensen and Showalter 2004).

Our model distinguishes firms in an industry in terms of their technological standing. The empirical analysis isolates the effects of patenting experience from those of incumbency by counting separately the cited and non-cited patents the firm has accumulated. We have shown that incumbents keep on innovating more often the more valuable are their cited patents younger than two years and the less valuable are their older cited patents. Therefore, it appears that the efficiency effect is replaced by the cannibalization effect after two years.

The effects of cash differences across firms have powerful effects even within the set of COMPUSTAT firms, where cash and size differences across firms that patent in the drugs and medical categories are not too big. Our model has shown that tighter cash constraints may result in situations where the strategic nature of the game is reversed. Such situations may arise in races between private firms, which are naturally more constrained. One interesting path for future research would be to condition the sensitivity of innovation success on exogenous measures of firm-specific costs of finance, e.g., venture backed vs. non-venture backed.

6 Conclusions

This paper provides a way to understand the role of financing constraints in innovation. It incorporates the contracting problem into a race between an incumbent and an entrant. Our theoretical model shows that wealthier firms are more likely to innovate and our empirical findings support this claim.

We study sequences of races but not the evolution of particular firms within the industry. An interesting question for future research is how the financing constraints of firms evolve over time as they accumulate patents and how this affects the dynamics of industry structure. We pursue these questions in ongoing research.

Appendix

Proof of Proposition 1. Let $V_I(a_E)$ be the first-best value of the incumbent's firm. $V_I(a_E)$ is defined by the asset equation

$$rV_I(a_E)\,dt = \max_{a_I}\left\{a_I^{\alpha}\left(V_I^{+} - V_I(a_E)\right) + a_E^{\alpha}\left(V_I^{-} - V_I(a_E)\right) + \pi - a_I\right\}dt.$$

The problem on the right hand side of this asset equation is a strictly concave in a_I. The first-order condition is

$$\alpha a_I^{*\alpha-1}\left(V_I^{+} - V_I(a_E)\right) = 1, \tag{17}$$

If we multiply both sides of (17) by a_I^*, and substitute the resulting equality into the asset equation, we can solve for the value of the firm:

$$V_I(a_E) = \frac{(1-\alpha)\,a_I^{*\alpha}V_I^{+} + a_E^{\alpha}V_I^{-} + \pi}{(1-\alpha)\,a_I^{*\alpha} + a_E^{\alpha} + r}. \tag{18}$$

Substituting back into equation (17), we observe that a_I^* is the unique solution to the equation

$$\alpha\left(\left(a_E^{\alpha} + r\right)V_I^{+} - \left(a_E^{\alpha}V_I^{-} + \pi\right)\right) = a_I^{*1-\alpha}\left((1-\alpha)\,a_I^{*\alpha} + a_E^{\alpha} + r\right) \tag{19}$$

The first-best is feasible if and only if there exists a contract that allows investors to break even, and, at the same time, does not distort the marginal incentive to provide effort in research. That is, the differences in values on the left hand side of conditions (17) and (10) must be identical:

$$\left(1 - s_I^{+}\right)V_I^{+} - V_I\left(a_E, W_I, \mathbf{s_I}\right) = V_I^{+} - V_I(a_E).$$

Substituting from equations (11) and (18) we obtain

$$\begin{aligned}
&\left(1 - s_I^{+}\right)V_I^{+} - \frac{(1-\alpha)\,a_I(\mathbf{s_I})^{\alpha}\left(1 - s_I^{+}\right)V_I^{+} + a_E^{\alpha}\left(1 - s_I^{-}\right)V_I^{-} + (1 - s_I)\,\pi}{(1-\alpha)\,a_I(\mathbf{s_I})^{\alpha} + a_E^{\alpha} + r} \\
= \;& V_I^{+} - \frac{(1-\alpha)\,a_I^{*\alpha}V_I^{+} + a_E^{\alpha}V_I^{-} + \pi}{(1-\alpha)\,a_I^{*\alpha} + a_E^{\alpha} + r}.
\end{aligned}$$

Clearly, by the definition of first-best, $a_I^* = a_I(\mathbf{s_I})$. Exploiting this fact we can simplify the condition on the equality of margins to the following simple condition

$$a_E^{\alpha}s_I^{-}V_I^{-} + s_I\pi = s_I^{+}V_I^{+}\left(a_E^{\alpha} + r\right). \tag{20}$$

In addition, investors must break even, i.e., condition (12) must be respected. Substituting condition (20) into condition (12) we obtain the relation

$$s_I^{+}V_I^{+} = F - W_I. \tag{21}$$

Substituting condition (21) back into condition (20) we obtain

$$\frac{a_E^\alpha s_I^- V_I^- + s_I \pi}{a_E^\alpha + r} = F - W_I. \tag{22}$$

The first-best is thus feasible if and only if we are able to find nonnegative numbers $\mathbf{s_I} = \left(s_I^-, s_I^+, s_I\right)$ smaller or equal to one that satisfy conditions (21) and (22). If $W_I \geq 0$ and $V_I^+ > F$ then it is always possible to find a $s_I^+ < 1$ such that $s_I^+ V_I^+ = F - W_I$. Hence condition (22) is the crucial one. We can find numbers s_I^- and s_I both smaller or equal to one that satisfy the implementability condition if and only if

