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ABSTRACT

Optimal Project Rejection and New Firm Start-ups*

Entrants are typically found to be more innovative than incumbent firms. Furthermore, these innovative ideas often originate with established firms in the industry. Therefore, the established firm and the start-up firm seem to select different types of projects. We claim that this is the consequence of their optimal project allocation mechanism, which depends on their comparative advantage. The start-up firm may seem more 'innovative' than the established firm because the comparative advantage of the start-up firm is to commercialize 'innovative' projects, i.e. projects that do not fit with the established firms' existing assets. Our model integrates various facts found in the industrial organization literature about the entry rate, firm focus, firm growth, industry growth and innovation. We also obtain some counter-intuitive results such that a reduction in the cost of start-ups may actually slow down start-ups and that the firm may voluntarily give away the property rights to the inventions discovered within the firm.

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1 Introduction

Entry into an industry is considered to be an important driver of innovation. Scherer (1980) argues that new entrants are responsible for a disproportionate share of all really new and revolutionary industrial products and processes. Carefully observing the process of how ideas are commercialized at start ups shows that in many cases the scientists and entrepreneurs in small innovative firms tend to come from large established firms in the industry and that these inventions are actually conceived at the incumbent's R&D department, but are passed up for other opportunities. For instance, Christensen (1997) claims that "ultimately, nearly all North American disk drive manufacturers can trace their founder's genealogy to IBM's San Jose division, which developed and manufactured its magnetic recording products." Bhidé (1996) conducted a survey of 87 Harvard Business School MBAs that became entrepreneurs, and found that more than 50% of them spotted a "need" while in a previous job. He also found that, 71% of the founders of 100 of the 1989 Inc. 500 fastest growing private companies had replicated or modified an idea encountered through previous employment. These facts suggest that established firms are an important source of project ideas even though they are not commercialized where they emerge. As the following quote illustrates, start-ups frequently occur as the result of *rejected ideas* of existing firms.

> "The presumption is that employees of the big companies leave and go to venture companies to found start-ups to make more money. That's not the way. Andy Grove, Bob Noyce and others left Fairchild to found Intel, not to make more money. They left to make a product that Fairchild was either unable or unwilling to make, or for what ever reason, didn't get around to making. That's why ventures are started: from lack of responsiveness in big companies... The only reason good people leave is because they become frustrated. They want to do something they can't do in their present environment."

Don Valentine, Venture Capitalist in Silicon Valley.[1]

Many similar stories exist: Co-founders of Apple, Steven Jobs and Steven Wozniak initially offered their personal computer to Hewlett-Packard Corporation, which turned it down; Between 1974 and 1984 HP executives were responsible for starting more than eighteen firms, including notable successes such as Rolm, Tandem, and Pyramid Technology (Saxenian, 1994); Microsoft is experiencing a similar phenomenon in the Seattle area where it has generated start-ups such as RealNetworks, Crossgain, ViAir, CheckSpace, digiMine, Avogadro, Tellme Networks to name only a few (Wall Street Journal); Mitch Kapor -founder of Lotus Development Corporation-left Digital Equipment Corporation (Kao, 1989); Finis Conner and John Squires left Seagate and set up Conner Peripherals in order to develop small hard drives for notebook computers (Christensen, 1997, Chesbrough, 1997); Sam Walton's idea to locate discount stores in small towns of the Southwest of the US was rejected by the management of Ben Franklin; Freemarkets' founder was an engineer at GE where he proposed the idea of creating a B2B market place for suppliers. After GE rejected his initial proposal he set up the market place from his basement.

In this paper, we develop a model that addresses the question why an established firm does not commercialize a seemingly good project while an entrant firm does. We propose a comparative advantage theory of project allocation where the comparative advantage of the established firm is to commercialize the projects which fit with the firm's assets in place while the entrant firm has a comparative advantage commercializing the projects which do NOT fit with the assets of the established firm. As a consequence the established firm may forgo a good project due to its poor fit with the firm's assets and may wait for a project with a better fit.[2] This theory does not need to assume that either the established firm or the entrant firm is better or more profitable than the other. But it does assume that the established firm cannot

[1] Quoted in Saxenian (1994).

[2] As Teece (1986) states"A firm's history and the assets it already has in place ought to condition its R&D investment decision. It is therefore rather clear that the R&D investment decision cannot be divorced from the strategic analysis of markets and industries and the firms position within them." Shane (2001b) finds that the low importance of complementary assets such as distribution or marketing and sales, increases the likelihood that MIT patents are commercialized through a start up.

commercialize infinitely many projects simultaneously and, hence, the capacity to commercialize an additional project has a positive option value. When this option value is high, the established firm becomes cautious in adopting a new project and, therefore, many projects are passed to entrant firms.

We study the determinants of this option value by developing a stylized model. The established firm sequentially receives project proposals on product innovations from scientists that are working in the R&D department of the firm. At random points in time scientists discover projects which characteristics are not known in advance. Once a scientist makes a discovery, the firm and the scientist negotiate about the fate of the project and the distribution of the surplus. There are three possible decisions regarding the fate of the project: the firm undertakes the project internally, the scientist starts up a new firm and undertakes it, or the project is shelved. The fate of the project depends on the characteristics of the project and the endogenously determined value of the option that the established firm maintains for adoption opportunities in the future. The distribution of the surplus between the established firm and the scientist depends on who owns the intellectual property rights over the project. We study two extreme cases: scientist ownership and firm ownership.[3]

Our model is able to organize and relate various facts found in the industrial organization literature. First, consistent with the evidence of Acs and Audretsch (1988), the model implies that when the industry to which the established firm belongs is experiencing a high rate of invention and/or is young, the option value increases and so does the start-up rate. When invention is more frequent, the established firm becomes patient in accepting an additional project since the next invention will come along soon. For this reason, the established firm rejects more projects and new firms pick up these projects. Shane (2001b) similarly finds that start ups are more likely to

[3] These rights are regulated by the legal environment of the state or country where the established firm is located. In most US states all rights of the scientist with respect to innovations can be legally signed over to the company. The signing over of these rights, especially the rights to innovations that the researcher developed on her own time and budget, is illegal in Europe and some US states such as California, Kansas, Minnesota, Washington, North Carolina and Illinois. Thus, in Europe and the US states where scientists rights are protected by law it is often difficult or impossible for the established firms to appropriate all the rents from the innovations that are not commercialized by the established firm.

commercialize the technology protected by MIT patents related to young technology areas.

Second, the size of the R&D department of the established firm affects the rate of start ups positively. This is consistent with the evidence of Acs and Audretsch (1988) where a larger employment share of *large* firms in the industry is positively related to the number of innovations and the innovation share of *small* firms. A larger R&D department generates more ideas with more rejected ideas left for start-ups to pick up.

