And the Winner is – Acquired.
Entrepreneurship as a Contest with Acquisition as the Prize

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Abstract

Motivated by a qualitative empirical study of the Electronic Design Automation Industry, we analyze a two-stage innovation game between an incumbent and a larger number of entrants. In the first stage, firms compete to develop innovations of high quality. They do so by choosing the risk level of their R&D approach, where higher success probability goes along with lower value in case of success. In the second stage, successful entrants bid to be acquired by the incumbent. Since entrants cannot survive on their own, being acquired amounts to a 'prize' in a contest. In line with empirical observation, we identify an equilibrium in which the incumbent chooses the least risky project. Entrants pick projects of pairwise different risk levels, and the larger the number of entrants, the riskier the most risky project becomes. Generally, entrants tend to choose riskier R&D approaches and are more likely to generate the highest-value innovation. Thus, entrants' need to be acquired yields yet another explanation, beyond cannibalization and organizational issues, why radical innovations tend to come from entrants rather than incumbents.

1. Introduction

Which type of firm is most likely to innovate? This fundamental question of innovation research has attracted the interest of scholars and policy makers alike, and has spawned a broad literature going back at least to Schumpeter (1912). Of particular interest is the question if incumbents or new entrants to an industry are more prolific sources of innovation. A large number of empirical studies concur that the answer depends on the type of innovation, with entrants being more likely to create breakthroughs and incumbent firms providing more incremental innovations (e.g., Scherer and Ross, 1990; Baumol, 2004). Theoretical studies are by and largely in line with these empirical findings (in particular, Reinganum, 1983).

An important distinction is in place, though, 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, more recent theoretical studies allow for a successful entrant to be acquired by (or license its invention to) one incumbent (Gans and Stern, 2000) or by one of several incumbents competing for the entrant (Norbäck et al., 2009).

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 type of innovation, much 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 innovation type, then the start-ups will compete for being acquired, rather than incumbents competing to acquire a successful start-up. Second, all studies that we are aware of choose innovation effort as the players' strategy variable. However, given their limited financial resources entrants may distinguish themselves not so much in the effort they invest in innovation, but rather in the risk level they choose.

We motivate our approach 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 very clearly those characteristics that we aim to study, namely, start-ups going for higher risk R&D projects and competing to be acquired by incumbents.

In more detail, 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. 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 riskier projects 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, the incumbent may acquire an entrant.

Central results of our analysis are the following. There always exists an equilibrium in which all entrants choose riskier and thus, in case of success, more valuable R&D projects than the incumbent. In turn, no equilibrium exists in which the incumbent chooses the riskiest project. Furthermore, for a specific value function we show that equilibria with the incumbent choosing an intermediate risk level, between the highest and the lowest level chosen by entrants, do not exist, and we conjecture that this is also true in the general case. Finally, competition between entrants drives the "radicalness" of their innovation, in the sense that a larger number of entrants leads to an increase in the riskiness, and thus the value in case of success, of the most risky innovation project. We thus find that, overall, entrants pursue more radical innovations than the incumbent.

This result appears familiar from the literature, yet it is 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 risk levels (rather than effort), and (b) entrants, if successful, need to be acquired in order to commercialize their innovation. No cannibalization effect or organizational rigidities on the side of the incumbent are assumed. Furthermore, the empirical study of the EDA industry confirms that our model is not only theoretically plausible, but also practically relevant. Thus, we think that for industries in which incumbents frequently acquire entrants, the mechanism we propose significantly and in a new way contributes to explaining the fact that radical innovations tend to come from new industry participants.

The remainder of the paper is structured as follows. In the following section, we provide a review of the pertaining literature. In Section 3, we present results from our qualitative study of the EDA industry, and motivate our central model assumptions. In Section 4, we introduce and analyze the model. In the final section, we summarize and discuss our findings and conclude.

2. Literature Review

Early studies of the relative innovativeness of entrants and incumbents assumed product market competition between both types of firms. In his classical model, Arrow (1962) showed that an incumbent has less to gain from an innovation than an entrant if the innovation replaces existing products, and so the entrant should be more likely to innovate. Gilbert and Newbery (1982) analyze the case that, upon successful innovation by an entrant, duopolistic competition ensues. If total industry profits in duopoly are below the monopoly level, they show, then the incumbent has an incentive to engage in preemptive invention and patenting. Their result of higher innovation incentives for the incumbent is partly reversed when innovation success is not deterministic but stochastic. For this case, Reinganum (1983) shows that the incumbent invests more than the entrant only if the prospective innovation is incremental, while for sufficiently radical innovations it is the entrant who invests more and, hence, is more likely to succeed.

