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Abstract

We study a situation in which an R&D department promotes the introduction of an innovation, which results in costly re-adjustments for production workers. In response, the production department tries to resist change by improving the existing technology. We show that firms balancing the strengths of the two departments perform better. This principle is employed to derive several implications concerning the hiring of talents, monetary incentives, and technology investment policies. As a negative effect, resistance to change might distort the R&D department's effort away from radical innovations. The firm can solve this problem by implementing the so-called "skunk works model" of innovation where the R&D department is isolated from the rest of the organization.

JEL Codes: *L2, M12, M54, O31, O32.*

Key words: Resistance to change, innovation, skunk works model, contest.

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1 Introduction

Innovation is one of the main drivers of a firm's competitive advantage. Innovation, however, has often a disruptive effect on the organization, because it is associated to or induces organizational change and adaptation. A new technology, a new product, or a new marketing method often imply the reshaping of relevant resources and expertise, the change of established norms and routines, and the rapid obsolescence of accumulated learning (Anderson and Tushman, 1986). The magnitude and intensity of such effects depend on the characteristics of the innovation, with radical innovations imposing major adjustments within the organization (Henderson, 1993). Change is costly, not only for the firm as a whole, but also for each of its individual members. In fact, the employees of the firm might react to change by fighting it back rather than adapting to it.[1]

How should a firm manage this resistance to change? This issue is of central importance for a firm's innovative capability and, ultimately, survival. To address this question, we build a model where the implementation of a successful innovation, backed by an R&D department, results in costly changes for a production department. In response, the production department tries to improve the current technology in an attempt to convince the management not to implement the innovation. As an example of the type of situation we have in mind, Foster (1986) describes the case of DuPont and its decision in the 1950s to move from the established nylon technology to the new polyester technology for the production of car tires. Behind the decision there was a conflict between production engineers at the nylon plant and researchers supporting the new technology. The production engineers managed to push the nylon technology to the limits, and provided sufficient evidence to convince the management that the nylon technology would remain competitive. The polyester technology was eventually shelved.

We model the organizational conflict between the two departments using tools borrowed from contest theory. Contests are situations in which the participants expend money or effort to increase their chances of winning a prize. Examples include rent-seeking and lobbying situations, tournaments, arms races, political campaigns, athletic contests, patent races and procurement of innovations (Baye et al., 1996; Taylor, 1997; Che and Gale, 2003; Ganuza and Hauk, 2006). In our model, the production and the R&D departments are involved in a contest of technologies. The R&D department tries to develop a new technology while the production department works

[1] Organizational theory has investigated the reasons behind resistance to change (March, 1991; Morrill, 1991). In addition to those already mentioned, it also lists reasons of a more psychological nature such loss of power and prestige, changing definitions of success, fear of technology, and fear of having to relearn.

on improving the existing technology. When the outcome of their efforts becomes known, the most valuable technology is adopted by the firm, and the winning department receives the corresponding reward. The prize of the R&D department can either be monetary or non-monetary, e.g. the satisfaction of seeing the innovation being used by the firm, whereas the reward of the production department is the saving in adjustment costs that it would have had to pay had the new technology been implemented.

We show that organizations with greater resistance to change, i.e. firms whose production departments face larger costs of re-adjustment, exhibit a lower probability of introducing a new technology. However, this is not always profit reducing for the firm as a whole. Indeed, it is shown that firms with highly motivated and productive R&D departments might benefit from a stronger resistance to change. By contrast, firms whose R&D departments are weak or badly motivated would suffer from stronger resistance to change. More in general and consistent with the literature on contests, our findings suggest that firms that maintain a balance of powers between the two departments outperform firms where one department largely dominates the other. The intuition is that when a department falls well behind the other department, it has almost no incentives to produce effort to enhance its technology, because it is very unlikely that such effort has an impact on the final outcome. This relaxes competition and, in turn, reduces the effort of the other department as well.[2] This basic principle is then discussed in a number of extensions that include the selection of talents, the use of monetary incentives, and technology-specific investments.