Third, comparing the project portfolio of an established company with the projects at start-up firms, the model implies that if we identify projects with a high "fit" as "marginal" inventions, that incumbents are more likely to introduce marginal innovations, while the start-up firm is more likely to introduce "radical" innovations. This is consistent with the fact that small (start-up) firms are more "innovative" than established firms (Scherer, 1980). Silverman (1999) finds that the probability of a firm diversifying into a certain industry strongly depends on the technological proximity of this industry to the technological position of the firm *relative* to any other (technological) diversification opportunities. Consistent with this evidence Shane (2001a) shows that more important, more radical, and broader patents from MIT are more likely commercialized through the establishment of a new firm. Furthermore, in a multi-project extension of the model, we find that the hurdle rate of the firm for accepting the project increases and that, therefore, the firm focus increases over time. As valuable capacity is filling up over time, the firm becomes more selective about which projects to accept. The model thus nicely distinguishes between the effects of the age of the firm and the maturity of the market. As the firm grows older, it becomes more selective, but as the industry gets more mature, the firm becomes less selective in its choice of projects.[4]

Our model is general in allowing a new project to either cannibalize or complement the existing business of the established firm. This flexibility of the model leads

[4]Relying on a model with decreasing returns to scale Jovanovic (1982) and Hopenhayn (1992) predict the negative relation between firm age and growth. The empirical evidence, however, is mixed (Evans 1987a,b and Hall 1987).

to some counter-intuitive results. First, we study the effects of changes in the start-up environment on the start-up rate. Contrary to common belief, we find that the development of venture capital markets and stock markets, or subsidies towards new firms does not always increase the start-up rate. This happens when the cannibalization effect is strong. When a start-up becomes less costly, the established firm expects that rejecting projects is more likely to lead to the start-up of competing firms. Because of this negative externality, the established firm reduces the R&D expenditures and consequently less ideas will be generated. Thus, the start-up rate may even decrease in a start-up friendly environment. This prediction is also derived by Burke and To (2001) in a different setting. Second, we find that if the complementarity effect is strong, the established firm may be better off if scientists rather than the firm own property rights to projects. This is because the firm's bargaining position may improve more than the one of the scientist by giving up property rights. If scientists own the property rights, they cannot commit not to start up a new firm and generate a positive externality on the established firm in the case the established firm and the scientist disagree to internally adopt the project. This positive outcome resulting from lack of the commitment and from the complementarity, strengthens the firm's bargaining position and therefore the firm captures a higher payoff than if it owns the property rights where the threat point is internally adopting the project. Finally, the model comprehends both corporate ventures and independent ventures. We identify corporate ventures as projects rejected for internal adoption, but sponsored by the established firm. The model implies that corporate ventures tend to be less profitable than independent start-ups. Many corporate ventures are projects that are complementary to the business of the established firm, but have insufficient stand alone profitability to be organized as a start-up. Therefore, they can only be successfully organized with a subsidy from the established firm.[5].

The model in this paper belongs to the literature on irreversible investments (Pindyck, 1988). For instance, Baldwin (1982) constructs a similar project evalua-

[5]Gompers and Lerner (1998) indeed find that corporate venture capitalists tend to invest at a premium compared to other firms.

tion mechanism as the one presented in this paper. A firm needs to decide about sequentially arriving investment opportunities. She shows that a standard NPV analysis does not provide the correct evaluation measure for projects when accepting a project today, reduces the possibility of accepting a project tomorrow. However, in her model rejected projects have no outside opportunity while in our model rejected projects are possibly developed outside the firm as a start-up. Therefore, the occurrence of start-ups is endogenous to the incumbent's project selection mechanism in our model. This also contrasts with the literature on whether incumbents or entrants have stronger incentives to commercialize an innovation. In this literature the entrant appears exogenously. By analyzing the incentives to invest in R&D of incumbent firms compared to entrants, economists argued that entrants are more likely to introduce "drastic" innovations that displace the incumbent firm (Arrow, 1962; Reinganum, 1983; Gilbert and Newbery, 1982). However, both Ghemawat (1991) and Henderson (1993) have shown that the typical innovations introduced by an entrant cannot be considered "drastic", i.e. forcing the incumbent to exit the market.

In the literature on intellectual property rights the entrant does appear endogenously, but the commercialization of the invention by the entrant is an attempt by the scientist to avoid expropriation by her employer because of the lack of protection of intellectual property (Anton and Yao, 1994, 1995). A scientist with an interesting idea would leave the company and set up her own organization without revealing the idea to her current employer. As we have indicated, most scientists in start ups seem to have revealed their idea to their former employer before deciding to start up on their own. Both of these explanations for the R&D commercialization incentives of entrants-the incentive theory and lack of intellectual property protection-are based on the output market effects of innovation and new entry. Contrary to the economics literature, the management literature explains the perceived innovativeness of entrant firms from an internal perspective, i.e. as the result of organizational inertia in investing in the next generation technology by the established firm. The sunk cost of learning the current technology conditions the firm to restrict attention to marginal improvements of the current technology, leaving the field wide open to entrants with radical (disruptive) new technologies (Tushman and Anderson; 1986, Henderson and Clark; 1990, Henderson, 1993; Christensen, 1997).[6] The decision of the incumbent not to pursue these radical technologies, however, is considered irrational and limited by the cognitive capabilities of the incumbent.

Structure of the Paper In the following section we set up the baseline model and derive its implications. We treat the R&D decision of the firm exogenously and assume that the scientist owns the property rights to the innovation and that the firm can adopt only one project. In Section 3, we extend the baseline model. First, we study the R&D decision of the firm. Second, we study the case in which the firm can adopt more than one project. Third, we consider the case in which the firm has the property rights to the innovation. Next we look at the effect of additional costs for the start up and examine the effect of costly replacement of scientists that leave to start up a firm. Finally, we consider the case of external acquisition of ideas. Section 4 illustrates the model with the case of the hard disk drive industry following Christensen's (1997) work. Section 5 concludes. All proofs are gathered in the Appendix.

2 The Model

We study the R&D and project selection decisions of an established firm. The firm possesses some critical asset that is lumpy and exhaustible. This asset could be the management team, the sales force, the design team, production facilities or the whole organizational structure. This resource is under-utilized and the firm is searching for a project that may exploit it. Unlike the established firm, a start-up firm does not own any of these assets initially. Good investment opportunities frequently arise in the established firm because these assets give it an option to expand cheaply whereas the start-up would need to acquire entire new resources to commercialize a project. A project is internally adopted if the established firm adopts the project and externally adopted if the start-up firm does so. For either type of adoption, the scientist is an

[6] Arrow (1974) derived similar conclusions about the effects of the information processing ability of young versus old organizations.

essential resource to adopt the project that she discovered.[7] That is, one cannot adopt a project without consent and cooperation of the scientist. For internal adoption, the established firm is also an essential resource and one cannot adopt a project internally without consent and cooperation of the established firm.

2.1 Project

A project is characterized by a triplet (a, b, u). We denote by u as the *private* net present value of the project if the necessary resources for the project must all be acquired on the market. Because undertaking the project may affect the cash flow to existing businesses of the established firm, the social value of the project may differ from u. Let b denote the amount of cash flow that is added to the existing businesses. This incidental effect may be positive or negative. If b is positive, the project is complementary to the existing businesses and if it is negative, the new project is a substitute for or competing with the existing businesses. To summarize, u accrues to the adopter of the project while b accrues to the established firm no matter who, the established firm or the start-up firm, adopts the project.

We study an established firm that owns critical assets that can be physical, technological, organizational or managerial. These assets allow the firm to better appropriate value from any innovation or idea (Teece, 1986). Rather than acquiring all the resource on the market, the project may utilize excess capacity of resources present at the established firm. In this case, the project can save some costs and its value increases by a. Because the start-up firm does not own assets at the outset, a is realized only if the established firm adopts the project. We call a the "fit" of the project with the existing assets of the established firm. There are two interpretations of a. First, a may measure the relatedness between the new project and the existing businesses of the established firm. The more related the new project, the more the existing assets can be used for undertaking the new project and the less the investment that the firm has to make. With this relatedness interpretation, we can say that the firm maintains

[7] This assumption is not necessary to obtain most of the results. Nonetheless, this assumption requires the scientist, not a third party, to start-up the firm to externally adopt the innovation. Otherwise, the scientist can simply sell the innovation to a third party without leaving the original employer.

its focus when adopting a high a project while it diversifies when adopting a low a project. Second, the fit, a, may be negatively related to the originality of the project. Highly original projects often embody surprising and unanticipated ideas such that the existing assets of the established firm are not readily adjustable to undertake the projects. For this reason, we will think of low a projects as "innovative".

Adopting a project is irreversible and exhausts the option for the established firm to adopt more projects in the future. We think that this assumption is plausible since the ability of the firm's managers to coordinate all the activities of the firm is limited as noted by Penrose (1959). We denote V as the option value of the established firm and we will derive V endogenously later on. Unless the firm can adopt an infinite number of projects simultaneously, the value of option V is positive. It will represent the expected value of a future project on the optimal adoption path. In sum, the social value of the project is equal to $u+b+a-V$ if the project is internally adopted.