At second thought, the assumption of product market competition underlying the models mentioned above is not obvious. Instead, under quite general conditions it should make sense for entrant and incumbent to cooperate, a possibility which calls into question the result by Gilbert and Newbery (1982). As Gans and Stern (2000: 487) point out: "*That a cooperative agreement should take place after technological success by the startup firm is natural, since the maintenance of monopoly profits is (in most cases) superior to the sum of duopoly profits.*" Such an agreement may come in various forms—a licensing contract, a joint venture, or an acquisition of the entrant by the incumbent.

To our knowledge, only two model-theoretical studies of R&D competition between entrants and incumbents with the possibility of licensing exist. Gans and Stern (2000) model such a scenario by assuming a stochastic R&D competition between one entrant and one incumbent, which in the first stage of the game choose their respective research intensities. If the sought-for invention is realized by the entrant first, then this firm can either enter the product market or bargain with the incumbent over licensing. As the authors show, under these conditions it depends on the expected licensing fee which firms researches more intensively. If this fee is sufficiently low, the entrant will invest more in research and is hence more likely to be successful than the incumbent.

Norbäck et al. (2009) similarly model R&D activity by a start-up followed, if successful, by the choice between product market competition and acquisition by an incumbent. In contrast to Gans and Stern (2000), however, they focus on research by the entrant only, and on competition between several incumbents for acquiring the entrant. Interestingly, they find that commercialization by sale becomes relative more attractive compared to commercialization by entry the higher the (exogenously given) quality of the innovation.

Our approach differs from the two models sketched above insofar as successful entrants do not have the choice of product market competition, but instead must be acquired in order to commercialize their invention. Furthermore, we consider competition between several entrants for being acquired, with important implications for the degree of "radicalness" of the commercialized invention. Finally, since cash-constrained start-ups seem unlikely to distinguish themselves by higher research investments than (financially stronger) incumbents, we assume as firms' choice variable in the first stage of the game not research intensity, but rather the success probability (or risk level) of the respective firm's innovation project, which is negatively related to the project's value in case of success. Before introducing the model, however, we motivate our analysis and demonstrate the plausibility of our assumptions by a qualitative empirical study of the EDA industry.

3. Innovation and Acquisition in the EDA Industry

3.1. Industry Background

The EDA industry is a sub-segment of the semiconductor industry providing tools which support the (automated) design of integrated circuits. Historically hardware-based, involving dedicated workstations for computer-aided design, it has 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 through to testing. It can be subdivided in a number of sub-processes each focusing on one special aspects 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 are ultimately acquired by one of three large incumbents.

3.2. Interviews

Our qualitative empirical study is based on semi-structured interviews with industry experts and larger EDA companies.[1] 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 if start-ups, in particular those that are later acquired by large incumbent firms, pursue more radical innovations than incumbents or not. The questions in the interview guideline are partly derived from extant literature (Henderson, 1993; Christensen and Bower, 1996) and are partly based

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[1] As can be seen in the appendix (Table A1), the organizations covered in our interviews vary as concerns their type (private firm versus public organization), their size, and the function of the interviewee (CEO, academic, consultant). Interview quotes were translated, where necessary, from the mother tongue of an interviewee (in our case exclusively German) to English.

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 ten interviewees were carried out with senior professionals and scientists with detailed knowledge of the EDA industry. The list of interviewees comprises representatives from the two largest and from some smaller EDA firms, 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.

3.3. Drivers of Innovation in the EDA Industry

In EDA, new requirements for technological products emerge on a regular basis. Two factors can be identified from the interviews as important drivers. One of these is the International Technology Roadmap for Semiconductors (ITRS). Even though the ITRS provides for continuous demand for innovation and improvement, one of the interviewee pointed out that the large EDA firms often to not systematically integrate its requirements into their new product development process, but rely on rules of thumb such as improving product performance by 10% per year. He also pointed out that EDA requirements are well predictable, stating that *"an EDA tool set is good for two semiconductor process generations [which are defined by the ITRS]. After that it needs updating."* Despite this, large EDA firms do little to link their innovation activities to the ITRS or derive their own roadmaps from it. The second factor creating a continuous demand for innovation and improvement is the cumulative nature of technological change in the industry together with the highly cyclical nature of the industry (Levy, 1994). For example during the most severe downturn, in 2000 to 2001, R&D expenditure in the industry has significantly dropped and has not recovered so far. Semiconductor firms try to mitigate this reduction by strongly pushing suppliers, including those of EDA tools, to innovate in order to reduce cost, since this is one important means to buffer against the cyclical nature of the industry. 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.

