DISCUSSION PAPER SERIES

No. 8147

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ISSN 0265-8003

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Discussion Paper No. 8147
December 2010

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CEPR Discussion Paper No. 8147

December 2010

ABSTRACT

And the Winner Is--Acquired: Entrepreneurship as a Contest with Acquisition as the Prize

R&D incentives of new entrants to a market may be shaped by the prospects of being acquired by an incumbent. In this paper, we analyze a two-stage innovation game between one incumbent and a large number of entrants. In the first stage, firms compete to develop innovations of high quality. They do so by choosing, at equal cost, the success probability of their R&D approach, where a lower probability goes along with a higher value in case of success—that is, a more radical innovation. In the second stage, successful entrants bid to be acquired by the incumbent. We assume that entrants cannot survive on their own, so being acquired amounts to a 'prize' in a contest. We identify an equilibrium in which the incumbent chooses the least radical project. Entrants pick projects of pairwise different success probabilities, and the larger the number of entrants, the more radical the most radical project becomes. Under certain conditions, we can show uniqueness of this equilibrium and robustness to changes in the timing of the game. Generally, entrants tend to choose more radical R&D approaches than the incumbent and are more likely to generate the highest value innovation. Thus, the need of entrants to be acquired yields yet another explanation, beyond cannibalization and organizational issues, of why radical innovations tend to come from entrants rather than from incumbents. We illustrate our theoretical findings by a qualitative empirical study of the Electronic Design Automation Industry, and derive implications for research and management.

JEL Classification: L13, L26, L86 and O31
Keywords: entrepreneurship and innovation

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Submitted 23 November 2010

1. Introduction

Firms differ in their ability to innovate. In particular, as numerous empirical studies found (e.g., Baumol 2004, Scherer and Ross 1990), new entrants to an industry are more likely to create breakthroughs, while incumbent firms are more prone to generate incremental innovations. Why is this? To the extent that the answer lies in myopia or organizational rigidities of established firms (Freeman et al. 1983, Hannan and Freeman 1977, Stinchcombe 1965), it makes sense for managers to try and emulate the strengths of new entrants. Internal corporate venturing—enabling entrepreneurship within the corporation—is an important approach in this direction (e.g., Block and MacMillan 1993, Miles and Covin 2002, Sykes and Block 1989). However, if the answer is rather that pursuing incremental innovations is economically rational for incumbents, and aiming at radical innovations optimal for entrants, then the normative implications are different. In this case, corporate venture capital—the investment in externally originated new ventures (e.g. Dushnitsky and Lenox 2005, Gompers and Lerner 2009, Miles and Covin 2002)—or the outright acquisition of such start-ups may provide solutions.

Various theoretical studies (in particular, Reinganum 1983) have analyzed incumbents' and entrants' economic incentives for innovation, by and large confirming the empirical findings mentioned above. An important distinction is in place, however, with respect to how entrants compete with incumbents. Early models assumed product market competition (Arrow 1962, Gilbert and Newbury 1982, Reinganum 1983). However, a cooperative agreement between an entrant and an incumbent should, in general, be superior, both because of increased market power (e.g., Gans and Stern 2000) and because entrants typically lack the broad resource base of incumbents. Hence, a more recent theoretical study allows for a successful entrant to be acquired by (or to license its invention to) one incumbent (Gans and Stern 2000).

Our paper contributes to this stream of the literature. However, our approach differs in two respects from earlier work. First, we note that in many industries the number of aspiring start-ups is, for each technological innovation, higher than the number of incumbents that could potentially acquire them. If this is the case, and if each incumbent buys at most one start-up for each innovative technology, then the start-ups will compete to be acquired. Second, with the notable exception of Färnstrand Damsgaard et al. (2009), all previous studies choose innovation effort as the players' choice variable. However, given the limited financial resources of entrants, effort in the sense of budget spent is likely not the most relevant lever for new firms to determine the quality of their innovations. In fact, capital requirements in early phases of R&D projects are relatively modest in many industries, among them software and biotechnology. Instead, it appears plausible that entrants distinguish themselves from incumbents by choosing R&D approaches of lower success probability and concomitant higher value in case of success. Thus, entrants may achieve more radical innovations—where "radical" refers to the value of the innovation in case of success—not by spending larger budgets, but by pursuing more novel (and hence riskier) approaches.

In our model, we consider an industry consisting of one incumbent and N entrants. The firms conduct R&D with the aim to develop an innovation at a fixed cost normalized to zero. Only the incumbent can commercialize an innovation, so the entrants' goal is to be acquired. Firms' choice variable is the success probability of their R&D projects, with projects of lower success probability having a higher value in case of success. A "value function" links this value to a project's success probability. In the first stage of the game, firms select their projects; in the second stage, after the outcomes of the projects are realized, the entrants compete for being acquired by the incumbent.

Central results of our analysis are the following. There always exists an equilibrium in which all entrants choose more radical R&D projects than the incumbent—i.e., projects of lower success probability and, in case of success, higher value. In this equilibrium, all entrants choose pairwise different strategies; competition between entrants drives the "radicalness" of their innovation in the sense that a larger number of entrants leads to an increase in the value, in case of success, of the most radical innovation project. In turn, no equilibrium exists in which the incumbent chooses the most radical project. Furthermore, for a specific value function we show that the equilibrium in which the incumbent chooses the least radical project is unique. For sequential moves, we can show under certain conditions that the same equilibrium outcome obtains as in the simultaneous game. We thus obtain the rather robust result that, overall, entrants pursue more radical innovations than the incumbent.

We then illustrate and support our analysis by a qualitative empirical study of the electronic design automation (EDA) industry. This industry, developing software tools for the automated design of computer chips, consists of three large incumbents and numerous start-ups. It features those characteristics that we assume in our model—start-ups that compete in R&D with each other and with incumbents, and that need to be acquired by the latter if they are successful—and shows outcomes that are predicted by our theoretical analysis, in particular, start-ups that go for R&D projects with lower success probability and higher value in case of success. This empirical study confirms that our model is not only theoretically plausible but also practically relevant.

Our results of entrants originating more radical innovations appear familiar from the literature, yet are based on a fundamentally different mechanism than similar findings in earlier studies. In our model, the fact that entrants take more radical innovation approaches derives from the assumptions that (a) firms choose innovation projects characterized by success probability (rather than effort), and (b) entrants, if successful, need to be acquired in order to commercialize their innovation. No cannibalization effect (Arrow 1962) or organizational rigidities (Freeman et al. 1983, Hannan and Freeman 1977, Stinchcombe 1965) on the side of the incumbent are assumed. Our model also makes predictions that differ from those of established models—in particular, that entrants choose pairwise distinct strategies and that the expected value of the most successful innovation increases with the number of entrants. More generally, our approach suggests that the structure of the respective market for technology plays an important role in explaining the above stylized facts in the innovation and entrepreneurship literatures.

The remainder of the paper is structured as follows. In the following section, we review the relevant literature. In Section 3, we introduce and analyze the model. Next, we illustrate this analysis by a qualitative empirical study of the EDA industry. In the final section, we summarize and discuss our findings and conclude.

2. Literature Review

There is broad evidence from a number of high-technology industries that acquisitions of small, innovative target firms frequently pursue the goal of gaining technology access and of preempting technology competition (Bloningen and Taylor 2000, Grimpe and Hussinger 2008a, b, Hall 1990, Lehto and Lehtoranta 2006, Lerner and Merges 1998).[1] In line with our analysis, Grandstrand and Sjölander (1990) show that start-ups' innovation is more radical than that of incumbents, and they suggest a division of scientific labor between entrants and incumbents that establishes their roles as targets and acquirers. This view is also supported by Lindholm (1996) who shows that small firms take active steps to increase their odds of being acquired. A weak position in complementary assets on the side of the entrant increases the gains from trade of technology, and well-established intellectual property rights and involvement of professional intermediaries are found to increase the likelihood that these gains are realized by the entrant and the incumbent (Gans et al. 2002, Hsu 2006).

R&D competition between entrants and incumbents in the shadow of acquisition (or, technology licensing) was first analyzed theoretically by Gans and Stern (2000). They model in detail the negotiations between an incumbent and an entrant over an innovation and show how the acquisition price depends crucially on the strength of intellectual property protection and on the possibility of the entrant to market the technology. This, in turn, determines the two firms' payoff from and incentives to do R&D. Compared to Gans and Stern (2000), we focus less on the subtleties involved in technology bargaining and assume a simple, competitive market for technology. This allows us to set up a tractable model where the *type* of R&D project chosen by the incumbent and multiple entrants can be analyzed.