$$\frac{a_E^\alpha V_I^- + \pi}{a_E^\alpha + r} \geq F - W_I. \tag{23}$$

The derivative of the left-hand side of inequality (23) with respect to a_E^α is equal to $\frac{V_I^- r - \pi}{\left(a_E^\alpha + r\right)^2}$, which is negative. Since the left-hand side tends to zero as a_E^α tends to infinity, there exists a strictly positive value of a_E^α such that (23) holds with equality if and only if $\frac{\pi}{r} > F - W_I$. In that case $\overline{a}_E^{FB}$ is defined by the condition

$$\left.\frac{a_E^\alpha V_I^- + \pi}{a_E^\alpha + r}\right|_{a_E = \overline{a}_E^{FB}} = F - W_I$$

To see the comparative statics properties of $\overline{a}_E^{FB}$, observe that the left-hand side of (23) is increasing in V_I^- and π, and the right-hand side is decreasing in W_I. ■

Proof of Proposition 2. ii) and iii) are trivial, so we prove only i). An equilibrium satisfies the condition

$$a_E = b_E\left(b_I\left(a_E; W_I, V_I^+\right); W_E, V_E^+\right)$$

Differentiating totally with respect to a_E^*, W_I, and W_E, we get

$$\left(1 - \frac{\partial b_E}{\partial a_I}\frac{\partial b_I}{\partial a_E}\right) da_E^* = \frac{\partial b_E}{\partial a_I}\frac{\partial b_I}{\partial W_I} dW_I + \frac{\partial b_E}{\partial W_E} dW_E$$

Setting dW_E and dW_I, respectively, equal to zero we find

$$\frac{da_E^*}{dW_E} = \frac{\frac{\partial b_E}{\partial W_E}}{\left(1 - \frac{\partial b_E}{\partial a_I}\frac{\partial b_I}{\partial a_E}\right)} \tag{24}$$

and

$$\frac{da_E^*}{dW_I} = \frac{\frac{\partial b_E}{\partial a_I}\frac{\partial b_I}{\partial W_I}}{\left(1 - \frac{\partial b_E}{\partial a_I}\frac{\partial b_I}{\partial a_E}\right)} \tag{25}$$

Performing the same analysis for the incumbent, we find

$$\frac{da_I^*}{dW_I} = \frac{\frac{\partial b_I}{\partial W_I}}{\left(1 - \frac{\partial b_I}{\partial a_E}\frac{\partial b_E}{\partial a_I}\right)} \tag{26}$$

and

$$\frac{da_I^*}{dW_E} = \frac{\frac{\partial b_I}{\partial a_E}\frac{\partial b_E}{\partial W_E}}{\left(1 - \frac{\partial b_I}{\partial a_E}\frac{\partial b_E}{\partial a_I}\right)} \tag{27}$$

By the fact that $\left|\frac{db_I\left(a_E;W_I,V_I^+\right)}{da_E}\right| < 1$ and $\left|\frac{db_E\left(a_I;W_E,V_E^+\right)}{da_I}\right| < 1$, the denominators in these expressions are positive, and since $\frac{\partial b_E}{\partial W_E} > 0$ and $\frac{\partial b_I}{\partial W_I} > 0$ it follows that $\frac{da_E^*}{dW_E} > 0$ and $\frac{da_I^*}{dW_I}$. Since $\left|\frac{db_I\left(a_E;W_I,V_I^+\right)}{da_E}\right| < 1$ the expression on the right-hand side of (25) is smaller than the expression on the right-hand side of (26) , so $\frac{da_E^*}{dW_I} < \frac{da_I^*}{dW_I}$. Likewise, since $\left|\frac{db_E\left(a_I;W_E,V_E^+\right)}{da_I}\right| < 1$, the expression on the right-hand side of (27) is smaller than the expression on the right-hand side of (24) , so $\frac{da_I^*}{dW_E} < \frac{da_E^*}{dW_E}$. ■

Proof of Proposition 3. The probability that the incumbent wins the race is equal to the probability that the incumbent's "first" innovation arrives before the entrant's "first" innovation. The arrival times follow independent Poisson distributions with hazard rates $a_I^{*\alpha}$ and $a_E^{*\alpha}$, respectively. So the arrival time of the first innovation has probability distribution function $1 - \exp\left(-a_i^{*\alpha}t\right)$ for $i = I, E$. Hence, the probability that the incumbent innovates first is

$$\int_0^\infty a_I^{*\alpha}\exp\left(-a_I^{*\alpha}t\right)\left(1-\left(1-\exp\left(-a_E^{*\alpha}t\right)\right)\right)dt = \frac{a_I^{*\alpha}}{a_I^{*\alpha}+a_E^{*\alpha}}$$