3.4. Sources of Innovation in the EDA Industry

Each emerging innovation need in the EDA industry is usually addressed by several start-ups and mostly also by the incumbents, which in parallel try to develop a solution to these needs. However, from our interviews it turned 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.

3.5. The Fate of Entrants in the EDA Industry

The increasingly complex combination of different tools used for chip design (the 'design flow') makes it more and more likely for entrants to be acquired and become integrated in 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 sub-segment 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 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*." Usually, prior to acquisition, start-ups have gained some market access, providing their products to at least some important customers and the products have gained a reputation in the EDA community of being technologically superior.

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."* Also, the interviews provide some evidence that incumbents behave strategic (e.g. by including a tool of minor quality which competes with one of an entrant in package deals) in order to diminish start-up sales to improve their position in potential acquisition negotiations (cf. Gans and Stern, 2000). 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.

3.6. Type of Innovation Pursued

From the interviews it emerges 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 that also in terms of the quality, small firms pursue more radical innovation projects—a characteristic that is correlated to the level of risk of 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, more valuable than those pursued by incumbents.

We now turn to developing a model of innovation competition between entrants and an incumbent that incorporates the first three stylized facts as assumptions, and with few additional assumptions will yield the last stylized fact, that entrants pursue more radical innovations, as a key result.

4. The Model

4.1. 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 risk-return combinations. To keep the analysis tractable, and in line with our motivation, we focus on risk level—more precisely, on the success probability—as the only choice variable rather than also including the level of R&D investment.

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 timing of the game is as follows. In Stage 1, firms take R&D decisions, upon which R&D outcomes are realized. In Stage 2, 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] Finally—not modeled explicitly—products are sold and profits in the market are realized.

4.2. Solving the Model

We solve the game backwards 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.

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*

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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. The entrants (minimum) willingness to accept an offer is zero. Our approach to modeling the negotiation allocates all negotiation power to the entrant in the sense that it can capture the incumbent's willingness to pay completely. In our model, this is an innocuous assumption since we do not study entrants' and incumbents' investments into R&D (as, e.g., Gans and Stern, 2000) but rather their choice of success probability levels. Any other rule regarding how to share the surplus in a negotiation would yield similar results.

$p_I > p_1 > \ldots > p_N$. 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 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 the entrants reflects thus 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 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 as a monopolist.

Fourth, part (*iii*) of the proposition suggests a certain "robustness" of the equilibrium, and part (*iv*) has implications for business stealing. The following proposition adds to the aspect of robustness and addresses welfare aspects.

Proposition 2 *(i) In a sequential game with the same player set and the same payoff functions as the game introduced above, and the order of moves given by I,* 1, *…, N, the same equilibrium actions p_I, $p_1, …, p_N$ obtain as described in Proposition 1 for the simultaneous-move game. This result holds when players are forward-looking with respect to subsequent choices of success probabilities and also when they are myopic.*

(ii) For a given number N of entrants and given that the incumbent picks the project with highest p, the choices of success probability levels in the equilibrium characterized in Proposition 1 are welfare maximizing.

Regarding part (*i*), some real-world R&D decisions are best modeled as simultaneous moves (e.g., when firms take irreversible R&D decisions before observing the competitors' choices), while others are better described as sequential moves. Reassuringly, part (*i*) of Proposition 2 shows that the equilibrium actions and profits are robust with respect to changes in the timing, a result that suggests validity of our findings beyond the specific shape of our model.

The second part of Proposition 2 shows that equilibrium actions remain unchanged also when 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. 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 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 as to maximize $p_I \pi(p_I)$. The marginal incentives of the incumbent and of a hypothetical social planner do therefore coincide when choosing p_I.