The adoption decision is also irreversible if it is externally adopted. Thus, the start-up firm loses a chance to start another new firm. At the same time, the start-up firm acquires a chance to become an established firm in the future. For simplicity, we assume that these two effects completely cancel each other out and therefore the social value of the project is simply equal to $u + b$ if it is externally adopted.[8]

2.2 Project Arrival and Selection

The firm has a R&D department which consists of a team of scientists and the number of the team members is equal to N, which is exogenously given. At any point in time, a scientist discovers a project with time-invariant probability, λ, that is, the arrival rate of a project per scientist is λ and the project arrival rate for the whole R&D division is $N\lambda$. According to the Poisson law of rare events, the probability with which more than one scientist discovers a project at the same time is zero. Each project is characterized by a triplet $a \in [\underline{a}, \overline{a}]$, $b \in [\underline{b}, \overline{b}]$ and $u \in [\underline{u}, \overline{u}]$. These

[8] The incidental effect is interpreted as the synergy of the project with its existing businesses. As Bankman and Gilson (1999) point out, the incidental effect may be also positively related to the tax saving in case that the new project makes losses. This effect is particularly acute when returns to the existing project and the new project are less correlated. The low correlation may however have a reverse effect on b by weakening the divisional managerial incentives. Therefore, we will stick to the synergy interpretation of b.

characteristics are drawn from the stationary joint distribution, G with the density, g. The density function is positive everywhere and continuous over the domain. Once the established firm exhausts its capacity to adopt any additional project, the R&D department will be shut down.[9]

Once a project is discovered, the scientist and the firm negotiate about the destiny of the project, which is either internal adoption, external adoption, or "shelving". We assume that both parties are symmetrically informed about all the relevant variables and that payoffs of both parties are transferable. We thus naturally use the Nash bargaining solution as the solution concept. A Nash bargaining solution is efficient such that the joint surplus is maximized and we therefore focus on the case in which the destiny of the project is determined efficiently. The efficient destiny of the project depends on the four variables, V, a, b and u. External adoption gives a net surplus equal to $b+u$; internal adoption, $a+b+u-V$ and shelving zero. Thus, letting $B = b+u$, the efficient destiny of the project is determined by $\max\{B, a+B-V, 0\}$. First, note that internal adoption occurs only if $a \geq V$ because otherwise external adoption yields a higher payoff than internal adoption. This implies that the established firms will only adopt projects with a sufficiently high "fit" with the existing assets. The necessary and sufficient condition that internal adoption occurs is therefore $a \geq V$ and $a+B-V \geq 0$. External adoption occurs if $a < V$ and $B \geq 0$. Consistent with Scherer (1980), the projects adopted by start ups are sufficiently "innovative", i.e. have low a. If $B < 0$ and $u < 0$, adoption by others is not profitable and never happens. Thus, the firm does not patent the project and simply forgets it. If $B < 0$, but $u \geq 0$, the firm may patent the project because if others adopt it, they would reduce the firm's profit by b.[10] Figure 1 graphically illustrates the efficient destiny of a project.

A crucial assumption is that the firm's adoption capacity is limited and, there-

[9] This assumption helps simplify the model. In reality, we think, most firms retain their R&D department while the firms are too occupied to adopt more projects, because maintaining the department will save the cost of reopening it when the firms free up their adoption capacity in the future. Complicating the model in this way will neither substantially change our results nor add much insights.

[10] In our model, shelving is a broader concept than the one in Gilbert and Newbery (1983). Gilbert and Newbery (1983) restrict attention to our latter case where a firm may patent a project but not adopt it in order to exclude the adoption by others and to keep competitive pressures low.

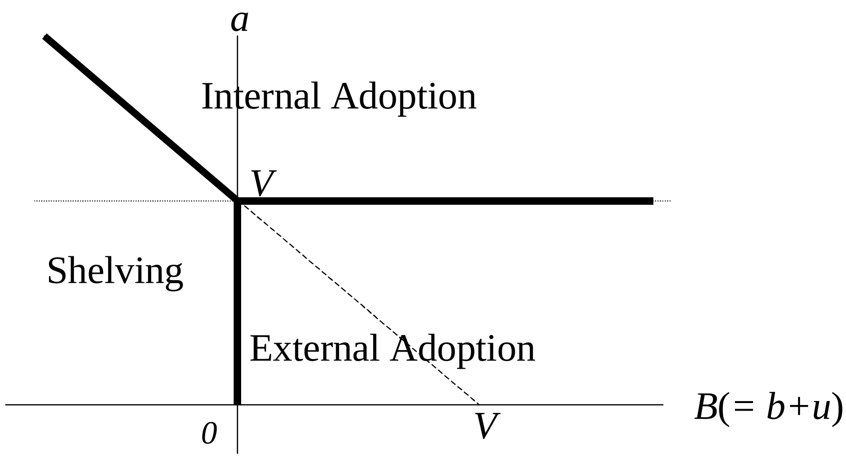

Figure 1:

fore, the option value V is strictly positive. If V is zero as assumed in the previous literature, the external adoption region vanishes. Given V, external adoption likely occurs if a is low, that is, the project does not fit well with the firm's existing resources.[11] Consistent with this prediction, Shane (2001b), in a study about the commercialization of MIT patented technologies, finds that start ups are more likely to commercialize technologies whenever complementarity assets are not important, i.e. when the fit with an established firm's assets is likely low.

In what follows, we derive the option value V. For now, we assume that the established firm can adopt at most one more project.

2.3 Negotiation

The firm and the scientist divide the joint surplus according to the Nash bargaining solution. We analyze a simple negotiation environment in which there is no prior contract but ownership of the property rights of the project is given. The allocation of ownership of the project determines the outside options of the parties in case they may disagree.[12] We study two extreme cases: scientist ownership and firm ownership.

[11] Lerner and Hunt (1998) found that in Xerox managers assessed proposed product ideas using several criteria. Not only did the technology have to be promising, but the product had to match Xerox's existing delivery system (e.g. Xerox's sales force). We also illustrate similar behavior in the case of US hard disk industry in Section 4.

[12] In Aghion and Tirole (1994) the allocation of property rights affects the allocation of effort by the scientist and the firm (customer) and hence the expected success rate of different organizational forms. Rotemberg and Saloner (1994) study the incentive problem of researchers with respect to

To be concrete, scientist ownership means that without the approval of the firm the scientist can externally adopt the project and receive u while firm ownership means that the scientist does need the approval of the firm before adopting the project externally. For now we study the case of scientist ownership.[13] The alternative case in which the firm owns the property rights is discussed in Section 3.

Under the scientist ownership, the scientist can externally adopt the project without cooperation from the firm. This fall back option is valuable and credible only if $u > 0$. Thus, if $u > 0$, the fall back option of the firm is b and the one of the scientist is u. Otherwise, if $u \leq 0$ the fall back option of the firm and the scientist are both zero. The negotiation about the adoption decision leads to the efficient decision described above and determines the transfer from the firm to the scientist. Let P_S be the transfer that the firm makes to the scientist. We assume that the firm gets a fraction of the surplus equal to $\delta \in [0,1]$ and the scientist gets $(1-\delta)$.

The following lemma summarizes the equilibrium distribution of the surplus.