Our paper is also related to the well-established literature that studies the choice of the "risk-return" profile of R&D projects, either in terms of the success probability, the variance in the return, or the

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[1] It should be noted, though, that Desyllas and Hughes (2008) attribute less importance to innovation-related variables, finding that from a target perspective they contribute little to explaining acquisition by a large firm.

correlation to competitors' R&D projects. This approach has, for example, been used to study the clustering of firms in geographical and product space (Gerlach et al. 2005, 2009), the efficiency of the portfolio of R&D projects in a competitive market (Bhattacharya and Mookherjee 1986, Dasgupta and Maskin 1987), the optimal selection of R&D projects (Ali et al. 1993, Cabral 1993), and the persistence of market dominance (Cabral 2002). Closest to our setup, Färnstrand Damsgaard et al. (2009) consider the choice of success probability by an entrant and an incumbent firm. They show that if the entrant incurs a higher cost of commercializing an innovation than the incumbent, then this induces the entrant to pursue a more radical R&D project.

3. The Model

3.1. Setup

We consider an industry consisting of one incumbent firm (I) and $N \geq 1$ entrants. All firms conduct R&D with the aim to develop a product for a new market segment. Only the incumbent can market an innovation, so the entrants' goal is to be acquired by the incumbent. Firms choose an R&D project from a given set of combinations of success probabilities and values in case of success. To keep the analysis tractable and in line with our motivation, we focus on success probability as the only choice variable rather than also including the level of R&D investment. That is, costs are identical for all firms and normalized to zero.

We assume that firm i (i = I, 1,…, N) chooses a project characterized by a success probability p_i from [0,1]. A successful project results in an innovation of value $\pi(p_i)$ if it is commercialized by the incumbent. If a project is not successful, its value is zero. We call $\pi(\cdot)$ the "value function" and assume it is differentiable and strictly decreasing. Furthermore, we assume that (i) $p\pi(p)$ is concave and (ii) $p\pi(p)$ takes on a maximum at some $\tilde{p}$, $\tilde{p} \in (0,1)$. For a given set of success probabilities $p_I, p_1, \ldots, p_N$, let Π_i denote player i's expected payoff. Notice that all firms are assumed to have the same R&D possibilities. Hence, if the incumbent and the entrant make different R&D choices, it is not due to intrinsic differences in their R&D capabilities. The expected value of the most valuable innovation, denoted by E[V_{max}], is a function of the N+1 success probabilities chosen by the incumbent and the entrants. We assume that E[V_{max}] is strictly concave such that there exists an unique combination of success probabilities (modulo symmetry among the firms) maximizing E[V_{max}].

We employ the value function of $\pi(p) = 1 - p$ in order to illustrate our results. This function fulfills the requirements defined above, with $p\,\pi(p)$ and E[V_{max}] being concave, and $p\,\pi(p)$ assuming its maximum at $\tilde{p} = 0.5$. For this specific case, we can furthermore prove several uniqueness results that are elusive for the general case.

We study two different timing structures with either simultaneous or sequential moves. In the simultaneous move game, all firms take R&D decisions in Stage 1. In the sequential move games, firms take these decisions sequentially in Stage 1 to Stage (N+1), with full information in each stage about all earlier moves. Upon choice of R&D decisions, Nature moves and R&D outcomes are realized. In the final stage—Stage 2 in the simultaneous game, Stage $N+2$ in the sequential game—the incumbent may acquire an entrant. In the acquisition stage, the entrants simultaneously make price offers to the incumbent, who either uses its own project or accepts the best offer.[2] Alternatively, the acquisition can be thought of as

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[2] When the incumbent negotiates with the most successful entrant, its threat point, or (maximum) willingness to pay, is the difference in value between the best and the second best project. This is also the negotiable surplus since the entrant's (minimum) willingness to receive is zero. Our approach to modeling the negotiation allocates all negotiation power to the entrant in the bilateral bargaining in the sense that it can capture the incumbent's willingness to pay completely. Notice that this does not imply that the incumbent is left with no gains from trade: if there is more than one entrant, the competition among the entrants implies the incumbent can appropriate a surplus corresponding to the value of the second best project. More generally, the allocation of the bargaining power is less critical in our framework since we do not study entrants' nor incumbent's investments into R&D (as, e.g., Gans and Stern 2000)—which obviously are strongly affected by the surplus sharing rule—but rather their choice of success probabilities.

involving only the entrant's innovation, not the entire firm. To keep the model solvable, we assume that the acquisition happens in a single step, without staged investments or toehold purchases. Finally—not modeled explicitly—products are sold and profits in the market are realized.

3.2. Simultaneous Moves

In this subsection, we prove existence of an equilibrium in which the incumbent picks the least radical project, show that this equilibrium is constrained welfare optimal, prove nonexistence of equilibria in which the incumbent chooses the most radical project, and for the specific value function of $\pi(p) = 1 - p$, show that the above mentioned equilibrium is unique. We conjecture that this is true more generally.

We solve the game backward by looking at the acquisition stage first. The incumbent acquires one entrant at most, as it can only use the technology of one of the entrants. We denote the value of firm i's realized R&D outcome by π_i , $\pi_i \in \{0, \pi(p_i)\}$.

Lemma 1. *(i) If two or more entrants have higher realized R&D values than the incumbent, then the incumbent acquires the start-up with the highest realized value (j) at a price of ($\pi_j - \pi_k$), where k is the entrant with the second-highest realized value.*
(ii) If only one entrant (j) has a higher realized value than the incumbent, then the incumbent acquires this entrant at a price of ($\pi_j - \pi_I$).
(iii) If no entrant has a higher realized value than the incumbent, then the incumbent makes no acquisition.

Proof: Follows from standard Bertrand competition logic.

We now turn to the R&D stage. All proofs are relegated to the Appendix.

Lemma 2. *There is no equilibrium in pure strategies in which two or more firms choose the same success probability.*

Having established that firms play asymmetric strategies in equilibrium, we are ready to present the main result of the theoretical analysis.

Proposition 1. *(i) There exists an equilibrium in pure strategies in which the incumbent chooses a project with higher success probability than all entrants and the entrants choose projects of pairwise different success probabilities. Renumbering the entrants, the success probabilities satisfy $p_I > p_1 > \ldots > p_N$. This is the unique equilibrium (modulo symmetry among the entrants) for which $p_I > p_k$ for all entrants k.*

(ii) In this equilibrium, the incumbent chooses $p_I = \tilde{p}$.

(iii) For $N \geq k$ the equilibrium value of p_k is independent of N.

(iv) Expected payoffs are highest for the incumbent. For the entrants, they decrease with k. That is, $\Pi_I > \Pi_1 > \ldots > \Pi_N$.

Proposition 1 has important implications. First, in this equilibrium, all entrants aim for more radical innovations than the incumbent. This finding is in line with observations from the EDA industry as well as with established results from the literature. Note, however, that it is not based on the cannibalization effect as the incumbent is not present initially in the market segment considered. Instead, it derives solely from the fact that the incumbent, but not the entrants, is able to market the innovation at hand. This makes a difference, because the incumbent has less incentive than the entrants to pursue a project of high quality but low success probability. In particular, unlike the entrants, the incumbent also benefits from having the second best project in the market, as it improves the bargaining position when negotiating with the entrant that developed the highest quality project. The entrants, on the other hand, are in a different situation as they only make profits by being acquired if they have developed the highest quality project. This creates a strong incentive for them to pursue a project of high quality but low success probability in order to have the best project among the successful ones. The equilibrium outcome where the incumbent pursues a less radical project than all entrants thus reflects the difference in the value of being second best in the market.

Second, the value, in case of success, of the respective most radical innovation project increases with the number of entrants. That is, increasing the number of entrants not only leads to a higher probability that some innovator will succeed at all but also pushes the limit of the highest attainable innovation value.

Third, the equilibrium identified in Proposition 1—and any potential other equilibrium—are characterized by pairwise different stage-one actions of the players. Given *ex ante* symmetry between all entrants, this is a nontrivial finding. This result further supports the preceding point that a larger number of market participants not only increases the probability that some firm will succeed, but also leads to a larger variety in terms of risk levels, and hence project values, that are pursued.

Fourth, the incumbent does not change the success probability level of its R&D projects in the face of market entry. This finding contrasts in an interesting way with results by Gans and Stern (2000), who show that an incumbent behaves differently (invests less) in the face of entry—anticipating the opportunity to acquire a successful entrant—than a monopolist.

Fifth, part (*iii*) and *(iv)* of the proposition show that as the number of entrants increases, there are entrants pursuing more and more radical and less and less profitable R&D projects. As the competition among entrants intensifies, the best response for these firms is, thus, to "gamble" by pursuing a radical R&D project with a high upside but a low success probability.