With respect to the number of firms that enter, we do expect excessive entry (assuming a fixed cost of entering) compared to the socially optimal number, because by entering a firm exerts the negative externality of business stealing on those that already entered. However, the fact that the marginal entrant (N) earns less than the other entrants (see Proposition 1(*iv*)) mitigates this welfare loss compared to a market in which all entrants anticipate identical expected profits.

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, $p_I = 0.5$, $p_1 = 0.375$, $p_2 \approx 0.305$, $p_3 \approx 0.274$, 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 0.257, while the entrants anticipate expected profits of $\Pi_1 \approx 0.098$ and $\Pi_2 \approx 0.093$, respectively.

The equilibrium identified in Proposition 1 is, among other things, characterized by pairwise different risk levels. Given ex-ante symmetry between all entrants, this is a non-trivial finding. The following proposition states that, should there be further equilibria, then they must share this feature. This result further supports the notion 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.

Proposition 3: *There is no equilibrium in pure strategies in which two or more firms choose the same success probability.*

We interpreted Proposition 1 as being 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 also equilibria with any other order of success probability levels 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 4: *There is no equilibrium in pure strategies in which the incumbent chooses a project with lower success probability than all entrants.*

The logical next step would be to formulate and prove a proposition about existence or non-existence 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, however, we can not 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 $N = 2$, $N = 3$.[3]

Proposition 5: *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 4 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 5 shows that the incumbent always chooses the project with lowest risk—and we conjecture that this holds true also 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, in line with our empirical study of the EDA industry, that entrants focus on riskier, but in case of success more valuable or more radical projects.

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 the success probability of their innovation project, we find that the incumbent aims at more certain innovations of lower value, while entrants pursue more risky and, in case of success, more valuable projects.

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[3] 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.

Furthermore, the more start-ups there are and the stronger thus competition between them, the riskier and more valuable becomes the most risky project pursued.

The qualitative empirical study of the EDA industry confirmed that our model assumptions are, in some industries at least, 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 for being acquired. In addition, other mechanisms are at work to make start-ups in EDA more successful at radical innovations than incumbents. Among these are an overly strong focus of incumbents on existing customers and products, organizational rigidities of incumbents, and advantages of start-ups in attracting talented engineers. Still, the fact that, in EDA, innovation for start-ups has the character of a contest with acquisition as the prize clearly contributes to start-ups being better at radical innovation.

Appendix

Table A.1: Interviews conducted

Interviewee(s) number	Organization type	Function	Language of interview (form of interview)	Date and duration of interview
1-3	Private firm	System Architect, Engineer, and Software Consultant at a large EDA firm	English (in person)	12 December 2005, 1h 45min
4	Public organization	Professor at a large Californian university, co-founder of a large EDA firm	English (over the phone)	12 December 2005, 1h 03min
5	Public organization	Professor Emeritus at a technical university, co-founder of a German EDA start-up	German (in person)	16 January 2006, 2h 16min
6	Private firm	Market Development Manager, former employee of a large EDA firm	English (in person)	7 March 2006, 0h 57min
7	Private firm	Co-founder, CEO and buyer of several small EDA firms	English (by email)	21 May – 26 June 2006, several email exchanges
8	Private firm	Founder and CEO of a small consulting firm focused on the EDA industry	English (over the phone)	31 January 2008, 1h 04min
9	Public organization	Professor at a technical university	German (in Person)	11 January 2008, 59min
10	Private firm	Vice President at a large EDA firm	English (in Person)	12 March 2008, 25 min

Proof of Proposition 1

The proof proceeds as follows. First (a), starting from the assumption that $p_I > p_1 > ... > p_N$ 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' that fulfills the same inequality as p_k. Having thus shown "local" stability of the equilibrium candidate, we then show (b) that also 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, …, N). As the following equation shows, Π_I consists of three additive terms which capture the cases that (a) two or more entrants are successful (and thus have higher realized profits than I), (b) exactly one entrant is successful, and (c) no entrant is successful.

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

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 $p_I^* = \widetilde{p}$, which proves part (ii) of the proposition.