Lemma 1 *Let R_F^k and $R_S^k, k = 1, ..., 6$ be the cash flow of payoffs to the firm and the scientist, respectively and let P_S be the transfer from the firm to the scientist. Also we define*

- $\omega^1 \equiv \{a, b, u | a - V > 0,\ a + b + u - V > 0 \text{ and } u > 0\}$
- $\omega^2 \equiv \{a, b, u | a - V > 0,\ a + b + u - V > 0 \text{ and } u \leq 0\}$
- $\omega^3 \equiv \{a, b, u | b + u \geq 0,\ a \leq V \text{ and } u > 0\}$
- $\omega^4 \equiv \{a, b, u | b + u \geq 0,\ a \leq V \text{ and } u \leq 0\}$
- $\omega^5 \equiv \{a, b, u | b + u < 0,\ a + b + u - V < 0 \text{ and } u > 0\}$ *and*

the organizational scope of the firm. They argue that firms might optimally limit the scope of their activities, i.e. their claims on innovations by employees, as a commitment not to implement inefficient projects ex post which distorts the incentives of the employees to come up with ideas. In this model we abstract from any moral hazard problems affecting the effort of the scientist and therefore the arrival rate of new projects (see also Subramanian, 2001).

[13] This would be the case in Europe or the US states mentioned before. Nevertheless, it seems that many companies have a policy of sharing the ownership of innovations with their employees as a motivational tool. Furthermore, employees of firms in Massachussets can start up a competing firm in California even though they have signed on a trailer clause in advance in Massachussets. In Europe, they can start up firms competing with their original employers unless they have signed on trailer clause in advance.

- $\omega^6 \equiv \{a, b, u | b + u < 0,\ a + b + u - V < 0 \text{ and } u \leq 0\}$.

1. *If* $\{a, b, u\} \in \omega^1$, *the project is internally adopted, and* $R_F^1 = b + \delta(a - V)$ *and* $R_S^1 = P_S = u + (1 - \delta)(a - V)$.

2. *If* $\{a, b, u\} \in \omega^2$, *the project is internally adopted, and* $R_F^2 = \delta(a + b + u - V)$ *and* $R_S^2 = P_S = (1 - \delta)(a + b + u - V)$.

3. *If* $\{a, b, u\} \in \omega^3$, *the project is externally adopted, and* $R_F^3 = b$ *and* $R_S^3 = u$. *The transfer,* $P_S = 0$.

4. *If* $\{a, b, u\} \in \omega^4$, *the project is externally adopted, and* $R_F^4 = \delta(b + u)$ *and* $R_S^4 = (1 - \delta)(b + u)$. *The transfer,* $P_S = b - \delta(b + u)$.

5. *If* $\{a, b, u\} \in \omega^5$, *the project is shelved and* $R_F^5 = b - \delta(b + u)$ *and* $R_S^5 = P_S = u - (1 - \delta)(b + u)$.

6. *If* $\{a, b, u\} \in \omega^6$, *the project is shelved and* $R_F^6 = 0$ *and* $R_S^6 = 0 = P_S$.

As discussed before, a project can be internally adopted (regions $\omega^1$and ω^2), externally adopted (regions $\omega^3$and ω^4), or, shelved (regions $\omega^5$and ω^6). The payoffs depend on the outside option of the scientist. In regions ω^1, $\omega^3$and ω^5 the project will be commercialized through a start up if no agreement is reached. The start up is not a viable threat in regions ω^2, $\omega^4$and ω^6 for the scientist. In the cases cited at the beginning of this paper, the established firms neither adopted the projects nor appropriated any returns from the projects undertaken by the new entrants, even though the original projects had emerged in the established firms. Such cases occur in region ω^3, where there is no transfer payment between the scientist and the firm. The outcome for projects with characteristics falling in region ω^4 has an interesting interpretation. The fit of the project a is too low ($a \leq V$) for internal adoption while the project yields a positive gain by external adoption ($b + u \geq 0$). Nevertheless, the base profitability, u is too low ($u \leq 0$) implying that the scientist does not want to start up without a subsidy from the firm. As a consequence, the firm subsidizes the scientist by $(1 - \delta)(b + u)$. This case resembles a corporate venture program in which the firm rejected the project for internal adoption but instead funds the scientist to undertake the project outside of the firm because of its complementarity with the firms existing businesses. Microsoft is known for subsidizing former employees when developing complementary technologies and products.

The firm's total payoff equals the discounted sum of the cash flows associated with arrivals of projects. If the firm internally adopts a project at time τ, then the firm's payoff is:

$$U = E\left[\int_0^\tau e^{-rt} C^F(t)\, dt\right],$$

where r is discount rate and $C^F(t)$ is firm's cash flow at time t. Note that the cash flow is equal to R_F if the project arrives and zero otherwise. We assume that the firm is risk neutral and that it chooses the adoption policy such that U is maximized.

We now determine the option value of the firm, V. Since G is time-independent and each scientist has a constant arrival rate of projects, λ, the firm's problem is also time-independent. As a consequence, the firm faces the stationary arrival rate of projects, $N\lambda$, and therefore has a stationary adoption and buyout policy for projects.

Let V be the expected payoff to hold an option to adopt a project given the adoption and buyout policy described in Lemma 1, then V must satisfy the following asset pricing formula:

$$rV = N\lambda \sum_{k=1}^{6} \int_{\omega^k} R_F^k dG.$$

That is: the foregone interest ($= rV$) is equal to the expected gain ($N\lambda \sum_{k=1}^{6} \int_{\omega^k} R_F^k dG$). Explicitly writing R_F^k, $k = 1, ..., 6$ and rearranging the terms give:

$$\begin{aligned} & V \\ = \; & \frac{\int_{\omega^1} (\delta a + b)\, dG + \delta \int_{\omega^2} (a + b + u)\, dG + \int_{\omega^3} b dG + \delta \int_{\omega^4} (b + u)\, dG + \int_{\omega^5} (b - \delta (b + u))\, dG}{\rho + \delta \int_{\omega^1 \cup \omega^2} dG} \end{aligned} \tag{1}$$

where $\rho = r/N\lambda$. Note that the equation (1) implicitly determines V because the regions ω depend on V.

The numerator of V consists of five elements. The first two parts represent expected future profits from internally adopting the project (regions $\omega^1$and ω^2). The next two integrals represent the payoffs when there is external adoption (regions

$\omega^3$and ω^4). The last part is the expected cost of avoiding competition or to secure shelving (region ω^5).

2.4 Comparative Statics

We are interested to know how the option value, V, is affected by ρ and δ. The results of comparative statics are summarized below:

Proposition 1 *V^* is decreasing in ρ, where $\rho = \frac{r}{N\lambda}$.*

This implies that the established firm becomes less selective about the projects for internal adoption as ρ increases. Note that ρ is negatively related to N -the size of the R&D department. Hence, a firm with a larger R&D department is more likely to reject a project, conditional on having the same adoption capacity. This is in line with Winter (1984) who states that small firm innovativeness should be proportional to the number of people exposed to the knowledge base from which innovative ideas might derive. Therefore, as more people within the established firm are exposed to the research ideas, the more likely innovative start ups will arise. In our model this link is modeled explicitly. Since ρ is negatively related to λ, the firm becomes more patient when it belongs to an industry experiencing a high rate of project generation in general. Furthermore, the firm adopts more marginal (high a) projects internally and thus the proposition also implies that the established firm becomes more focused in an innovative environment. This result explains why small firms are disproportionately more innovative in high-tech industries as found by Acs and Audretsch (1988). High-tech industries experience a high rate of new project arrivals. Because of these abundant project opportunities, established -large- firms are prudent and focused in adopting projects avoiding to exhaust their adoption capacity. As a result, many new firms -presumably small- pick up the projects that those large firms rejected. Consistent with these predictions, Shane (2001b) finds that MIT patents that are classified in more recently established patent classes, are more likely commercialized by a start up firm. Typically younger technologies spur a lot of invention.

Similarly, as ρ is positively related to r, the proposition also implies that if the firm cares less about the future or the business is more risky, it is more likely to accept the project.

Proposition 2 *V^* is increasing in δ.*

That is, if the bargaining power of the firm increases, it becomes pickier and more start-ups emerge.