Differentiating $\frac{a_I^{*\alpha}}{a_I^{*\alpha}+a_E^{*\alpha}}$ with respect to W_I we obtain

$$\begin{aligned}\frac{\partial}{\partial W_I}\frac{a_I^{*\alpha}}{a_I^{*\alpha}+a_E^{*\alpha}} &= \frac{\alpha a_I^{*\alpha-1}\left(a_I^{*\alpha}+a_E^{*\alpha}\right)\frac{da_I^*}{dW_I} - \left(\alpha a_I^{*\alpha-1}\frac{da_I^*}{dW_I} + \alpha a_E^{*\alpha-1}\frac{da_E^*}{dW_I}\right)a_I^{*\alpha}}{\left(a_I^{*\alpha}+a_E^{*\alpha}\right)^2} \\ &= \frac{\alpha a_I^{*\alpha}a_E^{*\alpha}}{\left(a_I^{*\alpha}+a_E^{*\alpha}\right)^2}\left(\frac{\frac{da_I^*}{dW_I}}{a_I^*} - \frac{\frac{da_E^*}{dW_I}}{a_E^*}\right)\end{aligned}$$

So, we have $\frac{\partial}{\partial W_I}\frac{a_I^{*\alpha}}{a_I^{*\alpha}+a_E^{*\alpha}} > 0$ iff $\frac{da_I^*}{dW_I} > \frac{a_I^*}{a_E^*}\frac{da_E^*}{dW_I}$. Cancelling terms on both sides this is equivalent to $\frac{a_E^*}{a_I^*} > \frac{\partial b_E}{\partial a_I}\left(a_I^*; W_E, V_E^+\right)$. We now show that this condition is indeed verified: applying the implicit function theorem to condition (6) , we have

$$\frac{da_E^*}{da_I^\alpha} = \frac{\left(-\alpha\left(F-W_E\right)\left(a_I^\alpha+r\right) + \alpha\left(a_E^{*\alpha}V_E^+ - \left(a_E^{*\alpha}+a_I^\alpha+r\right)\left(F-W_E\right)\right) - a_E^*\right)}{-\left(\alpha^2 a_E^{*\alpha-1}\left(V_E^+ - \left(F-W_E\right)\right)\left(a_I^\alpha+r\right) - \left(\left(1-\alpha^2\right)a_E^{*\alpha}+a_I^\alpha+r\right)\right)} \tag{28}$$

Using condition (6) (and some straightforward manipulations) to simplify expression (28) we obtain

$$\frac{da_E^*}{da_I^\alpha} = \frac{a_E^*}{a_I^\alpha + r}\underbrace{\frac{1}{\alpha}\left(1 - \frac{(1-\alpha)\left((1-\alpha)\,a_E^{*\alpha} + a_I^\alpha + r\right)}{\left(-\alpha^2 \frac{\left(a_I^\alpha + r\right)^2}{\hat{a}_E^*}\left(F - W_E\right) + (1-\alpha)\left(a_E^{*\alpha} + a_I^\alpha + r\right)\right)}\right)}_{\equiv \Gamma\left(a_E^*\right)} \tag{29}$$

For future reference it proves useful to introduce the term $\Gamma\left(a_E^*\right)$; straightforward algebra shows that $\Gamma\left(a_E^*\right) < 1$. The slope of the best reply is then obtained noting that $\frac{\partial b_E}{\partial a_I}\left(a_I; W_E, V_E^+\right) = \frac{da_E^*}{da_I} = \frac{da_E^*}{da_I^\alpha}\frac{\partial a_I^\alpha}{\partial a_I} = \frac{da_E^*}{da_I^\alpha}\alpha a_I^{\alpha-1}$. Hence,

$$\frac{\partial b_E}{\partial a_I}\left(a_I; W_E, V_E^+\right) = \alpha\frac{a_E^*}{a_I}\frac{a_I^\alpha}{a_I^\alpha + r}\underbrace{\frac{1}{\alpha}\left(1 - \frac{(1-\alpha)\left((1-\alpha)\,a_E^{*\alpha} + a_I^\alpha + r\right)}{\left(-\alpha^2 \frac{\left(a_I^\alpha + r\right)^2}{\hat{a}_E^*}\left(F - W_E\right) + (1-\alpha)\left(a_E^{*\alpha} + a_I^\alpha + r\right)\right)}\right)}_{\equiv \Gamma\left(a_E^*\right)} \tag{30}$$

Since $\alpha < 1$, $\frac{a_I^\alpha}{a_I^\alpha + r} < 1$, and $\Gamma\left(a_E^*\right) < 1$, we have shown that $\frac{a_E^*}{a_I^*} > \frac{\partial b_E}{\partial a_I}\left(a_I^*; W_E, V_E^+\right)$.

Likewise, $\frac{\partial}{\partial W_E}\frac{a_I^{*\alpha}}{a_I^{*\alpha} + a_E^{*\alpha}} < 0$ iff $a_E^*\frac{da_I^*}{dW_E} < a_I^*\frac{da_E^*}{dW_E}$, which is after cancelling terms, equivalent to $\frac{\partial b_I}{\partial a_E} < \frac{a_I^*}{a_E^*}$. Since (6) and (13) are identical up to an interchange of indices, exactly the sam argument can be used to show that indeed $\frac{\partial b_I}{\partial a_E} < \frac{a_I^*}{a_E^*}$. This is omitted. ■

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Footnotes

1. Our focus on COMPUSTAT makes us restrict attention only to publicly traded firms. These firms are typically less financially constrained than private firms. Thus, if the predictions of our model were verified for COMPUSTAT firms, they should also be satisfied for a set of smaller, private firms.