In the extension on technology-specific investments we address the tension between exploitation and exploration that is well-known to scholars of innovation management (Hannan and Freeman, 1984; Levinthal and March, 1993; March, 1991). Exploitation refers to achieving maximal profits in the current situation whereas exploration refers to the process of searching for new opportunities. The thrust of the argument in this literature is that these two activities are in constant tension. On the one hand, exploitation might generate structural inertia and reduce a firm's ability to adapt to future environmental changes and opportunities. On the other hand, exploring new alternatives might disrupt successful routines. Our paper, although it leaves many of the subtleties in the background, provides an additional view on such a tension. Particularly, we show that exploitation might under certain conditions *increase* exploration by exposing the

[2]Evidence consistent with the notion that this type of organizational conflicts spurs innovation can be found in Ginn and Rubinstein (1986). They study 61 new product introductions in a major chemical company. It is found that product introductions leading to a higher level of conflict, measured by how incompatible the R&D department's and the production department's goals are, tend to be more successful than product introductions causing less conflict.

R&D department to tougher internal competition.

The adoption of a new technology is a decision that has important redistributional effects within the organization. The economics literature has argued that such decisions are subject to "influence activities" by the involved parties, i.e. efforts aimed at affecting the decision maker (Meyer et al., 1992; Milgrom, 1988; Milgrom and Roberts, 1988). Such efforts distort resources from more productive uses, slow down the decision making process, and sometimes prevent organizational changes altogether (Schaefer, 1998). The story we tell here is closely related to this literature but with the important difference that efforts are spent on productive technology improvements rather than on unproductive influence activities. Our approach can be thought of as representing a different time horizon. Shortly before the decision is taken, the performances of the technologies are more or less given. The departments will therefore spend resources trying to promote their preferred technology by presenting it well, "buttering up" decision makers, etc. This is the situation captured by influence activity models. Foreseeing that a conflict might arise, we argue that there is an incentive earlier in the game to improve the technologies to have as strong a case as possible should the conflict occur. We focus here on this long-run effect, but this is, of course, not to say that influence activities do not exist or are irrelevant.

Although our analysis stresses the positive effects of conflict, we argue in the second part of the paper that (the threat of) conflict might entail important costs for the firm. In particular, the prospect of a costly contest of technologies might push the R&D department towards low risk, incremental projects that entail low adaptation costs for the production department. Such incremental innovations meet much less internal resistance than radical innovations that require the production department to undertake more costly changes. Thus, the R&D department refrain from investigating more path-breaking research trajectories at the detriment of long-run firm profits.

We analyze an organizational solution to this problem, known as the "skunk works model" of innovation, which consists in isolating the team of researchers from the influence of the rest of the organization. The Aurora project set up by Teradyne in the mid 90s is exemplar of such an organizational solution. Teradyne was the market leader (with about 22% of the world market) in automatic test equipment used in the production of semiconductors. Teradyne employed a technology based on UNIX operating system software, and was trying to shift to the CMOS technology based on Windows NT. In order to overcome the very high organizational resistance to this change, the company decided to create an independent unit, called the Aurora project, that had the autonomy and resources to work on the new technology (Bower, 2005). The skunk works model of innovation has received lots of attention from management scholars, but we are not aware of any formal economic model that attempts to pin down the virtues of this organizational solution.

We show that adopting the "skunk works" model of innovation can induce the R&D department to choose a radical research trajectory in situations where an in-house R&D department would have chosen an incremental trajectory to avoid the conflict with the production department. The basic idea is that isolating the R&D department prevents the production department from observing the trajectory chosen. Therefore, if the radical trajectory is attractive for the researchers, e.g., because it involves an exciting new technology, an equilibrium where the incremental trajectory is chosen cannot be sustained. The R&D department would here deviate to the more attractive radical trajectory, knowing that the production department cannot observe the deviation and react to it. As a consequence, the radical trajectory is pursued in equilibrium, and the production department responds accordingly by investing to improve the current technology.