As an illustration, consider the value function of $\pi(p) = 1 - p$. This function fulfills the requirements defined above, with $p\,\pi(p)$ being concave and assuming its maximum at $\tilde{p} = 0.5$. Independent of N, equilibrium actions for the incumbent and entrants 1 to 4 are, respectively, $p_I = 0.5$, $p_1 = 3/8 = 0.375$, $p_2 = 39/128 \approx 0.305$, $p_3 \approx 0.274$, and $p_4 \approx 0.225$. Expected profits, of course, depend on the number of entrants. Without entry, the incumbent's expected profit equals $\Pi_I = 0.25$. With one entrant, the incumbent's expected payoff remains unchanged, while for the entrant, $\Pi_1 \approx 0.141$. With two entrants, the incumbent benefits when both are successful and subsequently compete for being acquired. As a result, Π_I increases to approximately 0.293, while the entrants anticipate expected profits of $\Pi_1 \approx 0.098$ and $\Pi_2 \approx 0.093$, respectively. Figure 1 illustrates the firms' payoffs when deviating from equilibrium for the case of $N = 2$. Note that the payoff functions are kinked, but continuous, where the focal firm's success probability equals the (equilibrium) value of one of the two other firms (with the exception of $\Pi_{Inc}(p)$, which is differentiable at $p = p_2^*$).

--- Insert Figure 1 about here ---

The following proposition addresses welfare aspects.

Proposition 2. *For a given number N of entrants, the choices of success probability levels in the equilibrium characterized in Proposition 1 are welfare maximizing.*

Proposition 2 shows that equilibrium actions remain unchanged also if, given the number of entrants, the goal of individual profit maximization is replaced by the objective of welfare maximization. Hence, in a market that fits our model assumptions, there is no market failure with respect to the type (i.e., success level) of innovation that entrants pursue.[3] The intuition behind this somewhat surprising result is the following: the value of a successful project to entrant *i* is $Max\{0, \pi(p_i) - \pi_2\}$, where π_2 is the value of the

[3] Using the same type of R&D technology as in this paper, Gerlach et al. (2009) develop a symmetric duopoly model to analyze labor pooling in high-technology industries. They show that clustering induces firms to choose a more efficient portfolio of R&D projects at the industry level because of increased labor market competition, a result similar to Proposition 2.

second best project. This corresponds exactly to the social value of the project, which explains why the entrants make the welfare maximizing R&D decisions. In the equilibrium considered, the incumbent's project only adds value if it is the only successful project, i.e., the social value is $p_I \pi(p_I) \prod_{m=1}^{N} (1 - p_m)$.

While the incumbent's private value of the R&D project does not coincide with the social value, we show in the proof of Proposition 1 that the incumbent chooses the success probability so as to maximize $p_I \pi(p_I)$. The first-order conditions of the incumbent and of a hypothetical social planner do, therefore, coincide when choosing p_I.

Regarding the number of firms that enter in a free-entry equilibrium, assuming a fixed cost of entering, welfare optimality crucially depends on the role played by the marginal entrant. If the marginal entrant is the one choosing the lowest success probability in equilibrium, the profit of the entrant corresponds exactly to the social value that it creates. The equilibrium is then also welfare maximizing in terms of the number of active firms. However, if the expected profit of the marginal entrant is greater than this—for example, equal to the average profit among the entrants—then the equilibrium is characterized by excessive entry.

Proposition 1 is in line with the empirical observation that entrants tend to pursue innovation projects of lower success probability but higher value in case of success than incumbents. This interpretation would be moot if equilibria with any other order of success probability levels also existed, in particular with the incumbent choosing the highest risk project ($p_1 > \ldots > p_N > p_I$). The following proposition shows that the latter type of equilibrium can be excluded.

Proposition 3. *There is no equilibrium in pure strategies in which the incumbent chooses a project with lower success probability than all entrants.*

The next logical step would be to formulate and prove a proposition about existence or nonexistence of equilibria in which the incumbent chooses some intermediate risk level, that is, with $p_1 > \ldots > p_I > \ldots >$

p_N. We conjecture that no such equilibria exist, but we cannot prove it in full generality. However, we can prove the statement for the specific value function introduced above, $\pi(p) = 1 - p$, and for the cases of $N = 2$, $N = 3$.[4]

Proposition 4. *Let the value function be given by $\pi(p) = 1 - p$. Then, (i) for $N = 2$ there is no equilibrium in pure strategies in which $p_1 > p_I > p_2$. The unique equilibrium is characterized by $p_I = 0.5$, $p_1 = 0.375$, and $p_2 \approx 0.305$.*

(ii) For $N = 3$ there is no equilibrium in pure strategies in which $p_1 > p_I > p_2 > p_3$, and no equilibrium in which $p_1 > p_2 > p_I > p_3$. The unique equilibrium is characterized by $p_I = 0.5$, $p_1 = 0.375$, $p_2 \approx 0.305$, and $p_3 \approx 0.274$.

Proposition 3 establishes, for the case of general $\pi(p)$ and N, that in equilibrium the incumbent never chooses the highest risk project. For the specific case of $\pi(p) = 1 - p$ and $N \leq 3$, Proposition 4 shows that the incumbent always chooses the project with lowest risk—and we conjecture that this also holds true in the general case. Overall, thus, the mere definition of entrants as firms that need to be acquired in order to commercialize their innovation generates the result that entrants focus on riskier, but in the case of success, more valuable or more radical projects.

3.3. Sequential Moves

Real-world R&D decisions are often best modeled as simultaneous moves as done above, since it is plausible that firms have to make irreversible R&D decisions before observing their competitors' choices. Notwithstanding this, there may exist situations in which firms discover market opportunities at rather

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[4] We are confident that, for this value function, the conjecture can also be proved for higher N. However, the calculations become increasingly complex due to higher order polynomials. Furthermore, and more importantly, proving the conjecture for $N = 4$ (or 5, 6) still does not establish its validity for general N.

different points in time such that the R&D choices of early movers become observable to followers before the latter make their own R&D decisions. In the analysis of the sequential-move game, we restrict ourselves to $N = 2$. First, a game is analyzed where the incumbent moves first, then entrant 1, and finally entrant 2. A general value function is assumed here. Afterward, we consider all possible orders of moves for the value function $\pi(p) = 1 - p$. All proofs of the results in Section 3.3 are available from the authors upon request.

Turning to the first part of the analysis, the following lemma describes the equilibria of the subgames starting after the incumbent has chosen its success probability.

Lemma 2. *Consider the Nash equilibria of the subgames starting after the incumbent has chosen* p_I. *Then, (i) entrant 1 chooses the success probability that maximizes the welfare resulting from the innovations of the incumbent and of entrant 1 conditional on* p_I; *(ii) entrant 2 chooses the success probability that maximizes the welfare resulting from the innovations of all firms conditional on* p_I *and* p_1.

The profit of entrant 2 coincides with the social value of its innovation, as discussed above, which leads it to take the welfare maximizing R&D decision. Entrant 1 has to consider the reaction of entrant 2 when deciding on its R&D project. It is optimal for entrant 1 to choose a profitable R&D project with high success probability, and it foresees that entrant 2 will choose a more radical R&D project with lower success probability. Hence, entrant 1 will only make a profit if entrant 2 fails. Ideally, entrant 1 would like to pick a project that maximizes entrant 1's expected profit when entrant 2 fails and minimizes the success probability that entrant 2 chooses. It turns out that there is no conflict between these two objectives. By choosing the welfare maximizing success probability conditional on p_I, entrant 1 maximizes its expected profit when entrant 2 fails and maximizes the competitive pressure that entrant 2 experiences, thereby pushing entrant 2 to choose a more radical R&D project with a low success probability.

We define the success probabilities $\hat{p}_1$ and $\hat{p}_2$ by $\hat{p}_1\pi'(\hat{p}_1)+\pi(\hat{p}_1)=p_I\pi(p_I)$ and $\hat{p}_2\pi'(\hat{p}_2)+\pi(\hat{p}_2)=\hat{p}_1\pi(\hat{p}_1)+(1-\hat{p}_1)p_I\pi(p_I)$, respectively. Furthermore, we define $\overline{p}_I$ implicitly by $p_I\pi(p_I)+(1-p_I)\widetilde{p}\pi(\widetilde{p})=\hat{p}_1\pi(\hat{p}_1)+(1-\hat{p}_1)p_I\pi(p_I)$. With these definitions, we can put down:

Proposition 5. *The equilibrium success probabilities of the sequential-move game with the order of moves given by I, 1, 2 coincide with those of the simultaneous-move game if the following condition holds for all* $p_I \leq \overline{p}_I$*:*

$$\left.\frac{d^2\left(p\pi(p)\right)}{dp^2}\right|_{p=\hat{p}_2} \leq -\frac{\left(1-\hat{p}_1\right)\left(\pi(\hat{p}_1)-p_I\pi(p_I)\right)}{1-\hat{p}_2}.$$

Expressed verbally, the condition requires that the function $p\pi(p)$ is sufficiently concave. For $\pi(p) = 1 - p$, e.g., it is fulfilled. The intuition behind Proposition 5 is the following. When choosing the success probability of its R&D project, the incumbent faces a trade-off. On the positive side, $p_I = \widetilde{p}$ maximizes the expected profit of the incumbent when one or none of the entrants succeed in developing an innovation, because the incumbent earns $p_I\pi(p_I)$ in these circumstances. At the same time, however, $p_I = \widetilde{p}$ maximizes the competitive pressure that the entrants face, and so minimizes the best response success probabilities of the entrants as well as the surplus that the incumbent can extract from the entrants' R&D activities. For both (counteracting) effects, the first-order condition is fulfilled at $p_I = \widetilde{p}$. One can show that, if the condition in Proposition 5 is fulfilled, the direct effect of p_I on the value of the incumbent's R&D project dominates the indirect effect on the entrants' R&D choices, such that the solution $p_I = \widetilde{p}$ to the first-order condition indeed corresponds to a maximum.