2. It is widely acknowledged that firms in most other industries use other mechanisms to protect the competitive advantages of R&D (e.g., superior marketing, customer service, client switching costs) and in such industries patent records do not represent well their innovations and the races for them. We have limited ourselves to the study of patents in the pharmaceutical industry because we rely on patent data to measure success in a race. However, our method can be directly applied to any race in any industry provided that a satisfactory measure of success is available.

3. The authors state that the firms they sample account for approximately 25 to 30% of the worldwide sales and R&D of the Ethical Drugs Industry and claim that these firms are not markedly unrepresentative of the industry in terms of size, or of technical and commercial performance.

4. Note that this result is diametrically opposed to the results of Blundell, et al. (1999): technology laggards have more incentives to innovate because, unlike leaders, their innovative efforts do not cannibalize profits from "shelving" current innovations.

5. Another advantage of our approach is that we do not have to control for technological opportunity. Since we focus on races that have actually occurred and been won by someone, our observations are conditional on there being a technological opportunity to explore.

6. We could allow for a technology where the hazard rate is $f(a_h, k_h)$, where k_h is a variable investment complementary to effort. However, this introduces further technical complications without adding insights.

7. We have mentioned above that the thresholds $\overline{a}_I$ and $\overline{\overline{a}}_I$ are both non-decreasing in W_E and stricly increasing for a financially constrained entrant. Thus, an increase in W_E not only improves the terms of contracts when they do exist, but also enhances the existence and acceptance of contracts. For formal proofs of these effects, see our companion paper (Schroth and Szalay (2007)). We emphasize the internal margin in the text to keep the exposition short.

8. This equivalence holds only if we assume an extreme value distribution. The link between the theoretical and econometric probabilities is not direct if we use a normal distribution. We compute but do not report here parameter estimates using the normality assumption. As usual, the estimates we obtained in both cases are extremely similar/ They are different only because of the difference in the variances that scale the parameters under each distributional assumption (see, for example, Davidson and MacKinnon, 2004, Chapter 11).

9. Firms in many other industries use rather superior marketing, customer service or improved product characteristics instead of patents.

10. An incumbent is the player that is currently profiting from the existing technology, while an entrant is not. It is difficult to construct an equivalent empirical measure, unless a data set is constructed specifically for this purpose. Lerner (1997), for example, collects a data base of disk drive manufacturers, from the industry's annual reports. Hence he is able to observe the disk drive characteristics that each firms sells, and when innovators market higher disk drive densities. As far as we know, this is the only study that takes a step towards defining incumbency at the firm level.

11. We have also repeated our empirical tests for the cases where incumbency is defined as having cited your own patents that are up to 25 or 30 years old. Due to patent law, we should not expect 25 or 30 year old patents to have any incumbency value. However, we believe that repeating the exercise through these other definitions of incumbency can make more clear that incumbency matters and our empirical approach to define is relevant. We will comment these results later in the paper.

12. While preliminary, this observation is consistent with the predictions of Reinganum (1983) and the results of Lerner (1997): all other things constant, the incumbent will have less incentives than the entrant to invest more heavily in research and develop the next innovation.

13. We have illustrated the downward bias on the maximum likelihood estimates in a previous version, which is available upon request.

14. This test is performed by fitting the model

$$\widehat{V}_i^{-\frac{1}{2}}(I_i - \frac{\exp(\mathbf{X}_i\widehat{\boldsymbol{\beta}})}{\exp(\mathbf{X}_i\widehat{\boldsymbol{\beta}})+1}) = \widehat{V}_i^{-\frac{1}{2}} \frac{\exp(\mathbf{X}_i\widehat{\boldsymbol{\beta}})}{(\exp(\mathbf{X}_i\widehat{\boldsymbol{\beta}})+1)^2}\mathbf{X}_i\mathbf{b} + \widehat{V}_i^{-\frac{1}{2}} \frac{\exp(\mathbf{X}_i\widehat{\boldsymbol{\beta}})}{(\exp(\mathbf{X}_i\widehat{\boldsymbol{\beta}})+1)^2}(-\mathbf{X}_i\widehat{\boldsymbol{\beta}})\mathbf{Z}_i\mathbf{c} + u,$$

where $\widehat{V}_i^{-\frac{1}{2}}$ and $\widehat{\boldsymbol{\beta}}$ are the maximum likelihood estimates of the error variance and slope parameters, respectively, of the homoskedastic logit model, i.e., $\boldsymbol{\theta} = \mathbf{0}$. Under the null hypothesis, the explained sum of squares of this regression is asymptotically distributed as $\chi^2(r)$, where r is the dimension of $\mathbf{Z}$.

15. We have also used the value of total plant and equipment as a size control. The results are virtually unchanged, and thus not reported here.