For entrant k, the expected profit can be written as follows. To simplify notation, we use the index 0 (zero) synonymous with I for the incumbent. In the equation below, 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 ($m \in \{0, …, k\text{-}1\}$) is the most successful one among firms 0, …, k-1, multiplied by the payoff that k would receive then ($\pi(p_k) - \pi(p_m)$).

$$\begin{aligned}\Pi_k \quad &= \quad p_k\left(\prod_{j=k+1}^{N}(1-p_j)\right)\left[\pi(p_k)\prod_{m=0}^{k-1}(1-p_m) + \sum_{m=0}^{k-1} p_m\big(\pi(p_k)-\pi(p_m)\big)\prod_{j=m+1}^{k-1}(1-p_j)\right] \\ &= \left(\prod_{j=k+1}^{N}(1-p_j)\right)\left[p_k\pi(p_k)\left\{\prod_{m=0}^{k-1}(1-p_m) + \sum_{m=0}^{k-1} p_m \prod_{j=m+1}^{k-1}(1-p_j)\right\} - p_k\sum_{m=0}^{k-1} p_m\pi(p_m)\prod_{j=m+1}^{k-1}(1-p_j)\right]\end{aligned} \qquad (2)$$

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

$$\pi(p_k^*) + p_k^* \pi'(p_k^*) \quad = \quad \sum_{m=0}^{k-1} p_m \pi(p_m) \prod_{j=m+1}^{k-1} (1 - p_j) \quad =: \quad h_k \tag{3}$$

Note that, on the right-hand side of this equation, only $p_0 \equiv p_I, p_1, \ldots, p_{k-1}$ 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

$$h_{k+1} = h_k + p_k^* \big(\pi(p_k^*) - h_k\big). \tag{4}$$

Since h_k is the expected value of the second-highest realized profit 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 (3), strictly increases with k. Due to concavity of $p\ \pi(p)$, and since $p_k^* < \widetilde{p}$ for all entrants, it follows that in the equilibrium under consideration $p_k^* < p_j^*$ for $k > j$, proving part (i) of the proposition.

We then note that existence and uniqueness of the equilibrium candidate (which we have already shown to be stable with respect to small deviations) follow from the way it is recursively calculated from the first-order conditions (3) together with the fact that a border solution, $p_k = 0$, can not be an equilibrium action for entrant k since it would yield a certain profit of zero. Any other probability between zero and p_{k-1} will yield a positive and thus higher expected profit. Thus, equation (3) indeed gives player k's best response, under the assumption that the inequality $p_I > p_1 > \ldots > p_N$ holds.

(b) Finally, we show that the equilibrium candidate is stable also with respect to discontinuous deviations that change the order of success probability levels, first by entrant k from p_k^* to some $p_k' > p_k^*$, then to some $p_k' < p_k^*$, 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 (3), which yields p_m^*. However, $p_k' = p_m^*$ can not be (locally) optimal since, as we show in Proposition 3, there is always an incentive to deviate to slightly smaller or larger values of p when two players choose identical actions.[4] Deviating to larger values obviously makes no sense in this case (since the first-order condition within $[p_m^*, p_{m-1}^*]$ led to p_m^*), so deviating to some p_k' smaller than p_m^*—and hence lying in $[p_{m+1}^*, p_m^*)$—is more attractive. Applying this argument repeatedly finally shows that some p_k' in

[4] Note that k's profit function is, for all j, kinked at $p_k' = p_j^*$, but continuous. Note also that the proof of Proposition 3 does not draw on Proposition 1.

$[p_{k+1}^*, p_{k-1}^*)$ is more attractive than any $p_k' > p_{k-1}^*$, which implies that no profitable deviation exists for k to values of p_k' larger than p_k^*.

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, since the series of success probabilities $p_I^*, p_1^*, \dots p_{m-1}^*$ obtains also by maximizing the expected maximal value of realized successes (and thus welfare) for the case of m-1 entrants (as we show in Proposition 2), 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, within $[p_{m+1}^*, p_m^*]$, k's optimal choice is p_m^*. However, according to Proposition 3, if $p_k' = p_m^*$ then small deviations to either smaller or larger values of p_k' are profitable for k, which in this case means that deviations to larger values, which lie in $(p_m^*, p_{m-1}^*]$, are profitable. Hence, rather than deviate from p_k^* to some smaller p_k' such that $p_k' \in [p_{m+1}^*, p_m^*]$, k would deviate to some $p_k' \in (p_m^*, p_{m-1}^*]$. Applying this argument repeatedly shows that "remaining" in the interval $(p_{k+1}^*, p_{k-1}^*]$, and hence at $p_k' = p_k^*$, is more attractive for k than any deviation to smaller values of p_k'.