In the derivation of Proposition 5, we have assumed that the players are forward looking, following the logic of subgame perfection. Due to the recursive construction of the Nash equilibrium of the simultaneous-move game, myopic firms (i.e., firms that do not consider the effect of their choice on firms moving later in the game) would choose the same success probabilities in the sequential-move game as when moves are simultaneous.

For the case that not the incumbent, but one of the entrants moves first, one might expect that this firm moves closer to $\tilde{p}$ (which maximizes the expected project value). It might even pick a less radical project than the incumbent. Surprisingly, however, this does not seem to be the case. For $N = 1$ and a general profit function, the incumbent picks $\tilde{p}$ irrespective of the order of moves since its expected profit, $p_I \cdot \pi(p_I)$, is independent of p_1. Hence, the entrant will pick its best response to $p_I = \tilde{p}$ even if it moves first. While a general proof is elusive, numerical simulations for $\pi(p) = 1 - p$, $N = 2$, show robustness of the simultaneous-move outcome when players move sequentially:[5]

Conjecture 1. *Let the value function be given by $\pi(p) = 1 - p$ and let $N = 2$. Then, the players' equilibrium actions in a sequential game are identical to those in the simultaneous-move game, irrespective of the order of moves. That is, $p_I = 0.5$, $p_1 = 3/8 = 0.375$, $p_2 = 39/128 = 0.3046875$.*

The numerical analysis clearly supports this conjecture.[6] Within the numerical precision of 1e-8, the values of p_I, p_1, and p_2 that were determined in the respective final round of iterations are identical to

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[5] We refer to the result as a conjecture rather than a proposition as it relies on numerical simulations.

[6] For each order of moves, we numerically determine the approximate equilibrium values with eight different sets of starting values. In the first set, each variable varies between 0.01 and 0.99; in the later sets, these intervals are successively reduced in order to zoom in on the equilibrium values, with interval widths of 1.5e-6 in the final set. For each set, each of the three variables (p_1, p_2, p_I) takes on 1,000 equidistant values. The inner loop of the 10^9 iterations per set yields the best response of the last mover to the choices made by the first and the second mover; the middle loop, the best response of the second mover to the choice made by the first mover, taking the last mover's reaction into account; and the outer loop, the first mover's best strategy, taking the other players' reactions into account. A detailed account of the numerical analysis is available from the authors upon request.

those stated in Conjecture 1, no matter if the incumbent moves second or third (the case of I moving first is covered by Proposition 5). We conjecture, but cannot support at this point, that for larger N and other value functions, the equilibrium outcome also remains unchanged when the order of moves varies. But even restricted to the specific case, Conjecture 1 shows a surprising robustness of the result that the incumbent picks the least radical innovation project.

Notice that the analyses in this subsection point to a first-mover advantage for entrants. Given that the firms pick the same R&D projects as in the simultaneous-move game, Proposition 1 shows that entrant 1 earns higher expected profits than entrant 2.

4. Innovation and Acquisition in the EDA Industry

4.1. Industry Background

The EDA industry is a subsegment of the semiconductor industry, providing tools that support the (automated) design of integrated circuits. Historically hardware-based involving dedicated workstations for computer-aided design, it evolved into a software-based industry in the 1980s. EDA firms provide a large set of tools to aid chip designers in transforming an abstract logical representation of an integrated circuit into a structure that can be manufactured physically. These tools cover a complex process from chip design to testing. It can be subdivided in a number of subprocesses, each focused on one special aspect of design and design testing. The EDA industry is characterized by high industry concentration and by a larger number of small firms entering the industry every year that ultimately either are acquired by one of three large incumbents or go out of business. Sangiovanni-Vincentelli (2003) notes that over the last 30 years, the EDA industry has been characterized by three large firms with more than $500 million annual turnover and a large number of start-ups and young firms that has risen continuously to over 400 firms in 2003. The industry has historically grown on average 3% year on year. Each year, around 5% of the smaller firms exits the industry, partly through acquisition (Prabu 1995).

4.2. Interviews

Our qualitative empirical study is based on semi-structured interviews with industry experts and larger EDA companies. This approach has been applied in similar exploratory research settings and is also advocated methodologically (e.g., Miles and Huberman 1994). Through our interviews, we study whether or not start-ups, in particular those that are later acquired by large incumbent firms, pursue more radical innovations than incumbents. The questions in the interview guideline are partly derived from extant literature (Henderson 1993, Christensen and Bower 1996) and are partly based on our own knowledge of the industry and the phenomenon under study. In the interviews, we put a particular emphasis on entrants' and incumbents' relative innovation performance, the drivers of performance differentials, facts and figures regarding acquisitions of entrants by incumbents, and the reasons for these acquisitions, in particular those related to innovation. The interview guideline was adjusted as the research progressed to maximize the insights gained from the interviews. From December 2005 until January 2008, eight interviews with 10 interviewees were carried out with senior professionals and scientists who have detailed knowledge of the EDA industry. The list of interviewees comprises representatives from the two largest and from some smaller EDA firms, industry consultants, as well as academics from America and Europe. Each interview lasted between half an hour and two hours. Three interviews were carried out over the phone or by email, all others in person. Interviews were subsequently transcribed and the written material was then analyzed. Two interviews were conducted in German, so that interview quotes were translated to English.[7]

4.3. Drivers of Innovation in the EDA Industry

In the EDA industry, new requirements for innovation and improvement of technological products emerge on a regular basis. This need, identified from the interviews, is driven by two essential factors: the

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[7] Further details of each interview (date, duration, function of the interviewee, type of organization he or she is working with) are available from the authors upon request.

International Technology Roadmap for Semiconductors (ITRS) and the cumulative nature of technological change paired with the highly cyclical nature of the semiconductor industry (Levy 1994). For example, during the most severe downturn in 2000 to 2001, R&D expenditure in the industry significantly dropped and so far has not fully recovered. Semiconductor firms try to mitigate this reduction by strongly pushing suppliers, including those of EDA tools, to innovate in order to reduce cost. As a first stylized fact of the analysis, we put down that there are continuously increasing requirements for EDA tools and hence a permanent demand for innovation in the EDA industry.

4.4. Sources of Innovation in the EDA Industry

Each emerging innovation need in the EDA industry is usually addressed by several start-ups and the incumbents, which in parallel try to develop a solution to these needs. However, as we learned from our interviews, it turns out that incumbents often fail to address these in a systematic manner, as is illustrated in the following statement: *"An example here is in logic simulation. Synopsys, Cadence, and Mentor [the three largest firms in the EDA industry] all acquired their current generation of simulators to replace their existing products. In all cases, smaller companies came up with better algorithms that made their simulators significantly faster than those of the large companies. In all cases, the larger companies tried to compete by creating new simulators themselves prior to making their respective acquisitions, but failed."* Hence, with incumbents failing to innovate successfully, opportunities emerge for start-ups with better performing products. According to our interviewees, and illustrated by the quote above, these start-ups are frequently acquired by the larger incumbents. Such acquisitions, in turn, can trigger heightened acquisition efforts by competing incumbents to catch up.

As we argue below, the relative success of start-ups compared to incumbents derives partly from the fact that, unrestrained by existing customers and existing products, start-ups are free to pursue more radical innovations. This freedom attracts talented engineers, which in turn further increases the odds of start-ups to prevail in the competition with incumbents: "*It usually remains only a small number of people that create the fundamental technological difference. While these people certainly can be hired by large*

EDA companies … these people … go and start a new company. This starves the larger company of the knowledge and talent while promoting the potential success of the new venture.”

As a stylized fact, we note that both, entrants and incumbents innovate, but that incumbents often fail in doing so and in this case usually acquire start-ups.