Table 1: Percentage of Patents Won by Entrants in the Drugs and Medical Category, each Year for Different Definitions of Incumbency

	Percentage of patents awarded to an entrant in a year						
	Winner of the race is an entrant if youngest own citations is older than:						
Year patent was awarded	20 years	10 years	5 years	4 years	3 years	2 years	1 years
1975	76.26	76.26	78.58	81.61	85.53	90.41	98.32
1980	63.83	64.31	70.85	75.36	81.27	89.58	99.23
1985	63.94	65.48	73.61	78.35	83.00	89.55	97.15
1990	66.86	69.32	75.59	78.71	83.60	89.63	97.57
1995	62.94	65.42	72.88	76.53	81.89	89.72	97.96
1999	65.26	67.19	74.00	77.26	81.91	89.46	97.72
1975-1999	65.11	67.03	73.81	77.24	82.10	89.32	97.59

The percentages shown above are computed over 91,656 patents awarded between 1975 and 1999 in the US that are found in the NBER Patent Citations Data Files, in the technological category 3 (Drugs and Medical), subcategories 31,33 and 39.

Table 2: Comparison of the Citations Received by Patents Won by Entrants and by Incumbents in the Drugs and medical Technological Category, for Different Definitions of Incumbency

Panel A: Average citations received by patents

	Winner of the race is an entrant if youngest own citations is older than:						
Patents awarded to:	20 years	10 years	5 years	4 years	3 years	2 years	1 years
Entrants (μ_E)	4.29	4.25	4.18	4.18	4.18	4.18	4.21
Incumbents (μ_I)	4.10	4.16	4.32	4.37	4.40	4.53	4.99

Panel B: Difference of means test, assuming unequal variances.
Alternative hypothesis: $\mu_E - \mu_I > 0$

	Winner of the race is an entrant if youngest own citations is older than:						
	20 years	10 years	5 years	4 years	3 years	2 years	1 years
T statistic	3.103	1.336	-2.014	-2.563	-2.615	-3.370	-3.215
P-value	0.999	0.909	0.022	0.005	0.005	0.000	0.001

Panel C: Difference of means test, assuming unequal variances, and using citations re-scaled by the average number of citations by grant year in the same technological field.
Alternative hypothesis: $\mu_E - \mu_I > 0$.

	Winner of the race is an entrant if youngest own citations is older than:						
	20 years	10 years	5 years	4 years	3 years	2 years	1 year
T statistic	-2.120	-2.857	-2.418	-2.970	-3.279	-3.948	-2.778
P-value	0.017	0.002	0.008	0.002	0.001	0.000	0.002

The statistics shown above are computed over 91,656 patents awarded between 1975 and 1999 in the US that are found in the NBER Patent Citations Data Files, in the technological category 3 (Drugs and Medical), subcategories 31,33 and 39.

The factors for re-scaling are provided by Hall, et al., (2002).

Table 3: Summary Statistics of the Patents Characteristics in NBER patents before and after the merge with COMPUSTAT

Panel A: All patents in the Drugs and Medical Categories

	Number of observations = 91,656				
Variable	Mean	Standard Deviation	Median	Min	Max
Total citations received by the patent[a]	0.753	2.534	0.216	0	150
Citations received by the average cited patent that is:[a]					
less than 1 year old	0.586	8.113	0.000	0	600
between 1 and 2 years old	3.629	27.640	0.000	0	950
between 2 and 3 years old	10.744	85.110	0.000	0	3,650
between 3 and 4 years old	18.650	120.136	0.302	0	4,000
between 4 and 5 years old	28.107	172.036	0.606	0	5,300
between 5 and 10 years old	80.975	433.957	1.736	0	10,250
between 10 and 20 years old	149.390	1,140.979	2.200	0	31,550

Panel B: All patents in the Drugs and Medical Categories matched to COMPUSTAT

	Number of observations = 5,143				
Variable	Mean	Standard Deviation	Median	Min	Max
Total citations received by the patent[a]	0.741	1.423	0.350	0	55
- In incumbent-won races (n=2613)	0.716	1.270	0.324	0	22
- In entrant-won races (n=2530)	0.767	1.566	0.394	0	55
	$(\mu_I - \mu_E = -0.052, t - statistic = 1.303)$				
Citations received by the average cited patent that is:[a]					
less than 1 year old	0.084	0.519	0.000	0	15
between 1 and 2 years old	0.365	1.073	0.000	0	20
between 2 and 3 years old	0.678	1.578	0.100	0	20
between 3 and 4 years old	0.922	1.930	0.271	0	27
between 4 and 5 years old	1.111	2.276	0.350	0	27
between 5 and 10 years old	1.561	2.811	0.616	0	41
between 10 and 20 years old	1.657	2.913	0.668	0	41

The sample includes all patents awarded between 1975 and 1999 in the US that are found in the NBER Patent Citations Data File, in the technological category 3 (Drugs and Medical), subcategories 31,33 and 39, for which the assignee is found in COMPUSTAT.

[a] All counts of number of citations are re-scaled by the factors provided by Hall, et al., (2002).