3 Extensions

In this section, we extend the baseline model presented in the previous section. First, we study how robust the results previously obtained are when endogenizing the R&D intensity of the established firm, i.e. the size of its research department. Second, we allow the firm to adopt more than one project. Third, we study the case in which the firm rather than the scientist owns the property rights to the project. Next, we include a cost of external adoption and discuss the effect of policy measures affecting the cost of start ups and examine the effect of costly replacement of scientists that leave to start up a firm. Finally, we extend the model to allow the established firm to scan the external environment for new projects. In summary, the results obtained in the base-line model will turn out to be robust to such extensions.

3.1 R&D Choice

To keep the model as simple as possible, we assume that the established firm's decision on N, the degree of R&D activity is made at outset of the game. Now assume that the firm initially sets up the R&D division installing basic equipment that is necessary for starting the R&D activities in house. If the firm installs more equipment, the firm can hire more scientists. However the installation cost becomes increasingly more expensive implying decreasing returns to scale in R&D. For simplicity, the hiring cost of scientists and their wage is assumed to be zero. The consequence of this normalization is that the firm optimally hires the maximum number of scientists that the R&D equipment installed can accommodate. Then, there is an indirect and positive relation between the installation expense and the number of scientist, N. We express this relation as a function, $c(N)$, where c is non-negative, strictly increasing and convex. As before we assume that at any point in time after the R&D activity has started, each scientist discovers a project with time-invariant probability, λ, that is, the arrival rate of a project per scientist is λ and the one for the whole R&D division is $N\lambda$.

Initially, the firm chooses the size of the R&D equipment, N such that:

$$\max_N V^*(N) - c(N),$$

where $V^*(N)$ is the value function derived in the previous section as a function of N. The first order condition for this problem gives the following simple result:

Proposition 3 *The optimal size of the R&D department, N^* is increasing in δ and λ and decreasing in r.*

The interpretation of this proposition is straightforward. When δ and/or λ increases or r decreases, the marginal return to R&D effectively increases. Thus the firm has a higher incentive to conduct R&D. As a consequence, endogenizing N effectively reinforces the results presented in the previous section.

3.2 Optimal Dynamic Adoption of Many Projects

So far we assumed that the firm can adopt at most one more project. We now extend the model to the case in which the firm can adopt finitely-many projects. Suppose that the firm will live infinitely long from date 0. Also suppose that the firm can possibly adopt J projects. We label the projects adopted $j = 1, 2, ..., J$, sequentially. For instance, the project adopted earliest is the first project and $j = 1$. Let V_j be the option value of the firm when it is selecting the jth project and τ_j be the date of adopting the jth project. The firm's payoff in this case is:

$$U = E\left[\int_0^{\tau_J} e^{-rt} C^F(t)\,dt\right],$$

where τ_J is the time when the firm internally adopts the Jth project and $C^F(t)$ is the firm's cash flow at time t.

We say that the firm is in the jth period if it has already adopted $j-1$ projects but has not adopted the jth project. To make the problem tractable, we maintain the assumptions on G made in the previous section. Irrespective of how many projects the firm has already adopted, G is independently and identically distributed across time and period. Due to this assumption, there are only two state variables: one is j, in which period the firm is and t, the calendar time. Similar to the model in the previous section, using t is to simplify the formalization since the firm's maximization problem must be stationary within a period. Different from the previous section, internal adoption leads to not only the loss of the current option value but also to the gain of the option value in the next period. Let V_j be the option value when the firm is in jth period. Let $V_j\left(\mathbf{V}_j\right)$ be the discounted sum of expected cash flow from the jth project to the last project given that the firm has the option value sequence $\mathbf{V}_j\!=\left\{V_j, V_{j+1}, ..., V_J\right\}$. Lemma 2 in Appendix summarizes the equilibrium outcome of the negotiation and the value function in the jth period. The basic characteristics of the optimum and value function are similar to the one-project case. If we rewrite V by $v_j = V_j - V_{j+1}$ in Figure 1, we obtain a similar division of the regions for internal adoption, external adoption, and shelving. Thus, the firm still optimally rejects projects and a start-up may externally adopt them even though the firm has the capacity to accommodate several projects.

The next proposition states how the option value v_j evolves over time.

Proposition 4 *Let* $v_j = V_j - V_{j+1}, \forall j,\ \ v_j^* \geq v_{j-1}^*$.

The proposition implies that the firm becomes pickier over the time. As a mirror image, start-ups emerge if the established firm matures. Finally, the proposition also implies that the firm diversifies when young and becomes more focused in its project selection when it matures. This result should be contrasted with the effect of a change in λ. A slower innovation rate, which we associate with a more mature market results in the established firms becoming less selective in their project selection process.

3.3 The Firm Owns the Property Rights

We now study the case in which the firm owns the property rights to the projects. The key difference from the previous case in which the scientist owns the property rights is that the scientist cannot start up the firm without buying the property rights from the firm. Hence, the outside option of the firm and the scientist is zero in all cases when no agreement is reached. Because we don't need to distinguish a case in which $u > 0$, from the other, the division of the surplus becomes simpler than before.

The following lemma summarizes the outcome of the negotiation between the parties:

Lemma 3 *Let $\overline{R}_F^k$ and $\overline{R}_S^k$, $k = 1, ..., 6$ be the payoffs of the firm and the scientist, respectively and let P_F be the transfer from the firm to the scientist in case of the firm ownership. Then,*

1. *if $\{a, b, u\} \in \omega^1 \cup \omega^2$, the project is internally adopted, and $\overline{R}_F^1 = \overline{R}_F^2 = \delta(a + b + u - V)$ and $\overline{R}_S^1 = \overline{R}_S^2 = (1 - \delta)(a + b + u - V)$. The transfer $P_F = (1 - \delta)(a + b + u - V)$.*

2. *if $\{a, b, u\} \in \omega^3 \cup \omega^4$, the project is externally adopted, and $\overline{R}_F^3 = \overline{R}_F^4 = \delta(b + u)$ and $\overline{R}_S^3 = \overline{R}_S^4 = (1 - \delta)(b + u)$. The transfer, $P_F = b - \delta(b + u)$.*

3. *if $\{a, b, u\} \in \omega^5 \cup \omega^6$, the project is shelved and $\overline{R}_F^5 = \overline{R}_F^6 = 0$ and $\overline{R}_S^5 = \overline{R}_S^6 = 0$. The transfer is equal to zero.*

Proof of Lemma 3 is omitted because it is similar to the one of Lemma 1. It is interesting to compare $\overline{R}_F^k$ (firm ownership) with R_F^k (scientist ownership). For the sake of exposition let us assume that the endogenously determined option value, V, does not differ across the two ownership cases. Comparing Lemmas 1 and 3, we see that $\overline{R}_F^k$ and R_F^k have the same expression for $k = 2, 4, 6$ and that they are different for $k = 1, 3, 5$. This is intuitive. Note that $u \leq 0$ if k is even ($k = 2, 4, 6$) and that $u > 0$ if k is odd ($k = 1, 3, 5$). If $u \leq 0$, the allocation of the ownership does not matter because the fall back option is "not to externally adopt" for both cases. If $u > 0$, the fall back option is different across the two ownership regimes and so are the payoffs. Crucial here is that the firm can push down the scientist's as well as its own payoff to zero by leaving the negotiation table. Continuing to assume that V is the same across both regimes, we get:

$$\overline{R}_F^k - R_F^k = \delta u - (1 - \delta)\, b,\ k = 1, 3, 5.$$

By assumption, u is positive for $k = 1, 3, 5$. Thus, if b is negative, that is, the project cannibalizes the existing projects of the established firm, $\overline{R}_F^k > R_F^k$. This is an intuitive case such that the party who owns the property rights can appropriate more rents. It is however important to stress that this intuitive case does not hold when b is positive. Note that if b is positive, scientist ownership relative to firm ownership increases the fall back payoff not only of the scientist but also of the firm. This effect is stronger for the firm's fall back payoff than the scientist's if b and/or δ are large and/or u is small.