4.5. The Fate of Entrants in the EDA Industry

The increasingly complex combination of different tools used for chip design (the “design flow”) makes it increasingly likely for entrants to be acquired and become integrated into the design flow of one of the three large vendors, as succinctly described in one interview: *“It [acquisition] is getting more common because the tools are getting more complex. … You need more of a ‘solution’ nowadays. You can’t just come out with one point tool, you need to come out and have at least a solution to a subsegment of the problem.”*

Hence, it seems that entrants can succeed in the long run only if they are acquired. Our interviews support this conjecture, indicating that if acquisitions are not the only way to survival, they are certainly the most prevalent one. This is partly because being acquired is financially attractive to start-ups since initial public offerings (IPOs) are less predictable and since venture capitalists aiming for a profitable exit always consider the option of a trade sale. Several interviewees confirmed this view, stating that “*most of these small companies’ dream is to be bought by somebody big*” and “*the success path is to be acquired by a big company*.”

Next to these push factors, a number of pull factors were also identified in the interviews. One interviewee pointed out the important role of complementary assets such as a strong international sales force:*“… with their sales network which of course then [after acquisition] explodes compared with the small firm, because they [large incumbents] are already everywhere in Asia, Europe, and elsewhere and they get just another product to sell. And they get worldwide sales support when they need it. … They [small firms] eventually break down because of a lacking sales network and demand for application services which they cannot provide anymore with their own human resources.*” Even more to the point, one entrepreneur stated: "*The goal is always to be acquired. […] The more successful we are, the more urgent it becomes to be acquired.*"

One interviewee described how incumbents exploit the innovative activity of start-ups, in his statement capturing the central message of our model: "*The vast majority of start-ups in EDA fail, as they do in most industries. In some sense, this encourages big companies to only look outside to acquire new technologies—it's cheaper to let the cash efficient start-ups figure out how to design the product and build the market, suffering real failures in many cases, than it is to do it inside the large company.*" In sum, we can put down as a stylized fact that a large share of successful entrants in the industry are—almost always need to be—acquired, and that incumbents rely to some extent on this source of new technology.

4.6. Type of Innovation Pursued

It emerges from the interviews that entrants generally choose riskier innovation projects. Interviewees suggested a number of reasons for this fact. Partly these relate to the obstacles identified in the literature on disruptive innovation (Christensen and Bower 1996, Christensen 1997), namely, that incumbents are often forced to focus on large existing customers: *"So they [large incumbents] are relying on start-ups, which then are starting from scratch … so they can apply very new methodology with very new techniques without being restrained by all [existing] customers or all the methodology*."

At the same time, the nexus of new knowledge in the industry often resides in the small start-ups, as the following statement clearly illustrates: "*The current way is that the know-how, the innovation in terms of software, is mostly generated in small firms… The share of employees who in the larger EDA firms are really innovative should be small.*"

Fitting with these statements is the observations that large incumbents generally have a weak track record in developing new technologies in-house, but that they are rather successful in developing an existing project further, i.e., at carrying out incremental innovation. At closer inspection, what becomes clear is that not only much of the innovation in the EDA industry emerges out of start-ups but also that in terms of quality, small firms pursue more radical innovation projects—a characteristic that is negatively correlated to the level of probability of success for a project. This view has been confirmed by several interviewees, stating, e.g., *"… but there [in small firms] … has to be a radical core, I would say, otherwise it is not possible"* and *"… the radical stuff is always done by the start-ups."* Hence as a stylized fact, entrants pursue more radical innovation projects than incumbents. That is, they pursue innovation projects that are both more likely to fail and, in case of success, be more valuable than those pursued by incumbents.

Overall, the EDA industry fits both the assumptions made in our model and the key predictions derived from it rather well, thus lending empirical support to our theoretical analysis.

5. Discussion and Conclusion

New entrants to a market are characterized by various features, among them organizational flexibility, the lack of established customer relationships, and the absence of existing products. All of these features contribute to explaining why innovations, in particular radical innovations, are more likely to come from start-ups than from incumbents. Yet, one important explanation for this fact is missing in the list above. Defining entrants solely by the feature that they need to be acquired in order to commercialize their innovations, our model generates—based on a different mechanism than earlier studies—the familiar result that entrants are more likely to produce radical innovations. More precisely, since firms are modeled to choose not research investment but rather the success probability of their innovation project, we find that the incumbent aims at more certain innovations of lower value, while entrants pursue projects that are less likely to succeed but, in case of success, will be more valuable. Furthermore, the more start-ups there are and the stronger the competition between them, the more valuable becomes the most radical project pursued. Also, entrants pick projects of pairwise different success probabilities—a prediction of our model that differs from those of existing ones.

The qualitative empirical study of the EDA industry confirmed that our model assumptions can be realistic. The EDA industry is characterized by few incumbents and numerous start-ups. Both incumbents and start-ups perform R&D, but the latter, by and large, need to be acquired in order to survive in the long run. However, for each type of technology, an incumbent would—with some simplification—only acquire one start-up, so those developing similar technology compete to be acquired. While some of the existing explanations for entrants being superior in developing radical innovations also seem to play a role in the EDA industry, the fact that innovation for start-ups has the character of a contest with acquisition as the prize clearly contributes to the pursuit of radical innovation by start-ups.

Although our empirical study was focused on this one industry, the applicability of our theoretical results is broader. First, several other software-based industries are similar to EDA in that large incumbents provide system products, and therefore we expect our results to also hold in such industries. Second, Cabral (2003) cites evidence from the biotechnology industry where one of the two winners in the race for artificial human insulin was acquired. He also shows that contestants chose approaches differing in terms of their radicality, rather than their effort levels. Related to this, a study by Behnke and Hültenschmidt (2007) found that for the biotechnology industry, trade sales have become more frequent in recent years compared to IPOs (partly due to the macroeconomic conditions); furthermore, even after an IPO a firm may be acquired. Jointly, these aspects suggest that the biotechnology industry is increasingly characterized by features similar to those identified for EDA.

As always, our analysis builds on simplifying assumptions and has limitations that need to be considered when applying the results. First, we explored the robustness of the equilibrium in various ways, but we were not able to demonstrate the uniqueness of the equilibrium in full generality. Second, we assumed for reasons of tractability that only one incumbent is present in the market. An interesting avenue for further research would be to generalize the model to the case of several incumbents, as found in the EDA industry. We conjecture that our main result—the entrants picking more radical projects—remains robust, since it relies on the entrants' need to be acquired rather than on the number of acquirers. Furthermore, we conjecture that, if the number of entrants exceeds that of incumbents, the radicalness of the most radical project increases as the number of entrants persists, since it is based on competition between the entrants. Third, we made the simplifying assumption that entrants need to be acquired in order to commercialize their innovations. In reality, even in industries such as EDA it cannot be fully excluded that some entrant is successful on its own in the long run. However, when the probability of such an event is small enough, our model should be a good approximation.

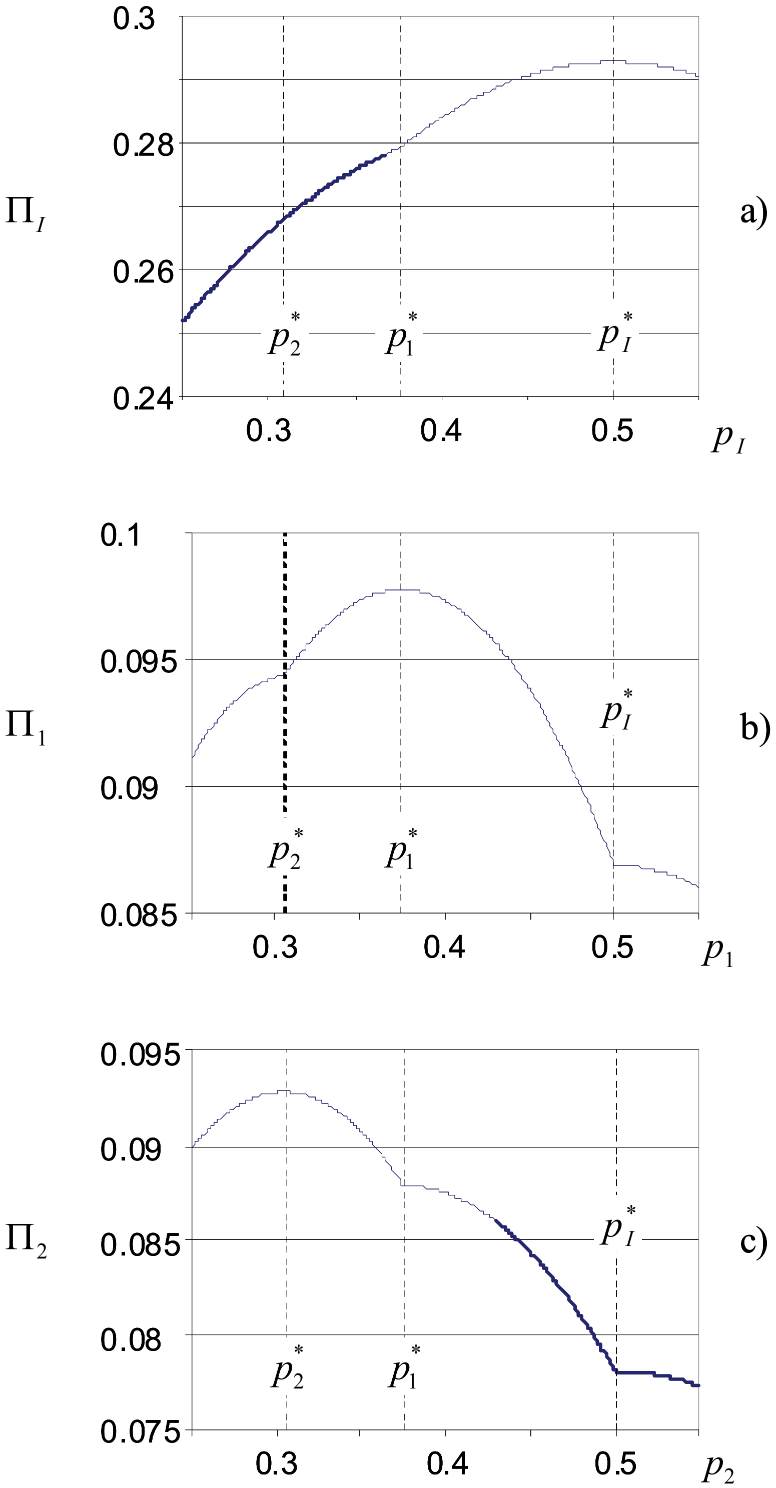
We see two promising avenues for future research, beyond those already pointed out. First, the effect of using success probability as a strategy variable for players should be further theoretically explored, and the theoretical predictions should be contrasted to those obtained when innovation effort is the relevant strategy variable. Empirical studies could then try to identify conditions under which one or the other assumption is more appropriate and test the theoretical predictions. Second, it appears interesting, if challenging, to test the model prediction of pairwise different success probability levels empirically.