Table 4: Summary Statistics of the Characteristics of the Firms in the Patent Races in the NBER data set after the merge with COMPUSTAT

Panel A: Incumbent-won patents

	Number of observations = 2,613		
Variable	Mean	Standard Deviation	Median
Incumbent's accumulated quad number of patents	192.385	175.424	141
Entrants' accumulated number of patents	12.417	6.717	13
Incumbent's cash[a]	363.781	273.877	278.400
Incumbent's assets[a]	3,363.250	3,901.235	2,524.968
Incumbent's cash to assets ratio	0.144	0.081	0.139
Entrants' cash[a]	115.056	60.729	115.105
Entrants' assets[a]	1,080.193	890.652	915.255
Entrants' cash to assets ratio	0.120	0.044	0.128

Panel B: Entrant-won patents

	Number of observations = 2,530		
Variable	Mean	Standard Deviation	Median
Incumbents' accumulated quad number of patents	116.838	139.253	68
Entrant's accumulated number of patents	142.385	156.617	94
Incumbents' cash[a]	731.525	316.851	713.929
Incumbents' assets[a]	6,194.027	4,473.791	5,847.748
Incumbents' cash to assets ratio	0.156	0.069	0.103
Entrant's cash[a]	315.219	267.267	260.542
Entrant's assets[a]	3,650.867	4,464.467	2,382.369
Entrant's cash to assets ratio	0.134	0.101	0.122

The sample includes all patents awarded between 1975 and 1999 in the US that are found in the NBER Patent Citations Data File, in the technological category 3 (Drugs and Medical), subcategories 31,33 and 39, for which the assignee is found in COMPUSTAT.

[a] All balance sheet data shown is expressed in $ Millions.

[b] All balance sheet data observed two years before the patent award. The incumbency definition is for 20 years.

Table 5: Parameter Estimates for Logit Regressions of the Probability that the Winner is an Incumbent on Incumbent's and Entrants' Measures of Financial Resources (I)

The dependent variable is the incumbent/entrant index, which equals 1 if the patent was awarded to an incumbent, and zero if it was awarded to an entrant.

Regressors	Winner is an entrant if youngest own citations is older than:					
	20 years	10 years	5 years	4 years	3 years	2 years
Incumbent's cash, divided by	12.702***	13.457***	12.561***	10.944***	9.591***	7.142***
total assets, lagged two years	(1.360)	(1.246)	(1.024)	(0.963)	(0.932)	(0.963)
Entrant's cash, divided by	-10.689***	-10.460***	-9.615***	-9.450***	-8.612***	-7.837***
total assets, lagged two years	(1.425)	(1.308)	(0.987)	(0.938)	(0.894)	(0.902)
Incumbent's total assets	0.089***	0.086***	0.061***	0.040**	0.019	-0.121***
($ Million), lagged two years	(0.023)	(0.021)	(0.018)	(0.018)	(0.020)	(0.028)
Entrants' total assets	-0.618***	0.665***	-0.567***	-0.538***	–0.529***	-0.626***
($ Million), lagged two years	(0.072)	(0.066)	(0.055)	(0.052)	(0.053)	(0.073)
Incumbent's average	0.823e-2***	0.863e-2***	0.896e-2***	0.888e-2***	0.887e-2***	0.935e-2***
accumulated patents	(0.083e-2)	(0.071e-2)	(0.064e-2)	(0.061e-2)	(0.061e-2)	(0.065e-2)
Entrant's average	-0.133***	-0.128***	-0.111***	-0.103***	-0.098***	-0.088***
accumulated patents	(0.009)	(0.008)	(0.006)	(0.006)	(0.006)	(0.006)
Total citations received by	0.140***	-0.217***	-0.087*	0.005	0.118***	-0.387***
the patent[a]	(0.036)	(0.046)	(0.042)	(0.050)	(0.034)	(0.058)
Average number of citations received by the cited patents that are[a]:						
less than 1 year old	0.906***	0.771***	0.723***	0.626***	0.678***	1.015***
	(0.219)	(0.202)	(0.169)	(0.150)	(0.140)	(0.160)
between 1 and 2 years old	0.022	-0.014	-0.056	-0.051*	-0.035	0.030
	(0.057)	(0.047)	(0.035)	(0.031)	(0.028)	(0.026)
between 2 and 3 years old	-0.107***	-0.137***	-0.123***	-0.139***	-0.170***	NA
	(0.033)	(0.027)	(0.023)	(0.022)	(0.022)	
between 3 and 4 years old	-0.139***	-0.151***	-0.149***	-0.179***	NA	NA
	(0.026)	(0.022)	(0.020)	(0.019)		

(continues)

Table 5: continued.

The dependent variable is the incumbent/entrant index, which equals 1 if the patent was awarded to an incumbent, and zero if it was awarded to an entrant.						
Regressors	Winner is an entrant if youngest own citations is older than:					
and regression statistics	20 years	10 years	5 years	4 years	3 years	2 years
(continued)						
Average number of citations received by the cited patents that are[a]:						
between 4 and 5 years old	-0.187***	-0.210***	-0.240***	NA	NA	NA
	(0.027)	(0.023)	(0.024)			
between 5 and 10 years old	-0.328***	-0.389***	NA	NA	NA	NA
	(0.026)	(0.025)				
between 10 and 20 years old	-0.634***	NA	NA	NA	NA	NA
	(0.050)					
Year dummies[b]	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	5,143	5,119	4,965	4,871	4,726	4,514
Likelihood ratio $(\chi^2)^c$	5,887.93	5,569.17	4779.44	4,380.99	3,853.60	2,973.80
P-value	0.000	0.000	0.000	0.000	0.000	0.000
Pseudo R^2	0.826	0.785	0.707	0.678	0.655	0.642
BRMR test of Heteroskedasticity $(\chi^2)^d$	0.31	0.93	0.90	0.57	0.37	0.73
P-value	0.999	0.996	0.989	0.989	0.985	0.867
Proportion of entrant won patents in full sample[e]	0.651	0.670	0.738	0.772	0.821	0.893
Proportion of entrant won patents in estimation sample	0.492	0.509	0.579	0.622	0.686	0.790