The above observation suggests that *the firm may want to voluntarily gives away the ownership to the property rights such that the scientists cannot commit not to externally adopt the project.* In this way, the firm may strengthen its own bargaining position relatively more than the scientist and as a consequence the firm can appropriate a bigger part of the surplus at the negotiation stage.

Noting that the problem is again time-invariant, the value function in the case of firm ownership is:

$$V = \frac{\delta \int_{\omega^1 \cup \omega^2} (a + b + u)\, dG + \delta \int_{\omega^3 \cup \omega^4} (b + u)\, dG}{\rho + \delta \int_{\omega^1 \cup \omega^2} dG} \tag{2}$$

The numerator of V consists of two parts: the first part represents the expected future profits from adopting the project, and the second part, the gain from selling the project to the scientist. The second part contrasts sharply with the previous case in which the scientist owns the property rights. The firm can now appropriate a part of the gain from external adoption, $b + u$ even though $u > 0$. Despite this difference, it is clear that the results on the comparative statics with respect to the option value presented in the previous section also apply to this case. Thus, changes in ownership allocation do not affect our basic results.

Let V^F be the optimal cut-off value that satisfies equation (2) and V^S the optimal cut-off value that satisfies equation (1). That is, V^F is the equilibrium option value to the firm when it owns the property rights and V^S is the one when the scientist owns the property rights. An interesting question is which option value, V^F or V^S, is the larger one. The answer to this question is ambiguous because of the reason stated above. Scientist ownership generally strengthens the bargaining position of the scientist while it may strengthen the bargaining position of the firm even more. Which effect dominates depends on G and, therefore, we don't have an unambiguous conclusion.

3.4 Extra cost for startup

Next, we study how the environment for start-up affects the project selection policy of the established firm. To do so, we denote i as the extra loss by adopting the project externally. That is, the total gain from start up is equal to $b + u - i$. A reduction in i can be interpreted as a start up subsidy or improved access to venture capital. The destiny of the project now depends on the five variables, V, a, b, i and u. External adoption gives the net surplus equal to $b + u - i$; internal adoption, $a + b + u - V$ and shelving zero. Thus, again letting $B = b + u$, the efficient destiny of the project is determined by $\max\{B - i, a + B - V, 0\}$. First note that internal adoption occurs only if $a \geq V - i$ because otherwise external adoption yields a higher payoff than internal adoption. On a similar account, external adoption occurs only if $a < V - i$. The necessary and sufficient condition that internal adoption occurs is therefore $a \geq V - i$ and $a + B - V \geq 0$ and the one that external adoption occurs is $a < V - i$ and $B - i \geq 0$. Figure 2 graphically shows the efficient destiny of a project and Lemma 4 in Appendix describes the equilibrium outcome of the negotiation.

A decrease in i unambiguously increases the internal adoption region because V^* decreases. Interestingly, the effect on the external adoption region is ambiguous. One can interpret a decrease in i as the introduction of start-up subsidies or the development of a venture capital market. Nonetheless, such regulatory changes may not promote start-up in our model. They increase the number of profitable projects

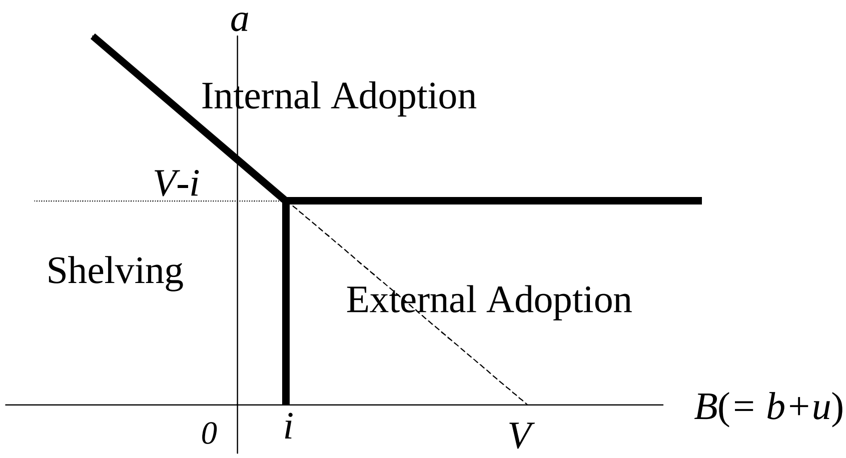

Figure 2:

for start-ups but also make the established firms adopt more projects internally. Hence, whether such changes promote start-ups depends on which effect, the former direct effect or the latter indirect, is larger.[14] Burke and To (2001) find a similar result when analyzing the effect of lower entry barriers on an industry. The reduced cost of entry may lead to the reduction of entry rate and reduce economic efficiency because the incumbent limits the number of employees it hires in the first place in order to reduce the future threat of entry by employees. The proposition also implies that the established firm becomes more diversified with respect to project selection upon a positive regulatory change towards start-ups.

3.5 Cost of searching for scientists

So far we implicitly assumed that when scientists leave to adopt their project externally, the firm can find their replacement without any cost. We were implicitly assuming this by supposing that the project arrival rate $N\lambda$ won't change after any external adoption. In reality, replacing the former scientists may be costly. The firms need to advertise the vacancy, to interview candidates and to negotiate with them. This extension is easily incorporated into the analysis however. Similar to the case

[14] For instance, Michelachi and Suarez (1999) show that the development of a stock market increases the number of start-ups by facilitating to match entrepreneur and venture capitalists easier. This is different from our model in not considering the effect on the project adoption behavior of the established firms.

above in which external adoption requires extra costs, we just need to subtract the replacement cost from the total efficiency gain. One difference from the case above is that the firm rather than the scientist must incur this cost *per se*. As a consequence, the firm stands at a weaker bargaining position and its payoff will go down.

3.6 Acquisition of ideas

Up to now we have restricted attention to ideas generated by the research department of the firm. However, the firm could also scan the technology space for interesting inventions to commercialize. If we assume that the scientists own the intellectual property rights to their ideas, the established firm is competing for ideas outside the firm as well as ideas developed within the firm. This has no real consequences for the optimal project rejection decision of the established firm. These inventions would then be measured against the same option value, i.e. using the scarce, critical resource of the established firm.

Our model does not include uncertainty about the commercialization of an idea. Once the idea is known, its fit and profitability are certain. In reality this is unlikely to be true. Typically the evaluation of an idea and its commercialization will involve several stages. A project could be rejected at an early stage because of the uncertainty surrounding its fit and profitability, i.e. it does not make the cut at the established firm. Nevertheless, after commercialization by a start up firm, some of this uncertainty is resolved and the innovation might now pass the cut for one of the next evaluation stages at the established firm. In that case the established firm can consider acquiring the start up firm in order to reintegrate the project.

4 Illustrative Case

The evolution of the hard disk drive industry provides a nice illustration of our model. Christensen (1997) distinguishes between two types of innovations: sustaining technologies and disruptive technologies. The sustaining technologies improve the performance characteristics of hard disk drives from the perspective of the existing customer base (high a innovations). Disruptive technologies, however, improved characteristics of hard disk drives that were potentially appealing to new customers, but these new customers were not yet clearly identified at the time of innovation (low a innovations). Sustaining technologies were typically related to improvements of the storage capacity and access times of the hard disks. This, nevertheless, did not mean that these technologies were not drastic. Moving from ferrite-oxide read/write heads to thin-film heads in the 1980s and to magneto-resistive heads by the mid-90s involved continuous investments in R&D. The new technologies were risky, complex and expensive to develop. For example, IBM and its rivals each spent about $100 million developing the thin-film heads. Interestingly, *all sustaining technologies, whether drastic or not, were first introduced by existing hard disk drive manufacturers.*