Our study has a number of implications for managers. In industries where our model is applicable, incumbents benefit from a larger number of entrants not only by a lower expected acquisition price but also by an increase in the expected quality of the focal innovation. Accordingly, they might want to support entry and competition among entrants even more, e.g., by making relevant intellectual property accessible (e.g., interface specifications in the field of software, or patents covering specific tests in the field of biotechnology). Furthermore, both incumbents and entrants should assess early on if and to what extent entrants must rely on being acquired, and should adjust their strategies accordingly. For entrepreneurs, our analysis points to a new variant of the well-known first-mover advantage. If an entrepreneur is able to move first, pursue an R&D project of high expected value, and communicate this (credibly) to the market, e.g., through its hiring decisions, other entrepreneurs pick more radical but less attractive R&D projects with a lower probability of success. This reduces the competition that the entrepreneur faces when selling the firm (or the technology) and increases profit.

Market dynamics are multifaceted, in particular the interplay between incumbents and new entrants. With its focus on success probability as a choice variable, entrants' need to be acquired, and competition between a large number of entrants we believe that our study has contributed important new aspects to this variegated picture.

Figures

Figure 1 Firms' Payoffs when Deviating from Equilibrium, for $N = 2$ and $\pi(p) = 1 - p$



Appendix

Proof of Lemma 2

Assume there was an equilibrium in which two or more firms picked the same success probability. Renumber firms, including I, such that $p_0 \geq \ldots > p_k = \ldots = p_{k+m} > \ldots \geq p_N$. We denote $p_k = \ldots = p_{k+m}$ by $\hat{p}$. At least one of firms k to $k + m$ is an entrant, and we order the firms such that firm k is an entrant. As an auxiliary function, we define h_k as the expected value of the highest realized value among firms 0, 1,…, $k - 1$:

$$h_k = \sum_{j=0}^{k-1} p_j \left(\prod_{n=j+1}^{k-1} (1 - p_n) \right) \pi(p_j) \tag{1}$$

Using h_k, we can write firm k's profit function in case of a small deviation to larger or smaller values of p as follows (with $\varepsilon > 0$):

$$\begin{aligned} \Pi_k(\hat{p}+\varepsilon) &= (\hat{p}+\varepsilon)\left(\prod_{i=k+m+1}^{N} (1-p_i) \right)(1-\hat{p})^m \left(\pi(\hat{p}+\varepsilon) - h_k\right) \\ \Pi_k(\hat{p}-\varepsilon) &= (\hat{p}-\varepsilon)\left(\prod_{i=k+m+1}^{N} (1-p_i) \right)\left((1-\hat{p})^m \left(\pi(\hat{p}-\varepsilon) - h_k\right) + \left(1-(1-\hat{p})^m\right)\left(\pi(\hat{p}-\varepsilon) - \pi(\hat{p})\right)\right) \end{aligned} \tag{2}$$

Differentiating with respect to ε and calculating the limit of ε going to zero from above, we obtain:

$$\begin{aligned} \left.\frac{d\Pi_k(\hat{p}+\varepsilon)}{d\varepsilon}\right|_{\varepsilon \xrightarrow{+} 0} &= \left(\prod_{i=k+m+1}^{N} (1-p_i) \right)(1-\hat{p})^m \left(\pi(\hat{p}) + \hat{p}\pi'(\hat{p}) - h_k\right) \\ \left.\frac{d\Pi_k(\hat{p}-\varepsilon)}{d\varepsilon}\right|_{\varepsilon \xrightarrow{+} 0} &= -\left(\prod_{i=k+m+1}^{N} (1-p_i) \right)\left((1-\hat{p})^m \left(\pi(\hat{p}) + \hat{p}\pi'(\hat{p}) - h_k\right) + (1-(1-\hat{p})^m)\hat{p}\pi'(\hat{p})\right) \end{aligned} \tag{3}$$

A necessary condition for the assumed equilibrium is that both of the above terms are nonpositive. However, if $\left.\frac{d\Pi_k(\hat{p}+\varepsilon)}{d\varepsilon}\right|_{\varepsilon \xrightarrow{+} 0} \leq 0$, this implies that $\left.\frac{d\Pi_k(\hat{p}-\varepsilon)}{d\varepsilon}\right|_{\varepsilon \xrightarrow{+} 0} > 0$, because $(1-(1-\hat{p})^m)\hat{p}\pi'(\hat{p}) < 0$. Hence, an equilibrium of the type specified in the proposition cannot exist.

Proof of Proposition 1

The proof proceeds as follows. First (a), starting from the assumption that $p_I > p_1 > \ldots > p_N$ in the sought-for equilibrium, we characterize the equilibrium candidate, show that it exists and that it is unique, and show that no player k has an incentive to deviate to some $p_k' \in [p_{k-1}, p_{k+1}]$. Having thus shown "local" stability of the equilibrium candidate, we then also show (b) that deviations that change the order of p's (i.e., deviations from p_k to some $p_k' < p_{k+1}$ or $p_k' > p_{k-1}$) are not attractive. We mark equilibrium actions by an asterisk (p_k^*).

(a) We denote by Π_k the expected profit of firm k ($k = I, 1, \ldots, N$). As the following equation shows, Π_I consists of three additive terms that capture the cases that (a) two or more entrants are successful (and thus have projects of higher realized value than I), (b) exactly one entrant is successful, and (c) no entrant is successful.

$$\Pi_I = \sum_{j=2}^{N}\sum_{k=1}^{j-1} p_j p_k \pi(p_k) \prod_{\substack{m=k+1 \\ m\neq j}}^{N}(1-p_m) + p_I\pi(p_I)\sum_{j=1}^{N} p_j \prod_{\substack{m=1 \\ m\neq j}}^{N}(1-p_m) + p_I\pi(p_I)\prod_{j=1}^{N}(1-p_j) \tag{4}$$

The first summand does not depend on p_I, while the other two can be written as $p_I\,\pi(p_I)$ multiplied by a term that is independent of p_I. Thus, differentiating Π_I with respect to p_I and setting the derivative to zero yields the condition $\pi(p_I^*) + p_I^*\,\pi'(p_I^*) = 0$ (since the other term is positive). This condition is fulfilled only for $p_I^* = \tilde{p}$, which proves part (ii) of the proposition.