The sample includes all patents awarded between 1975 and 1999 in the US that are found in the NBER Patent Citations Data Files, in the technological category 3 (Drugs and Medical), subcategories 31,33 and 39, for which the assignee is found in COMPUSTAT. The estimates are obtained by maximum likelihood, from a logit regression of the probability that the winner of the race is an incumbent, on the regressors shown above. Estimates of the standard errors are shown below the parameter estimate, in parenthesis. Those followed by *** are significant to the 0.01 level, by ** to the 0.05 level, and by * to the 0.1 level.

[a] All counts of number of citations are re-scaled by the factors provided by Hall, et al., (2002).

[b] A dummy for 24 of the 25 years in the sample. Equals one when the observation corresponds to that year.

[c] The null hypothesis is that all the parameters in the model are equal to zero.

[d] The null hypothesis is that the model is homoskedastic. The model for hesteroskedasticity specifies the variance of the logit error term as an exponential function of the citations received by the patent and by the average of its cited patents of different ages.

[e] The total number of patents in the sample before the match with COMPUSTAT is 91,656.

Table 6: Marginal Effects of Explanatory Variables on the Probability that the Incumbent Wins and their Economic Significance

All estimates using the results reported in Table 5.
All estimates are computed at the sample median of all variables, unless noted.

Variables	Cash measure lagged two years[1]			Cash measure lagged three years[1]		
	Winner is an entrant if youngest own citations is older than:					
	20 years	10 years	5 years	20 years	10 years	5 years
Incumbent's cash / assets[1]	0.808e-3	0.829e-3	0.614e-3	0.753e-3	0.781e-3	0.483e-3
$\Delta P_{(1\rightarrow 9)}$ [a]	0.5181	0.5426	0.4497	0.4767	0.4977	0.3588
Entrants' cash /assets[1]	-0.209e-2	-0.198e-2	-0.148e-2	-0.214e-2	-0.205e-2	-0.128e-2
$\Delta P_{(1\rightarrow 9)}$	-0.3966	-0.3882	-0.3333	-0.3782	-0.3879	-0.2903
Incumbent's average accumulated patents	0.002	0.002	0.002	0.002	0.002	0.002
Entrant's average accumulated patents	-0.032	-0.031	-0.023	-0.021	-0.026	-0.024
Total citations received by the patent[b]	0.034	0.029	0.001	0.025	0.027	0.002
Average number of citations received by the cited patents that are[b]:						
less than 1 year old	0.220	0.187	0.152	0.155	0.139	0.205
between 1 and 2 years old	0.005	-0.003	-0.012	0.003	-0.001	-0.013
between 2 and 3 years old	-0.026	-0.033	-0.026	-0.021	-0.032	-0.034
between 3 and 4 years old	-0.220	-0.037	-0.031	-0.022	-0.031	-0.035
between 4 and 5 years old	-0.034	-0.051	-0.050	-0.030	-0.043	-0.055
between 5 and 10 years old	-0.045	-0.094	NA	-0.051	-0.087	NA
between 10 and 20 years old	-0.080	NA	NA	-0.104	NA	NA

The sample includes all patents awarded between 1975 and 1999 in the US that are found in the NBER Patent Citations Data Files, in the technological category 3 (Drugs and Medical), subcategories 31,33 and 39, for which the assignee is found in COMPUSTAT.

[a] $\Delta P_{(1\rightarrow 9)}$ is the predicted average difference between the probability that the incumbent wins when the incumbent's or the entrant's cash/assets correspond to the 9th and the 1st decile of their distributions.

[b] All counts of number of citations are re-scaled by the factors provided by Hall, et al., (2002).

Table 7: Parameter Estimates for Logit Regressions of the Probability that the Winner is an Incumbent on Incumbent's and Entrants' Measures of Financial Resources (II)

The dependent variable is the incumbent/entrant index, which equals 1 if the patent was awarded to an incumbent, and zero if it was awarded to an entrant.