Besides the already mentioned works, our analysis is related to two papers by Rotemberg and Saloner. In Rotemberg and Saloner (1995), using a quite different model, the authors study the conflict between the sales and the production departments, with the former wanting a broad product line and the latter wanting long production lines. The firm can potentially benefit from the conflict, because the two departments present valuable information concerning costs to defend their respective positions. Nevertheless, as their emphasis is on cost revelation, they do not study questions related to innovation policies, which is our main interest here. Rotemberg and Saloner (2000) analyze competition between two R&D teams inside a firm. Again, the focus of their paper is quite different from ours. Rotemberg and Saloner study how hiring a biased ("visionary") CEO can induce higher efforts by the teams, but they do not look at issues such as, e.g., the skunk works model and the conflict between exploitation and exploration, which constitute the main contribution of our work.

The rest of the paper is organized as follows: The next section describes the basic model that is then solved and discussed in section 3. In section 4 the basic framework is extended to explore several issues related to innovation activity. Section 5 contains the analysis of the skunk works model of innovation, and section 6 concludes.

2 The Basic Model

Our firm is composed by three risk-neutral agents: A production unit (PU), a research unit (RU) and a management unit (MU), which we describe in more detail below. The firm is actually employing a standard technology to produce a given product, which results in a profit of π_1 if no further improvements are made.

The Research Unit The RU expends unobservable *creative effort*, e_R, that probabilistically generates valuable innovations or "ideas". The creative effort results in a new technology of value $\pi_2 + \Delta_R$ with probability p where $\Delta_R = \gamma e_R$. With the complementary probability, $1 - p$, the effort is fruitless. The cost of effort is $c(e_R) = e_R$. The RU receives a reward B if the new technology is adopted and 0 if it is not. Here, B can contain both monetary and non-monetary elements such as peer-recognition or personal satisfaction. We will discuss both these possibilities as we go along. The RU maximizes its utility, which is given by the difference between the expected reward and the cost of creative effort.

The Production Unit The PU expends two types of effort: *Production effort* and unobservable *defensive effort*. The production effort is indispensable for running the technology. The PU receives a payoff of w as compensation for the production effort. We take the level of w as given in the analysis. The defensive effort, e_P, enhances the performance of the existing technology. We have in mind changes in the layout of production facilities, re-engineering of processes, cost reductions obtained through marginal innovations, elimination of inefficiencies, changes in the design of the products which bring about cost savings or quality improvements, and so on. The defensive effort increases the payoff of the existing technology by $\Delta_P = e_P$. The total value of the existing technology is therefore $\pi_1 + \Delta_P$. Such effort does not come for free, and the PU incurs a cost of $c(e_P) = e_P$. We call the effort "defensive", because the PU expends it only when threatened by a new technology. The reason is that the PU has made technology-specific investments in the existing technology such as mastering it, learning how to deal with break downs, establishing routines and rules, etc. A change of technology forces the PU to reinvest in order to be able to produce. The firm can partially compensate such costs through training programs, monetary incentives and other policies. However, totally offsetting the inconveniencies of change might be hard.[3] In particular, we assume that the introduction of a new technology imposes

[3] As we discussed in the introduction, the cost of change for the PU should be interpreted broadly to include also psychological factors.

a cost of F on the PU. Faced with the potential threat of a new technology developed by the RU, the PU is thus willing to exert effort to improve the existing technology, thereby reducing the likelihood that the new technology is adopted, i.e. the PU tries to resist change. The PU maximizes its expected utility that is given by the potential savings in the cost of change minus the cost of the defensive effort.

The Management Unit The last building block of our firm is the MU whose aim is to maximize firm profits. We assume that the firm is able to implement at most one technology, either the existing technology or the new one. There are several reasons why this might be the case. First, the two technologies might produce exactly the same product. Using both would therefore lead to inefficient duplication of costs. Second, the two technologies might depend on different organizational routines, and nurturing both of them would generate incompatibilities. Finally, the technologies might compete for the use of scarce, complementary resources (managerial talents, dedicated sales forces, financial resources, etc.). The key decision of the MU is therefore the choice of the technology. The MU either decides to continue with the existing technology or to implement the new technology, in which case the PU has to adapt to the new course of actions. The profits of the firm consist of the payoff from the technology chosen minus the fixed wage of the PU, and a possible monetary reward to the RU.