To simplify notation, we use the index 0 (zero) synonymous with I for the incumbent. For entrant k, the expected profit can be written as follows:

$$
\begin{aligned}
\Pi_k &= p_k\left(\prod_{j=k+1}^{N}(1-p_j)\right)\left[\pi(p_k)\prod_{m=0}^{k-1}(1-p_m)+\sum_{m=0}^{k-1}p_m\big(\pi(p_k)-\pi(p_m)\big)\prod_{j=m+1}^{k-1}(1-p_j)\right] \\
&= \left(\prod_{j=k+1}^{N}(1-p_j)\right)\left[p_k\pi(p_k)\left\{\prod_{m=0}^{k-1}(1-p_m)+\sum_{m=0}^{k-1}p_m\prod_{j=m+1}^{k-1}(1-p_j)\right\}-p_k\sum_{m=0}^{k-1}p_m\pi(p_m)\prod_{j=m+1}^{k-1}(1-p_j)\right]
\end{aligned}
\tag{5}
$$

In the equation above, the first term behind p_k indicates the probability that no entrant with a potentially more valuable project than entrant k is successful. The first summand in the squared brackets equals the probability that no firm with a lower-value project than k is successful, multiplied by the payoff $\pi(p_k)$ that k would receive in this case. The second summand gives the probability that firm m ($m \in \{0,\dots, k\text{-}1\}$) is the most successful one among firms 0, …, k-1, multiplied by the payoff that k would receive then ($\pi(p_k) - \pi(p_m)$).

As one can show by induction, the term in brackets equals unity. Hence, the first-order condition for Π_k can be written as follows:

$$
\pi(p_k^*)+p_k^*\pi'(p_k^*) \quad = \quad \sum_{m=0}^{k-1}p_m\pi(p_m)\prod_{j=m+1}^{k-1}(1-p_j) \quad =: \quad h_k
\tag{6}
$$

Note that, on the right-hand side of this equation, only $p_0 \equiv p_I, p_1, \dots, p_{k-1}$ appear. This fact implies that the entrants' first-order conditions can be solved recursively, and that the solution for p_k^* does not depend on N. The latter point proves part (iii) of the proposition.

We now prove that $h_{k+1} > h_k$. From the definition of h_k, one can derive that $h_0 = 0$ and

$$
h_{k+1} = h_k + p_k^*\big(\pi(p_k^*) - h_k\big).
\tag{7}
$$

Since h_k is the expected value of the best project among firms 0, 1, …, k-1 and since $\pi(p)$ is decreasing in p and $p_k < p_j$ for all $j < k$, the term in brackets in the above equation is positive. This implies that $\pi(p_k^*) + p_k^*\,\pi'(p_k^*)$, the left-hand side of equation (6), strictly increases with k. Due to concavity of $p\pi(p)$, and since $p_k^* < \tilde{p}$ for all entrants, it follows that in the equilibrium under consideration $p_k^* < p_j^*$ for all $k > j$. The first-order conditions are therefore consistent with the assumption of $p_k < p_j$ for all $j < k$. Furthermore, concavity of $p\pi(p)$ implies that p_k^* maximizes profits for $p_k \in \left[p_{k-1}^*, p_{k+1}^*\right]$.

We then note that uniqueness of the equilibrium candidate follow from the way it is recursively calculated from the first-order conditions, equation (6), together with the fact that a border solution, p_k = 0, cannot be an equilibrium action for entrant k since it would yield a certain profit of zero. This proves (i) of the proposition, except for showing that "non-local" deviations are not profitable.

(b) Finally, we show that the equilibrium candidate is also stable with respect to deviations that change the order of success probability levels, first by entrant k from p_k^* to some $p_k' \geq p_{k-1}^*$, then to some $p_k' \leq p_{k+1}^*$, and then by the incumbent.

Assume that k deviates from p_k^* to p_k' such that $p_k' \in [p_m^*, p_{m-1}^*]$, where $m < k$. The optimal choice of p_k' within this interval is given by the first-order condition, equation (6), which yields p_m^*. We now show that a deviation to $p_k' = p_m^*$ results in lower expected profits than p_k^*. First, $p_k' = p_m^*$ cannot be (locally) optimal since, as we show in Lemma 2, there is always an incentive to deviate to slightly smaller or larger values of p when two players choose identical actions. Since the optimal choice of p_k' in $[p_m^*, p_{m-1}^*]$ is p_m^*, it is not profitable to choose a slightly larger value than p_m^*. Hence, there exists some $p_k' \in [p_{m+1}^*, p_m^*)$ resulting in greater profits than $p_k' = p_m^*$. Applying this argument repeatedly finally shows that some p_k' in $[p_{k+1}^*, p_{k-1}^*)$ is more attractive than any $p_k' > p_{k-1}^*$. In particular, this implies that deviating to $p_k' = p_m^*$ is not profitable for k. Hence, no profitable deviation exists for k to values of p_k' larger than p_{k-1}^*.

Now assume that k deviates from p_k^* to some smaller p_k' such that $p_k' \in [p_{m+1}^*, p_m^*]$, where $m > k$. Then the first-order condition for p_k' says that the derivative of $p\,\pi(p)$ at p_k' equals the expected maximal value of realized successes of players m, m-1, …, k+1, k-1, … , 2, 1, and I. Denote this expected maximal value by A. In contrast, the first-order condition for p_m^* stipulates that the derivative of $p\,\pi(p)$ at p_m^* equals the expected maximal value of realized successes of players m-1, …, 2, 1, and I. Denote this value by B. Now, we show in the proof of Proposition 2 that the series of success probabilities $p_I^*, p_1^*, \ldots p_{m-1}^*$ obtains also by maximizing the expected maximal value of realized successes (and thus welfare) for the case of m-1 entrants. Therefore, B is larger than A. Due to concavity of $p\pi(p)$, this fact implies that the first-order condition for p_k' can only be fulfilled at some p_k' larger than p_m^*. It also implies that for $p_k' \in$

$[p_{m+1}^*, p_m^*]$, k's optimal choice is p_m^*. Using Lemma 2 again, there exists some $p_k' \in (p_m^*, p_{m-1}^*]$ resulting in greater profits than $p_k' = p_m^*$. Applying this argument repeatedly finally shows that some p_k' in $(p_{k+1}^*, p_{k-1}^*]$ is more attractive than any $p_k' < p_{k-1}^*$, in particular than $p_k' = p_m^*$, which implies that no profitable deviation exists for k to values of p_k' smaller than p_{k-1}^*.

Finally, we need to show that for the incumbent also, a deviation that would change the order of success probability levels cannot be profitable. Assume that the incumbent deviates from p_0^* to some greater p_0' such that $p_0' \in [p_{m+1}^*, p_m^*]$, $0< m$. To simplify expression, denote by S the number of successful projects among entrants $m+1$ to N. Also, define $P(S)$ as the probability of exactly S successful projects among entrants $m+1$ to N and $E(\Pi_I|S)$ as the incumbent's profit conditional on S. Furthermore, we introduce

$$\hat{h}_{k+1} = \hat{h}_k + p_{k+1}^*\left(\pi(p_{k+1}^*) - \hat{h}_k\right) \text{ and } \hat{h}_0 = 0 \tag{8}$$

where $\hat{h}_k$ is the expected value of the best project among entrants $\{1, 2, ..., k\}$. Now, as shown in the proof of Proposition 2, the equilibrium success probabilities maximize the expected value of the best project conditional on the number of firms. Hence, it follows that $h_k \geq \hat{h}_k$. Using the above notation, the incumbent's expected profit when deviating to p_0' can be written as

$$\sum_{j=2}^{N-m} P(j)E(\Pi_I|S=j) + \left(1 - \sum_{j=2}^{N-m} P(j)\right)\left(\pi(p_0')p_0' + (1-p_0')\left(P(S=1)\hat{h}_m + P(S=0)\sum_{j=1}^{m} p_j \hat{h}_{j-1} \prod_{k=j+1}^{m}(1-p_k)\right)\right) \tag{9}$$

The first term in equation (9) is the incumbent's expected profit when more than two projects of higher value than $\pi(p_0')$ succeed. The second term in equation (9) is the expected profit in the complementary case where the incumbent either obtains the profit equal to the value of its own project, if successful, or the value of the second-best project among the entrants. Maximizing the incumbent's expected profits with respect to p_0', the first-order derivative becomes

$$\pi(p_0') + p_0'\pi'(p_0') - P(S=1)\hat{h}_m - P(S=0)\sum_{j=1}^{m} p_j \hat{h}_{j-1} \prod_{k=j+1}^{m}(1-p_k) \ . \tag{10}$$

Since $p_0' \leq p_m^*$, it follows from concavity of $p\pi(p)$ that $\pi(p_0') + p_0\pi'(p_0') \geq h_m$, and we have:

$$\pi(p_0')+p_0\pi'(p_0')-P(S=1)\hat{h}_m-P(S=0)\sum_{j=1}^{m}p_j\hat{h}_{j-1}\prod_{k=j+1}^{m}(1-p_k)\geq$$

$$h_m-P(S=1)\hat{h}_m-P(S=0)\sum_{j=1}^{m}p_j\hat{h}_{j-1}\prod_{k=j+1}^{m}(1-p_k)=$$

$$P(S=1)(h_m-\hat{h}_m)+P(S=0)\sum_{j=1}^{m}p_j(h_m-\hat{h}_{j-1})\prod_{k=j+1}^{m}(1-p_k)+\left(1-P(S=1)-P(S=0)\sum_{j=1}^{m}p_j\prod_{k=j+1}^{m}(1-p_k)\right)h_m>0,$$

where the last inequality follows from $h_m > \hat{h}_m$, $h_m > h_{j-1} > \hat{h}_{j-1}$ for j-1 < m, and

$\sum_{j=1}^{m}p_j\prod_{k=j+1}^{m}(1-p_k)\equiv 1-\prod_{k=1}^{m}(1-p_k)<1$. Therefore, the optimal deviation for $p_0' \in [p_{m+1}^*, p_m^*]$ is $p_0' =$ p_m^*. Using Lemma 2, there exists some $p_0' \in (p_m^*, p_{m-1}^*]$ resulting in greater profits than $p_0' = p_m^*$. Finally, applying this argument repeatedly (as done above for deviations by the entrants) shows the incumbent has no incentive to deviate to some $p_0' \leq p_1^*$.