Disruptive technologies in this industry typically related to the size and weight of the hard disk drives. The standard size of hard disk drives decreased from 14 inch in the 70s to 8 inch in the early 80s, down to 5.25 inch and 3.5 inch in the 90s. The latest technology has introduced 1.8 inch hard disks. *All of these new disruptive technologies were first introduced by new entrants* and later adopted by the existing hard disk drive manufacturers that had survived the introduction of the disruptive technology. These disruptive technologies were not technologically complex. In fact, these new model sizes typically had been constructed from off the shelf components and some of the existing hard drive manufacturers actually possessed the technology, but rejected the idea of introducing the new technology because it did not satisfy the needs of the existing customer base. A case in point is the rejection by management and customers of Seagate, the leading 5.25 inch hard disk drive producer, of the 3.5 inch technology in 1985. Customers of Seagate, manufacturers of full sized desktop computers like IBM, preferred the 5.25 inch drives with storage capacity of 40 to 60 MB. At the time of their introduction the 3.5 inch drives could only store 20 MB at a higher cost per MB. In 1987 Conner Peripherals, a new entrant in the hard disk drive market formed by disaffected employees from Seagate and Miniscribe, the two largest 5.25 inch manufacturers, started shipping 3.5 inch drives. Conner realized sales of $113 million in its first year of existence. Nearly all of these sales came from Compaq Computers which primarily used the 3.5 inch drives for its new portable and laptop machines as well as small desktop models for which customers were willing to accept lower capacity and higher cost per MB to get lower weight, greater ruggedness and lower power consumption. (Interestingly, Compaq made a $30 million initial investment in Conner). The rate of technological improvements with respect to storage capacity and access time of the new drive format outstripped the improvements in the old format so that after a few years customers of the old format switched to the new format. Existing hard drive manufacturers that survived the shift in format, such as Seagate, started supplying their existing customer base with the new format, but had a hard time penetrating the market for portable/laptop/notebook computers. Similar stories can be told about the shifts from 14 inch to 8 inch drives, from 8 inch to 5.25 inch drives and currently from 2.5 inch to 1.8 inch drives.

The predictions of our model are consistent with the findings in the hard disk drive market. The existing manufacturers of disk drives needed to make decisions about which projects to fund and implement. Therefore, they preferred to develop technologies that catered to their current customer base and rejected technologies for which the firms at that point in time did not have a competitive advantage in introducing given their strategic commitment to the existing customer base. Nor did these technologies represent a competitive threat at the moment of the decision: the technology was not complex and the performance of the hard disk drives was inferior to their existing product. (i.e. the disruptive technology has a low success probability and provided a bad fit for the hard drive manufacturers of the previous generation hard drives). The "disruptive" technology projects (low a projects) are rejected and the researchers in charge, unhappy with the situation, decide to set up a new company to produce the new drive format building up a new customer base. Given the frenetic pace of technological evolution of the disk drive industry, the price per MB declined at about 5% per quarter for more than 20 years, the new formats quickly entered into competition with the old format.

5 Conclusions

In many industries, radical innovations are introduced by new entrants, in many cases start up firms. In the management literature this has been seen as a failure of the incumbent firms to respond to changes in their environment because of organizational inertia. Often the knowledge for the innovation is present within the firm, but the inefficient decision making by the firm results in foregoing promising projects. In the economics literature, this fact has been explained as a market failure on the one hand, and as efficient underinvestment because of diverging incentives to invest in R&D on the other. The market failure relates to the absence of property rights over innovations. The only way that scientists can appropriate some of the returns to their ideas is by setting up their own firm. They refuse to reveal their ideas to their current employer for fear of being expropriated. The efficient underinvestment theory claims that for drastic innovations, an entrant has a higher incentive to commercialize the innovation. However, when reading the case history of many new ventures carefully, one finds that many successful entrepreneurs set up their own firms only after they did reveal their ideas to their employers and the employers declined to develop the idea within the firm. Furthermore, many of these innovations are not drastic in the economic sense, but are introduced by entrants nevertheless. If this was due to inefficient behavior by the management of incumbents firms, one would expect that over time firms correct for this mistake.

In contrast to these existing views, our model hinges neither on inefficient decision making nor on weak protection of property rights or the existence of drastic innovations. We claim that the established firm and the start-up firm adopt different types of projects as a consequence of optimal project allocation based on a comparative advantage theory. The start-up firm may seem more "innovative" than the established firm because the comparative advantage of the start-up firm is to commercialize "innovative" projects, which do not fit with the established firms' existing assets. In addition, the model integrates various facts found in the industrial organization literature about the new firm start-up rate, firm focus, firm growth, and innovation. Contrary to common belief, we find that the development of venture capital markets and stock markets, or, subsidies toward new firms do not always increase the start-up rate. We also find that the established firm may want to give away the ownership to the project.

A number of interesting extensions of the model are left for further research. One extension is related to the growth of the firm. In order to really introduce firm growth we need to make the "fit" parameter a dynamic and dependent on previously accepted projects. Our intuition, guided by the results in section 3.2, suggests that as firms grow, the fit of new projects becomes more important. Therefore, the firms are more likely to reject project proposals implying a slow down in the growth rate of the firm. In addition, we might expect that as we accept more projects, excess capacity to implement projects is reduced.

Second, we treated the adoption capacity of the firm exogenous. Nevertheless, certain firms have a very active tradition of intrapreneurship and seem to have a higher adoption capacity. Examples of these firms are 3M, Dupont, and General Electric. This begs the question why some firms have a bigger capacity to accommodate more projects than others and how firms choose this adoption capacity. Finally, although our model has a clear prediction on firm focus and diversification, we have not yet been successful in relating the results with historical data. For instance, in the late 1960s we observe the conglomerate merger wave in which many firms diversify their operations. On the contrary, in 1980s, many firms became more focused. We wish to explore if our model can shed some light on these events.

6 Appendix

6.1 Proof of Lemma 1

We distinguish four cases each of which gives different fall-back options for the firm and the scientist.

First, suppose $\{a, b, u\} \in \omega^1$, then if the firm does not buy out the innovation, the scientist's payoff is equal to u and the firm's payoff is $V + b$ because the scientist does want to start up a new firm. Thus, the total surplus in this case is equal to $b + u + V$. If the firm buys out the innovation, the total surplus is $a + b + u$. Since

$a+b+u \geq V$, the buyout occurs and the payment is $u+(1-\delta)(a-V)$. This proves the first sentence of the lemma.

Second, $\{a,b,u\} \in \omega^2$, then if the firm does not buy out the innovation, the scientist's payoff is equal to zero and the firm's payoff is V because the scientist does not want to start up a new firm. Thus, the total surplus in this case is equal to V. If the firm buys out the innovation, the total surplus is $a+b+u$. Since $a+b+u \geq V$, the buyout occurs and the payment is $(1-\delta)(a+b+u-V)$. This proves the second sentence of the lemma.

Third, suppose that $\{a,b,u\} \in \omega^3$, then if the firm does not buy out the innovation, the scientist's payoff is equal to u and the firm's payoff is $b+V$ because the scientist does want to start up a new firm. Thus, the total surplus in this case is equal to $b+u+V$. If the firm buys out the innovation, the total surplus is V. Hence the buyout does not occur and the payment is zero. This proves the third sentence in the lemma.

Fourth, suppose $\{a,b,u\} \in \omega^4$, then if the firm does not buy out the innovation, the scientist's payoff is equal to zero and the firm's payoff is V because the scientist does not want to start up a new firm. Thus, the total surplus in this case is equal to V. If the scientist starts up, the total surplus is $b+u+V$. As $b+u \geq 0$, the firm subsidizes the scientist to start up by making a payment of $P_S = b-\delta(b+u)$. This proves the fourth sentence in the lemma.

Fifth, suppose that $\{a,b,u\} \in \omega^5$, then if the firm does not buy out the innovation, the scientist's payoff is equal to u and the firm's payoff is $b+V$ because the scientist does want to start up a new firm. Thus, the total surplus in this case is equal to $b+u+V$. If the firm buys out the innovation, the total surplus is V. Hence the buyout occur and the payment is $u-(1-\delta)(b+u)$. This completes the proof of the fifth sentence in the lemma.