Timing The RU expends creative effort to generate a new technology. Simultaneously, the PU expends defensive effort to improve the performance of the existing technology. After uncertainty is resolved, the MU takes a decision about accepting or rejecting the technology proposed by the RU (if a new technology has emerged). At the end of the game, payoffs are realized.

3 Solution of the Basic Model

To grasp the intuition, we solve the model in its simplest version. Several extensions are introduced and discussed later on. We assume that both F and B are exogenously given non-monetary rewards. Here, F represents the adjustment costs that the PU has to bear if a new technology is introduced. The reward to the RU, B, captures non-monetary benefits from having its innovation implemented. What we have in mind here is personal satisfaction, career concerns, internal recognition and status.[4] Alternatively, B could be interpreted as the saved cost of frustration if

[4] A recent paper by Stern (2004) shows that scientists are willing to give up some monetary rewards in exchange for the possibility to work on their preferred research agenda.

a project on which the RU has worked successfully is ultimately rejected. Finally, it is assumed that $\pi_1 = \pi_2 = 0$, since these two parameters do not play a crucial role in the solution of the basic model.

We solve the game starting from the last stage in which the MU takes a decision. Suppose that the RU has developed a new technology. The MU will reject the technology proposed by the RU if $e_P > \gamma e_R$, whereas it will abandon the existing technology if $e_P < \gamma e_R$. This selection rule for the technology is extremely simple and only requires the MU to make ordinal comparisons among alternatives.[5] Both the RU and the PU exert efforts in order to influence the MU's decision in their respective interest. This competition between departments can be conceived as a contest with exogenously given different prizes for the contestants. As tie-breaking rule, we assume that if $e_P = \gamma e_R$ the MU chooses the technology of the dominant unit, i.e. the unit with the highest willingness to invest in the contest. This assumption is commonly made in the contest literature (see, for instance, Che and Gale, 2003, page 653). It is of a similar nature to the assumption that guarantees the existence of a pure strategy equilibrium in a game of Bertrand competition with homogenous products and asymmetric costs.

We distinguish two cases: $F > \gamma B$ and $F < \gamma B$. In the first case the PU has the highest willingness to invest effort into the internal contest. This case, e.g., corresponds to the situation where inertial forces inside the firm are very strong and production workers and engineers are very adverse to change (F large), i.e. there is a strong resistance to change. The researchers are not or cannot be strongly motivated (B low), or their creative effort maps very poorly into valuable technology (γ low). In the second case the RU is willing to invest more effort than the PU to ensure that the new technology is always adopted whenever it materializes. This corresponds to a firm with very flexible human capital in its production department that does not fear change (F low). It is also a firm with highly motivated and capable researchers (B high and γ low).

Before finding the equilibrium of the contest, we establish the following result.

Lemma 1 *There is no equilibrium in pure strategies.*

Intuitive proof: Since the new technology only materializes with probability p, the maximum amount of effort that the PU and the RU are willing to exert are pF and pB, respectively. Consider the case in which $F > \gamma B$. The other case is symmetric. For any $e_R \leq pB$, the PU is

[5] In addition, different selection rules based on cardinal comparisons among alternatives suffer from commitment problems since, although possibly profit enhancing ex-ante, they imply inefficient decisions ex-post. We discuss this issue further in the conclusion.

willing to make a defensive effort such that the MU's decision is tilted in its favor. If it chooses such an effort, the best response of the RU is to exert no creative effort. However, the best response to $e_R = 0$ is $e_P = 0$ given the tie-breaking rule assumed. This is still not an equilibrium because the RU can do better by exerting a creative effort just large enough to win the contest. As this circular argument suggests, no equilibrium in pure strategies exists. ■

Lemma 1 is a standard result in the contest literature (Baye et al. 1996; Che and Gale, 2003). A potential avenue to rescue a pure strategy equilibrium is to make the relationship between the efforts of the contestants and the value of their technology less deterministic.[6] For instance, one could assume that Δ_R and Δ_P are stochastic variables whose distributions depend on e_R and e_P respectively, and that the effort cost functions are convex. Although this formulation would deliver a pure strategy equilibrium, it turns out to be much harder to handle analytically. Thus, the literature on contests has broadly resorted to mixed strategy equilibria that are theoretically perhaps less appealing but are much easier to solve in explicit form. Since the solution allows a very intuitive interpretation as well, we have chosen to follow in this tradition.