Regressors	Cash measure lagged two years[1]			Cash measure lagged three years[1]		
	Winner is an entrant if youngest own citations is older than:					
	20 years	10 years	5 years	20 years	10 years	5 years
Incumbent's cash, divided by	17.540***	18.104***	15.649***	16.305***	15.740***	12.372***
total assets[1]	(1.274)	(1.086)	(0.937)	(1.156)	(1.011)	(0.867)
Incumbent's cash interacted	-2.224**	-2.251***	-2.176***	-2.414***	-1.862***	-1.400***
with the number of citations	(0.958)	(0.547)	(0.341)	(0.429)	(0.375)	(0.329)
Entrant's cash, divided by	-18.905***	-19.657***	-18.486***	-19.408***	-19.561***	-17.984***
total assets[1];	(1.375)	(1.037)	(1.607)	(1.204)	(1.012)	(0.905)
Entrant's cash interacted	0.384	1.109**	1.040***	1.041*	1.040***	1.181***
with the number of citations	(1.164)	(0.455)	(0.264)	(0.580)	(0.355)	(0.304)
Incumbent's total assets	0.138***	0.101***	0.014	-0.056***	0.032	0.104***
($ Million)[1]	(0.022)	(0.022)	(0.019)	(0.018)	(0.022)	(0.024)
Entrants' total assets	-1.212***	-1.263***	-1.204***	-1.322***	-1.334***	-1.288***
($ Million)[1]	(0.073)	(0.066)	(0.057)	(0.058)	(0.067)	(0.076)
Incumbent's average	0.404e-2***	0.482e-2***	0.471e-2***	0.409e-2***	0.456e-2***	0.427e-2***
accumulated patents	(0.046e-2)	(0.040e-2)	(0.036e-2)	(0.042e-2)	(0.036e-2)	(0.032e-2)
Entrant's average	-0.179e-3***	-0.105e-3***	0.008e-3	-0.179e-3***	-0.087e-3*	0.039e-3
accumulated patents	(0.063e-3)	(0.055e-3)	(0.050e-3)	(0.056e-3)	(0.048e-3)	(0.042e-3)
Total citations received by	0.727***	-0.489***	0.209***	0.683***	0.121***	0.140**
the patent[a]	(0.147)	(0.081)	(0.054)	(0.094)	(0.034)	(0.055)
Average number of citations received by the cited patents that are[a]:						
less than 1 year old	1.074***	0.715***	0.706***	1.068***	0.664***	0.740***
	(0.180)	(0.145)	(0.120)	(0.172)	(0.145)	(0.127)
between 1 and 2 years old	0.077	0.030	0.024	0.035	0.026	0.006
	(0.051)	(0.036)	(0.028)	(0.048)	(0.036)	(0.028)
between 2 and 3 years old	-0.076***	-0.110***	-0.081***	-0.086***	-0.122***	-0.110***
	(0.028)	(0.022)	(0.020)	(0.025)	(0.020)	(0.019)

(continues)

Table 7: continued.

Panel A: the dependent variable is the incumbent/entrant index, which equals 1 if the patent was awarded to an incumbent, and zero if it was awarded to an entrant.						
	Cash measure lagged two years[1]			Cash measure lagged three years[1]		
Regressors	Winner is an entrant if youngest own citations is older than:					
and regression statistics	20 years	10 years	5 years	20 years	10 years	5 years
Average number of citations received by the cited patents that are[a]:						
between 3 and 4 years old	-0.080***	-0.103***	-0.105***	-0.106***	-0.077***	-0.108***
	(0.021)	(0.018)	(0.017)	(0.018)	(0.020)	(0.017)
between 4 and 5 years old	-0.134***	-0.186***	-0.249***	-0.129***	-0.172***	-0.234***
	(0.023)	(0.022)	(0.022)	(0.021)	(0.020)	(0.021)
between 5 and 10 years old	-0.328***	-0.382***	NA	-0.349***	-0.383***	NA
	(0.022)	(0.020)		(0.022)	(0.020)	
between 10 and 20 years old	-0.907***	NA	NA	-0.836***	NA	NA
	(0.050)			(0.045)		
Year dummies[b]	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	5,143	5,119	4,965	5,431	5,400	5,245
Likelihood Ratio (χ^2)[c]	4,807.11	4,073.30	3,160.69	5,111.88	4,375.59	3,417.10
P-value	0.000	0.000	0.000	0.000	0.000	0.000
Pseudo R^2	0.674	0.574	0.467	0.679	0.796	0.480
BRMR test of Heteroskedasticity (χ^2)[d]	1.48	0.60	0.68	1.33	1.83	0.74
P-value	0.993	0.999	0.995	0.995	0.969	0.994
Proportion of entrant won patents in full sample[e]	0.651	0.670	0.738	0.651	0.670	0.738
Proportion of entrant won patents in estimation sample	0.492	0.509	0.579	0.493	0.513	0.584

Panel B: estimates of marginal effects. All estimates are computed at the sample median of all variables, unless noted.						
	[1]Lagged two years			[1]Lagged three years		
Variables	Winner is an entrant if youngest own citations is older than:					
	20 years	10 years	5 years	20 years	10 years	5 years
Incumbent's cash / assets[1]	0.100e-2	0.101e-2	0.079e-2	0.648e-3	0.904e-3	0.561e-3
$\Delta P_{(1\to 9)}$	0.5894	0.6005	0.5156	0.4048	0.5385	0.4025
Entrants' cash / assets[1]	-0.120e-2	-0.118e-2	-0.099e-2	-0.085e-2	-0.120e-2	-0.086e-2
$\Delta P_{(1\to 9)}$	0.6211	0.6195	0.5994	0.458	0.6145	0.5629

Notes: same as Table 5.

$\Delta P_{(1\to 9)}$ is the predicted average difference between the probability that the incumbent wins when the incumbent's or the entrant's cash/assets correspond to the 9th and the 1st decile of their distributions.