Finally, we need to show that also for the incumbent, 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 $p_0' \in [p_{m+1}^*, p_m^*]$, $m \le N$. Denote by S the number of successful projects, and by $P(S)$ the probability of exactly S successful projects, among entrants $m+1$ to N. Furthermore, define $\hat{h}_{k+1} = \hat{h}_k + p_{k+1}^*\left(\pi(p_{k+1}^*) - \hat{h}_k\right)$ and $\hat{h}_0 = 0$. Notice, as the equilibrium success probabilities maximize h_k, it follows that $h_k \ge \hat{h}_k$. Then, the incumbent's expected profit when deviating to p_0' can be written as

$$\sum_{j=2}^{N-(m+1)} P(j)E\left(\Pi_I \middle| S=j\right) + \left(1 - \sum_{j=2}^{N-(m+1)} P(j)\right)\left(\pi(p_0')p_0' + (1-p_0')\left(P(S=1)\hat{h}_m + P(S=0)\sum_{j=1}^{m} p_j \hat{h}_{j-1} \prod_{k=j+1}^{m}(1-p_k)\right)\right) \quad (5)$$

where $E\left(\Pi_I \middle| S=j\right)$ is the incumbent's profit conditional on $S = j$, which is independent of p_0' as $S \ge 2$. Hence, the first-order derivative to the incumbent's problem becomes:

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

$$h_m-P(S=1)\hat{h}_m-P(S=0)\sum_{j=1}^{m}p_j\hat{h}_{j-1}\prod_{k=j+1}^{m}(1-p_k)= \tag{6}$$

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

where for the first inequality we have used the first-order condition of entrant m and the fact that $p\pi(p)$ is concave in p. Furthermore, the first-order derivative to the incumbent's problem when deviating to some $p_0' < p_N*$ is equal to the one when deviating to some $p_0' \in [p_{N-1}^*, p_N^*]$. Therefore, as $p\pi(p)$ is concave in p, the first-order derivative is also positive for all $p_0' < p_N*$. The final line of (6) is positive as $h_m > \hat{h}_m$, $h_m > h_{j-1} > \hat{h}_{j-1}$ for j-1 < m, and $\sum_{j=1}^{m}p_j\prod_{k=j+1}^{m}(1-p_k)\equiv 1-\prod_{k=1}^{m}(1-p_k)<1$ (and hence the term in braces is positive). Applying the same argument as above for the entrants shows that the incumbent has no incentive to deviate to in the equilibrium considered.

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 (2), one obtains:

$$\begin{aligned}\frac{d\Pi_k}{dp_{k-1}}&=\left(\prod_{j=k+1}^{N}(1-p_j)\right)(-p_k)\left(\pi(p_{k-1})+p_{k-1}\pi'(p_{k-1})-\sum_{m=0}^{k-2}p_m\pi(p_m)\prod_{j=m+1}^{k-2}(1-p_j)\right)\\ \frac{d\Pi_{k-1}}{dp_{k-1}}&=\left(\prod_{j=k}^{N}(1-p_j)\right)\left(\pi(p_{k-1})+p_{k-1}\pi'(p_{k-1})-\sum_{m=0}^{k-2}p_m\pi(p_m)\prod_{j=m+1}^{k-2}(1-p_j)\right)\end{aligned} \tag{7}$$

Both equations hold not only for equilibrium values of p_i, but for any values as long as the above inequality is fulfilled (i.e., the order of p_i's remains unchanged). In particular, they hold when p_{k-1} is changed continuously from p_{k-1}^* to p_k^* while all other p_i take on their equilibrium values p_i^*. 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 positive for $p_{k-1} \in [p_k^*, p_{k-1}^*)$, $d\Pi_k/dp_{k-1}$ is 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. Second, note that also (k-1)'s payoff changes continuously in that process, and becomes identical to Π_k when p_{k-1} equals p_k^*. Third, we establish that, if the initial set of success probabilities corresponds to the equilibrium characterized above, then the assumption of $\Pi_k^* \geq \Pi_{k-1}^*$ (denoting payoffs in equilibrium) leads to a contradiction: If this inequality was fulfilled, then (according to steps one and two in the proof) entrant (k-1) could improve its payoff compared to the equilibrium by deviating from p_{k-1}^* to p_k^*. However, this can not be true since the initial situation is an equilibrium. Hence, $\Pi_k^* < \Pi_{k-1}^*$.