Lemma 2 states the mixed strategy equilibrium for the case where the RU dominates the contest, $F < \gamma B$. In the proof we derive the equilibrium in some detail to illustrate how the equilibrium of a contest is constructed. Hillman and Riley (1989) show that the equilibrium reported here is in fact the unique equilibrium.

Lemma 2 *($F < \gamma B$: The RU dominates) In equilibrium the PU randomizes according to the distribution function $G(e_P) = 1 - \frac{F}{\gamma B} + \frac{e_P}{p\gamma B}$ for all $e_P \in [0, pF]$ and the RU randomizes according to the distribution function $H(e_R) = \frac{\gamma e_R}{pF}$ for all $e_R \in \left[0, \frac{pF}{\gamma}\right]$. The expected payoffs for the PU, the RU and the firm are respectively: $U_P = w - pF$, $U_R = p\left(B - \frac{F}{\gamma}\right)$, and $\Pi = \frac{pF}{\gamma B}\frac{F(3-2p)+3\gamma pB}{6} - w$.*

Sketch of the proof: The maximal amount that the RU and the PU would be willing to invest into the contest are pB and pF, respectively. Following the argument outlined in the proof of Lemma 1, it can be shown that there does not exist an equilibrium in mixed strategies where the two units randomize among a finite number of effort levels. Consider instead an equilibrium where the two units randomize among an infinite number of effort levels. In particular, the PU randomizes among all $e_P \in [0, pF]$ according to the distribution function $G(.)$, and the RU randomizes among all $e_R \in \left[0, \frac{pF}{\gamma}\right]$ according to the distribution function $H(.)$. Assuming that

[6] Another alternative is to use a contest function to determine the winner. Here, the probability to win the prize increases with a contestant's effort and decreases with the rival's effort in a continuous manner. We have preferred not to resort to such a function because it leaves unspecified the decision process, which plays an important role in our story.

the RU does not put probability mass on any effort level, which is satisfied in equilibrium, the expected utility of the PU can be written as:

$$\begin{aligned} U_P &= p(1 - H(e_P/\gamma))(w - e_P - F) + (1 - p(1 - H(e_P/\gamma)))(w - e_P) \Leftrightarrow \\ H(e_R) &= \frac{U_P - w + pF}{pF} + \frac{\gamma e_R}{pF}. \end{aligned}$$

Turning to the RU, we have:

$$\begin{aligned} U_R &= pG(\gamma e_R)(B - e_R) + (1 - pG(\gamma e_R))(-e_R) \Leftrightarrow \\ G(e_P) &= \frac{U_R}{pB} + \frac{e_P}{p\gamma B}. \end{aligned}$$

Using $G(pF) = 1$ and $H(pF/\gamma) = 1$, it follows that:

$$\begin{aligned} H(e_R) &= \frac{\gamma e_R}{pF} \text{ for all } e_R \in \left[0, \frac{pF}{\gamma}\right] \text{ and } U_P = w - pF, \\ G(e_P) &= 1 - \frac{F}{\gamma B} + \frac{e_P}{p\gamma B} \text{ for all } e_P \in [0, pF] \text{ and } U_R = p(B - \frac{F}{\gamma}). \end{aligned}$$

Finally, the expected profits of the firm can be written as:

$$E\Pi = \int_0^{\frac{pF}{\gamma}} \left\{ G(\gamma e_R) \left[(p\gamma e_R + (1-p)E(e_P|e_P < \gamma e_R) \right] + (1 - G(\gamma e_R))E(e_P|e_P > \gamma e_R) \right\} h(e_R) de_R - w,$$

where $E(e_P|e_P > \gamma e_R) = \frac{pF+\gamma e_R}{2}$, $E(e_P|e_P < \gamma e_R) = \frac{1}{G(\gamma e_R)} \int\limits_0^{\gamma e_R} \frac{e_P}{p\gamma B} de_p$, and $h(e_R) = \frac{\gamma}{pF}$. Simplifying the expression, we obtain the expected profits reported in the Lemma. ■

The next lemma summarizes the equilibrium outcome for the case where the PU dominates, $F > \gamma B$. The equilibria of all the contests we present in the rest of paper are derived using the method illustrated in the proof of Lemma 2. For this reason, we present the equilibrium strategies, often in the Appendix, but leave out the algebra. Details are available from the authors upon request.