To prove point (iv) of the proposition, we proceed in three steps. First, we show that, for any set of success probabilities $p_I > p_1 > \ldots > p_N$, the expected profit of entrant k increases when entrant (k-1)'s action is continuously decreased from p_{k-1} to p_k. From equation (5), one obtains:

$$\frac{d\Pi_k}{dp_{k-1}}=\left(\prod_{j=k+1}^{N}(1-p_j)\right)(-p_k)\left(\pi(p_{k-1})+p_{k-1}\pi'(p_{k-1})-\sum_{m=0}^{k-2}p_m\pi(p_m)\prod_{j=m+1}^{k-2}(1-p_j)\right)$$
$$\frac{d\Pi_{k-1}}{dp_{k-1}}=\left(\prod_{j=k}^{N}(1-p_j)\right)\left(\pi(p_{k-1})+p_{k-1}\pi'(p_{k-1})-\sum_{m=0}^{k-2}p_m\pi(p_m)\prod_{j=m+1}^{k-2}(1-p_j)\right) \quad (11)$$

Both equations hold as long as $p_{k-1} \in [p_k^*, p_{k-1}^*)$. In particular, they hold when p_{k-1} is changed continuously from p_{k-1}^* to p_k^* while $p_j = p_j^*$ for $j \neq k-1$. Now, since $d\Pi_k/dp_{k-1}$ obtains from $d\Pi_{k-1}/dp_{k-1}$ by multiplying the latter with the negative factor $(-p_k)/(1-p_k)$, and since $d\Pi_{k-1}/dp_{k-1}$ is strictly positive for $p_{k-1} \in [p_k^*, p_{k-1}^*)$, $d\Pi_k/dp_{k-1}$ is strictly negative when p_{k-1} lies in this interval. This implies that, when p_{k-1} is continuously decreased from p_{k-1}^* to p_k^*, then Π_k continuously increases. Hence, as $\Pi_k^* = \Pi_{k-1}^*$ for $p_{k-1} = p_k^*$, $\Pi_k^* < \Pi_{k-1}^*$ for $p_{k-1} = p_{k-1}^*$ and $p_j = p_j^*$ for $j \neq k-1$.

It only remains to also show that $\Pi_I^* > \Pi_1^*$. To see this, note that (a) $\Pi_I^* \geq \tilde{p}\pi(\tilde{p})$, since this is the value that the incumbent can secure without any acquisition, and will only acquire a start-up if doing so increases its profit; (b) $\Pi_1^* < p_1^*\pi(p_1^*) < \tilde{p}\pi(\tilde{p}) \leq \Pi_I^*$, since $p_1\,\pi(p_1)$ is the expected value of entrant 1's project and some of this value will be competed away by other entrants and the incumbent.

Proof of Proposition 2

(i) If, in a sequential game, players are myopic regarding subsequent entry, they will optimize their choices of p_k taking into account only those other players I, 1, …, k-1 that already have entered the market. This optimization is described by the first-order conditions given in equation (3), and thus leads to the same equilibrium values as obtained in the simultaneous game. If players are forward-looking, then player k anticipates that when she picks her p_k according to equation (3), then subsequent players will choose values of p_j ($j > k$) that are smaller than p_k. This, in turn, justifies determining p_k according to equation (3), and so, again, the same equilibrium values obtain as in the simultaneous game.

(ii) Absent any cost items, a social planner maximizes the expected highest value, E[V_{max}]. Numbering the N+1 firms as k = 0, …, N such that $p_0 \geq p_1 \geq \ldots \geq p_N$, we obtain:

$$E[V_{\max}] = \sum_{m=0}^{N} p_m \pi(p_m) \prod_{j=m+1}^{N} (1 - p_j) \tag{12}$$

Differentiating with respect to p_k and setting the result to zero yields the same first-order condition as described by equation (3) for the simultaneous-move equilibrium characterized in Proposition 1. Hence, the success probability levels chosen in this equilibrium are also, for given N, welfare maximizing.

Proof of Proposition 3

Consider the candidate equilibrium with $p_1 > p_2 > \ldots > p_N > p_I$. Define h_k as the expected value of the highest realized value among the start-ups 1, …, $k - 1$, and B as the expected value of the second-highest realized value among all start-ups. With these definitions, we can write the expected payoffs of the incumbent and of entrants 1 and N as follows:

$$
\begin{aligned}
\Pi_1 &= p_1\pi(p_1)(1-p_I)\prod_{k=2}^{N}(1-p_k) \\
\Pi_N &= p_N(1-p_I)\big(\pi(p_N)-h_N\big) \\
\Pi_I &= p_I\pi(p_I)+(1-p_I)B
\end{aligned}
\tag{13}
$$

The resulting first-order conditions are:

$$
\begin{aligned}
\pi(p_1)+p_1\pi'(p_1) &= 0 \\
\pi(p_N)+p_N\pi'(p_N) &= h_N \\
\pi(p_I)+p_I\pi'(p_I) &= B
\end{aligned}
\tag{14}
$$

From the first-order condition for p_1, we obtain $p_1 = \widetilde{p}$. Since $p\pi(p)$ is concave and increasing for $p < \widetilde{p}$ and since, by assumption, $p_1 > p_N > p_I$, it follows that $B > h_N$. However, the definition of h_N and B implies the inverse of the above inequality. To see this, note that

$$
B = \sum_{j=2}^{N}\left(p_j\prod_{k=j+1}^{N}(1-p_k)\right)h_j \tag{15}
$$

In this equation, the term in brackets describes the probability that entrant j obtains the highest realized value, which is multiplied by the expected value of the highest realized value among all entrants $1, \ldots, j-1$. That is, B obtains as a weighted average of $h_2, \ldots, h_N$, where each weighting factor is positive. The result thus must be smaller than the largest of these values, h_N. That is, $B < h_N$, which constitutes a contradiction to what was deduced above from the first-order conditions. An equilibrium with $p_1 > \ldots > p_N > p_I$ thus cannot exist.

Proof of Proposition 4

(i) Analytically solving the system of first-order conditions for the candidate equilibrium with $p_1 > p_I > p_2$ yields the unique solution of $p_1 = 0.5$, $p_I \approx 0.461$, and $p_2 \approx 0.308$. This, however, turns out to be only a "local" equilibrium, in the sense that a small deviation from p_j reduces the expected payoff of firm j. A larger deviation, however, can increase the payoff of firm 1. For example, deviating from 0.5 to 0.4 increases firm 1's expected payoff from approximately 0.0931 to approximately 0.0972. Thus, there exists no equilibrium with $p_1 > p_I > p_2$. Together with Proposition 2 and Proposition 3 this proves that the only equilibrium is given by $p_I = 0.5$, $p_1 = 0.375$, and $p_2 \approx 0.305$.

(ii) Solving the system of first-order conditions for the candidate equilibrium with $p_1 > p_I > p_2 > p_3$ yields the unique solution of $p_1 = 0.5$, $p_I \approx 0.445$, $p_2 \approx 0.307$, and $p_3 \approx 0.260$. However, as for case (i) above, this is only a local equilibrium. Deviating from 0.5 to 0.4 increases firm 1's payoff from approximately 0.0712 to approximately 0.0724. Note that, due to the need to calculate roots of higher-order polynomials, the equilibrium had to be calculated numerically. Regarding the second part of the statement, starting with the assumption that $p_1 > p_2 > p_I > p_3$ and (numerically) solving the system of first-order conditions leads to a unique solution that, however, does not fulfill the above sequence of inequalities: $p_1 = 0.5$, $p_2 \approx 0.375$, $p_I \approx 0.414$, and $p_3 \approx 0.264$. That is, there is no equilibrium in which $p_1 > p_2 > p_I > p_3$. Together with Proposition 2 and Proposition 3 this proves that the only equilibrium is given by $p_I = 0.5$, $p_1 = 0.375$, $p_2 \approx 0.305$, and $p_3 \approx 0.274$.

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