Sixth, suppose that $\{a,b,u\} \in \omega^6$, then if the firm does not buy out the innovation, the scientist's payoff is equal to zero and the firm's payoff is V because the scientist does want to start up a new firm. Thus, the total surplus in this case is equal to V. If the firm buys out the innovation, the total surplus is V. Hence the buyout does not occur and the payment is zero. This completes the proof of the sixth sentence in the lemma.

6.2 Proof of Propositions 1-2

Rearranging the terms of the equation (1) gives:

$$\begin{aligned} & V\left(\rho+\delta \int_{\omega^1 \sqcup \omega^2} dG\right) \\ & -\left(\int_{\omega^1}(\delta a+b)\, dG+\delta \int_{\omega^2}(a+b+u)\, dG+\int_{\omega^3} b dG+\delta \int_{\omega^4}(b+u)\, dG+\int_{\omega^5}((1-\delta) b-\delta u)\, dG\right) \\ = & \ 0 . \end{aligned}$$

Let Q be the left hand side of the equation above. The second order condition for the optimality of V implies that $sign\,(dV/dj) = -dQ//dj$. Since

$$-\frac{dQ}{d\rho} = -V < 0,$$

and

$$-\frac{dQ}{d\delta} = \int_{\omega^1 \sqcup \omega^2} (a - V)\, dG + \int_{\omega^4} (b+u)\, dG - \int_{\omega^5} (b+u)\, dG > 0,$$

then the two propositions follow. Q.E.D.

6.3 Proof of Proposition 3

In the first order condition, (1), N, λ, δ, and $1/r$ are super modular. Thus the proposition follows. Q.E.D.

6.4 Lemmas 2 and 4

Lemma 2 *Let $V_j - V_{j+1} = v_j$ and*

- $\omega^{1j} \equiv \{a, b, u | a - v_j > 0,\ a + b + u - v_j\ > 0 \text{ and } u > 0\}$
- $\omega^{2j} \equiv \{a, b, u | a - v_j > 0,\ a + b + u - v_j\ > 0 \text{ and } u \leq 0\}$
- $\omega^{3j} \equiv \{a, b, u | b + u \geq 0,\ a \leq v_j \text{ and } u > 0\}$
- $\omega^{4j} \equiv \{a, b, u | b + u \geq 0,\ a \leq v_j \text{ and } u \leq 0\}$
- $\omega^{5j} \equiv \{a, b, u | b + u < 0,\ a + b + u - v_j < 0 \text{ and } u > 0\}$ *and*

- $\omega^{6j} \equiv \{a, b, u | b + u < 0, \ a + b + u - v_j < 0 \text{ and } u \leq 0\}$.

1. *If* $\{a, b, u\} \in \omega^{1j}$, *the project is internally adopted, and* $R^F = b + \delta(a - v_j)$ *and* $R^S = P_S = u + (1 - \delta)(a - v_j)$.

2. *If* $\{a, b, u\} \in \omega^{2j}$, *the project is internally adopted, and* $R^F = \delta(a + b + u - v_j)$ *and* $R^S = P_S = (1 - \delta)(a + b + u - v_j)$.

3. *If* $\{a, b, u\} \in \omega^{3j}$, *the project is externally adopted, and* $R^F = b$ *and* $\pi^S = u$. *The transfer,* $P_S = 0$.

4. *If* $\{a, b, u\} \in \omega^{4j}$, *the project is externally adopted, and* $R^F = \delta(b + u)$ *and* $R^S = (1 - \delta)(b + u)$. *The transfer,* $P_S = b - \delta(b + u)$.

5. *If* $\{a, u\} \in \omega^{5j}$, *the project is shelved and* $R^F = b - \delta(b + u)$ *and* $R^S = P_S = u + (1 - \delta)(b + u)$.

6. *If* $\{a, u\} \in \omega^{6j}$, *the project is shelved and* $R^S = 0$ *and* $R^S = 0 = P_S$.

Lemma 4 *We define*

- $\omega^1 \equiv \{a, b, u | a - V + i > 0, \ a + b + u - V > 0 \text{ and } u - i > 0\}$
- $\omega^2 \equiv \{a, b, u | a - V + i > 0, \ a + b + u - V > 0 \text{ and } u - i \leq 0\}$
- $\omega^3 \equiv \{a, b, u | b + u - i \geq 0, \ a \leq V - i \text{ and } u - i > 0\}$
- $\omega^4 \equiv \{a, b, u | b + u - i \geq 0, \ a \leq V - i \text{ and } u - i \leq 0\}$
- $\omega^5 \equiv \{a, b, u | b + u - i < 0, \ a + b + u - V < 0 \text{ and } u - i > 0\}$ *and*
- $\omega^6 \equiv \{a, b, u | b + u - i < 0, \ a + b + u - V < 0 \text{ and } u - i \leq 0\}$. *Then,*

1. *If* $\{a, b, u\} \in \omega^1$, *the project is internally adopted, and* $R^F = b + \delta(a - V + i)$ *and* $R^S = P_S = u - i + (1 - \delta)(a - V + i)$.

2. *If* $\{a, b, u\} \in \omega^2$, *the project is internally adopted, and* $R^F = \delta(a + b + u - V)$ *and* $R^S = P_S = (1 - \delta)(a + b + u - V)$.

3. *If* $\{a,b,u\} \in \omega^3$, *the project is externally adopted, and* $R^F = b$ *and* $\pi^S = u - i$. *The transfer,* $P_S = 0$.

4. *If* $\{a,b,u\} \in \omega^4$, *the project is externally adopted, and* $R^F = \delta(b+u-i)$ *and* $R^S = P_S = (1-\delta)(b+u-i)$.

5. *If* $\{a,b,u\} \in \omega^5$, *the project is shelved and* $R^F = b - \delta(b+u-i)$ *and* $R^S = P_S = u - i + (1-\delta)(b+u-i)$.

6. *If* $\{a,b,u\} \in \omega^6$, *the project is shelved and* $R^S = 0$ *and* $R^S = 0 = P_S$.

Proof of Lemmas 2 and 4 is omitted because it is similar to the one of Lemma 1.

6.5 Proof of Proposition 4

According to the asset pricing formula, the firm's value function in the jth period is therefore:

$$\begin{aligned} & V_j \\ = \; & \frac{\int_{\omega^1}(\delta(a+V_{j+1})+b)\,dG + \delta\int_{\omega^2}(a+b+u+V_{j+1})\,dG}{\rho+\delta\int_{\omega^1\cup\omega^2}dG} \\ & + \frac{\int_{\omega^3} bdG + \delta\int_{\omega^4}(b+u)\,dG + \int_{\omega^5}((1-\delta)b-\delta u)\,dG}{\rho+\delta\int_{\omega^1\cup\omega^2}dG} \end{aligned} \tag{3}$$

for $j = 1, ..., j-1$ and $V_{J+1} = 0$.

Rearranging the equation (3) gives:

$$\begin{aligned} v_j = & \left(\frac{\delta\int_{\omega^1\cup\omega^2}dG}{\rho+\delta\int_{\omega^1\cup\omega^2}dG} - 1\right)V_{j+1} \\ & + \frac{\int_{\omega^1}(\delta a+b)\,dG + \delta\int_{\omega^2}(a+b+u)\,dG + \int_{\omega^3} bdG + \delta\int_{\omega^4}(b+u)\,dG + \int_{\omega^5}((1-\delta)b-\delta u)\,dG}{\rho+\delta\int_{\omega^1\cup\omega^2}dG}. \end{aligned} \tag{4}$$

Totally differentiating the equation (3) gives:

$$\frac{dv_j^*}{dV_{j+1}} < 0, \;\forall j < J.$$

Noting that $V_j > V_{j+1}$, then it follows that $v_j^* > v_{j-1}^*$. Q.E.D.

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