Lemma 3 *($F > \gamma B$: The PU dominates) In equilibrium the PU randomizes according to $G(e_P) = \frac{e_P}{p\gamma B}$ for all $e_P \in [0, p\gamma B]$ and the RU randomizes according to $H(e_R) = 1 - \frac{\gamma B}{F} + \frac{\gamma e_R}{pF}$ for all $e_R \in [0, pB]$. The expected payoffs for the PU, the RU, and the firm are respectively: $U_P = w - p\gamma B$, $U_R = 0$, and $\Pi = \frac{B}{F} \frac{\gamma p(3F + \gamma p B)}{6} - w$.*

The following remark compares the equilibrium outcomes for different values of the exogenous parameters.

Remark 1 *(Comparative Statics) When the RU dominates, the expected creative effort is increasing in F and decreasing in γ, whereas the expected defensive effort is increasing in F and decreasing in γ and B. Expected profits are increasing in F and decreasing in γ and B. When the PU dominates, the expected creative effort is increasing in B and γ and decreasing in F, whereas the expected defensive effort is increasing in B and γ. Expected profits are increasing in B and γ and decreasing in F. Finally, expected efforts as well as expected profits are always increasing in the probability that the new technology is developed, p.*

Proof: The comparative statics follow directly from differentiating the profit expressions in Lemma 2 and 3 and from noticing that the expected creative effort is $\frac{B^2 p\gamma}{2F}$ if $F > \gamma B$ and $\frac{Fp}{2\gamma}$ if $F < \gamma B$, whereas the expected defensive effort is $\frac{Bp\gamma}{2}$ if $F > \gamma B$ and $\frac{F^2 p}{2B\gamma}$ if $F < \gamma B$. ■

To interpret these comparative static results one should bear in mind that the efforts exerted by the two units are aimed at influencing the MU's decision between the existing and the new technology. First, it is obvious that the efforts of the PU and the RU are (weakly) increasing in their respective rewards, F and B. Second, it is interesting to notice that a larger F does not necessarily mean less profits, as one might have expected given that F parametrizes resistance to change.[7] In fact, when the RU dominates, a larger F implies that both units exert more effort and hence profits are higher. More in general, these comparative statics suggest that the firm always prefers to maintain a balance of powers between the RU and the PU. In particular, for given B and γ the profits of the firm are maximized for the value of F that makes the contestants equally strong, $F = \gamma B$. This is reminiscent of the suggestion by organizational theorists that the firm should pursue a balance between exploration of new alternatives and the exploitation of current capabilities. For instance, Levinthal and March (1993) suggest that "...the basic problem confronting an organization is to engage in sufficient exploitation to ensure its current viability and, at the same time, to devote enough energy to exploration to ensure its future viability". Finally, notice that the expected probability of observing a change in the technology, i.e. the expected probability of the RU winning the contest, is increasing in B, p and γ and is decreasing in F.[8]

4 Managing Internal Competition

In this section we analyze different ways in which the MU can manage the competition between the PU and the RU to maximize the rents generated from the creative and the defensive efforts.

[7] By the same argument, having a more motivated R&D department might not always be profit enhancing.

[8] The probability of the RU winning the contest is $pB\gamma/2F$ when PU dominates and $p(1 - F/2B\gamma)$ otherwise.