It only remains to show that also $\Pi_I^* > \Pi_1^*$. 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) $\Pi_1^* < p_1^* \pi(p_1^*)$, since $p_1 \pi(p_1)$ is the value that entrant 1 creates stand-alone and some of this value will be competed away by other entrants and the incumbent; and (c) $\tilde{p}\pi(\tilde{p}) > p_k^*\pi(p_k^*)$ for all k.

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 (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 (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 $k = 0, \ldots, N$ such that $p_0 \geq p_1 \geq \ldots \geq p_N$, we obtain:

$$E\left[V_{\max}\right] = \sum_{m=0}^{N} p_m \pi(p_m) \prod_{j=m+1}^{N} (1 - p_j) \tag{8}$$

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

Assume there was in equilibrium in which two or more firms picked the same success probability. Renumber firms, including I, such that $p_1 \geq \ldots > p_{k+1} = \ldots = p_{k+m} > \ldots \geq p_{N+1}$. We denote $p_{k+1} = \ldots = p_{k+m}$ by $\hat{p}$. As an auxiliary function, we define EV_m as the expected value of the highest realized value among firms 1 … m:

$$EV_m \quad = \quad \sum_{j=1}^{m} p_j \left(\prod_{n=j+1}^{m} (1 - p_n) \right) \pi(p_j) \tag{9}$$

Using EV_m, we can write firm (k+1)'s profit function in case of a small deviation to larger values of p and firm (k+m)'s profit function in case of a small deviation to smaller values of p as follows:

$$\begin{aligned}\Pi_{k+1}(\hat{p}+\varepsilon) &= (\hat{p}+\varepsilon)\left(\prod_{i=k+2}^{N+1}(1-p_i)\right)\left(\pi(\hat{p}+\varepsilon)-EV_k\right)\\ \Pi_{k+m}(\hat{p}-\varepsilon) &= (\hat{p}-\varepsilon)\left(\prod_{i=k+m+1}^{N+1}(1-p_i)\right)\left(\pi(\hat{p}-\varepsilon)-EV_{k+m-1}\right)\end{aligned} \tag{10}$$

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

$$\begin{aligned}\left.\frac{d\Pi_{k+1}(\hat{p}+\varepsilon)}{d\varepsilon}\right|_{\varepsilon \xrightarrow{+} 0} &= \left(\prod_{i=k+2}^{N+1}(1-p_i)\right)\left(\pi(\hat{p})+\hat{p}\pi'(\hat{p})-EV_k\right)\\ \left.\frac{d\Pi_{k+m}(\hat{p}-\varepsilon)}{d\varepsilon}\right|_{\varepsilon \xrightarrow{+} 0} &= -\left(\prod_{i=k+m+1}^{N+1}(1-p_i)\right)\left(\pi(\hat{p})+\hat{p}\pi'(\hat{p})-EV_{k+m-1}\right)\end{aligned} \tag{11}$$

A necessary condition for the assumed equilibrium is that both of the above terms are non-positive. Since the respective first term in brackets is positive, this is equivalent to the conditions

$$\begin{aligned}\pi(\hat{p})+\hat{p}\pi'(\hat{p})-EV_k &\leq 0\\ \pi(\hat{p})+\hat{p}\pi'(\hat{p})-EV_{k+m-1} &\geq 0\end{aligned} \tag{12}$$

However, since $EV_{k+m-1} > EV_k$, both conditions can not be fulfilled simultaneously. This implies that an equilibrium of the type specified in the proposition can not exist.

Proof of Proposition 4

Consider the candidate equilibrium with $p_1 > p_2 > \ldots > p_N > p_I$. Define A_i as the expected value of the highest realized value among the start-ups 1, …, $i-1$, 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:

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

The resulting first-order conditions are:

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

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

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

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, …, j – 1. That is, B obtains as a weighted average of A_2, …, A_N , where each weighting factor is positive. The result thus must be smaller than the largest of these values, A_N. That is, $B < A_N$, 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 can not exist.

Proof of Proposition 5

(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_X reduces the expected payoff of firm X. 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 approx. 0.0931 to approx. 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 approx. 0.0712 to approx. 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 which, however, does not fulfill the above sequence of inequalities: $p_1 = 0.5$, $p_2 \approx 0.375$, $p_A \approx 0.414$, 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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