4.1 Talent of the Employees

One way of influencing the relative strength of the PU and the RU is through the choice of the talent of the people hired for the two units. For simplicity, let us assume that the PU faces a cost of change of F, which is exogenously given at the point in time considered. However, the MU has to decide how talented the researchers of the RU should be. The talent is measured by γ where higher values of γ correspond to more talented researchers, $\gamma \in [0, \overline{\gamma}]$. We also assume that the benefit of having the new technology implemented, B, is independent of the talent.[9] The members of the RU are hired on a market for researchers where more talented researchers command a higher wage. The total wage of the RU is therefore $w_R(\gamma)$ where $\partial w_R(\gamma)/\partial\gamma > 0$ for all γ. Furthermore, $w_R(\gamma)$ is assumed to be sufficiently convex to ensure that the firm's problem is concave in γ. The total expected profits of the firm can be written as:

$$\Pi(\gamma) = \begin{cases} \frac{B}{F}\frac{\gamma p(3F+\gamma pB)}{6} - w_R(\gamma) - w & \text{if } \gamma < F/B \\ \frac{pF}{\gamma B}\frac{F(3-2p)+3\gamma pB}{6} - w_R(\gamma) - w & \text{if } \gamma > F/B \end{cases},$$

where w is the fixed wage of the PU. The expected profits are decreasing in γ when the RU is so talented that it dominates the PU in the contest, i.e. $\gamma > F/B$. Therefore, the optimal level of talent γ^* is the minimum between F/B and the solution to:

$$\frac{B}{F}\frac{p\,(3F + 2\gamma pB)}{6} - w_R'(\gamma) = 0.$$

Since both candidate solutions are increasing in F, the implication is that firms with more resistance to change should hire more able researchers to leverage the internal competition further. This emphasizes the point made above that strong inertial forces are not necessarily a disadvantage for a firm, but can - if properly managed - spur both creative and defensive efforts.

We have looked at the talent of the RU, but a similar argument could be put forward for the PU. Indeed, if the PU dominates in equilibrium, the firm would be willing to pay a wage premium to obtain more talented production workers that face lower costs of adapting to the new technology. Again, the general principle is that the firm chooses a labor force composition that balances the strength of the two units. This result is of a similar flavor as early work by Lazear and Rosen (1981) who suggested that workers in a promotion contest should be matched in groups of similar ability. By contrast, Rotemberg and Saloner (1995) argue that when the conflict between the two departments results in resources being wasted on influence activities,

[9] The results of this section would go through qualitatively unchanged as long as more talented researchers care more about having their ideas implemented than less talented researchers.

the firm can potentially mitigate such a negative effect by making the conflict very unbalanced, i.e. by hiring talented employees only in one division.

4.2 Exploitation versus Exploration

In this extension we address more carefully the relationship between exploitation and exploration that was mentioned in the discussion of the basic model. Organizational theorists have suggested that adaptation to existing environmental demands may foster structural inertia and reduce a firm's capacity to adapt to future environmental changes and new opportunities (Hannan and Freeman, 1984; March, 1991). In other words, a firm that invests in augmenting its current capabilities and maintaining its current focus might perform rather poorly in generating ideas that are outside its core capabilities. Although this tension is already present in our basic model, a better characterization calls for a dynamic setting. We will use a very simple extension of our model to analyze this issue. Assume that there is a previous period ($t = 0$) before the very same game described above ($t = 1$). In period 0 the firm uses the standard technology. This activity generates profits $\pi_0(\alpha)$ where α measures the degree of exploitation. By exploiting the current technology the firm becomes more efficient, eliminates slacks, reduces costs, routinizes activities, enhances specialization and expertise. Hence, we assume that $\partial\pi_0(\alpha)/\partial\alpha > 0$. The cost of pushing up the exploitation of the standard technology in period 0 is $C(\alpha)$. Again, $C(\alpha)$ is assumed to be sufficiently convex to ensure that the firm's problem is concave in α.

In period 1 the PU can improve the standard technology as before. Thus, the improvements are on top of $\pi_0(\alpha)$. The more the firm invests in the standard technology in period 0 the stronger the PU is in period 1. For simplicity, we assume that $p = 1$ and $\pi_2 = 0$. Also, let $\gamma B - \pi_0(\alpha) > 0$ in the relevant range, otherwise the best strategy for the RU is always to exert zero creative effort.

The following lemma reports the expected period 1 profits as a function of α and $\pi_0(\alpha)$.

Lemma 4 *If the PU dominates ($F + \pi_0(\alpha) > \gamma B$), then*

$$\pi_1(\alpha) = \frac{(B\gamma - \pi_0(\alpha))(B\gamma(3F + B\gamma) + (3F - 2B\gamma)\pi_0(\alpha) + \pi_0(\alpha)^2)}{6BF\gamma}$$

and $\partial\pi_1(\alpha)/\partial\alpha < 0$. If instead the RU dominates ($F + \pi_0(\alpha) < \gamma B$), then

$$\pi_1(\alpha) = \frac{F^2 + 3BF\gamma - 3F\pi_0(\alpha) + 12B\gamma\pi_0(\alpha)}{6B\gamma},$$

and $\partial\pi_1(\alpha)/\partial\alpha > 0$.

Proof: The expected profits are calculated using the equilibrium strategies found in the Appendix. The sign of $\partial\pi_1(\alpha)/\partial\alpha$ follows directly from $\partial\pi_1(\alpha)/\partial\alpha = [\partial\pi_1(\alpha)/\partial\pi_0(\alpha)]\,[\partial\pi_0(\alpha)/\partial\alpha]$ where $\partial\pi_0(\alpha)/\partial\alpha > 0$. ■

We now turn to the firm's optimal choice of α in period 0.

Proposition 1 *Let a myopic firm be a firm that maximizes profits period by period. If a myopic firm in period 0 chooses a level of α such that the PU dominates in period 1, then a fully rational, forward-looking firm invests less in the standard technology than a myopic one. However, if a myopic firm in period 0 chooses a level of α such that the RU dominates in period 1, then a fully rational, forward-looking firm invests more in the standard technology than a myopic one.*

Proof: A myopic firm chooses α to solve $\partial\pi_0(\alpha)/\partial\alpha - \partial C(\alpha)/\partial\alpha = 0$ whereas a forwarding-looking firm solves $\partial\pi_0(\alpha)/\partial\alpha + \partial\pi_1(\alpha)/\partial\alpha - \partial C(\alpha)/\partial\alpha = 0$. The proof follows then from the concavity of the profit function in α and the sign of $\partial\pi_1(\alpha)/\partial\alpha$ as reported in Lemma 4. ■

Greater investment in exploiting the standard technology makes the PU stronger. Indeed, it becomes harder for the RU to produce enough creative effort to change the status-quo. Put differently, greater exploitation tilts the contest between the RU and the PU in favor of the latter. As long as the PU is already strong and has an advantage in the contest, exploitation makes the competition between the two units even more unbalanced, so it erodes incentives to exert efforts and reduces profits in period 1. For this reason, a forward-looking firm would invest less in the standard technology than a myopic firm that only considers period 0 profits when choosing the optimal degree of exploitation. This corresponds well to the notion that exploiting the current technology may hinder the exploration of future opportunities (March, 1991; Levinthal and March, 1993). Nevertheless, our model suggests that this is only a part of the story. When the RU is the strongest unit, for instance because the firm is operating in a fast developing technological area, further exploitation helps making the competition between the two units tougher and increases both explorative activities and expected profits.

4.3 Monetary Incentives

In the analysis of the basic model all rewards were non-monetary. Notwithstanding the importance of non-monetary rewards in our context, monetary incentives may play an important role as well in shaping behaviours. In the following we introduce monetary incentives into the analysis and discuss how our results are affected.

4.3.1 Setup and Assumptions

Contracts At the general level, it is clear that the role of internal competition as an incentive mechanism is more pronounced when other incentive mechanisms, in particular contracts, are inefficient or unavailable. We thus focus on a situation where it is hard to contract on the value generated by the technology. This is, e.g., likely to happen in large diversified firms with many different sources of revenues where it is difficult to verify the exact project cash flow in court.

We follow Rotemberg and Saloner (1994, 2000) in assuming that it is either impossible or prohibitively expensive for outsiders to measure and compare the two technologies in terms of absolute as well as relative value. This holds both ex-ante when the technologies are proposed and ex-post when one of them has been implemented. The only information available to contract upon is whether the technology proposed by the RU is implemented or not. This can either be thought of as an explicit contract upheld in court or as an implicit contract maintained through reputational concerns.[10] We have explored other forms of contractual incompleteness as well. For example, in line with the idea that one of the advantages of a contest is that it requires only ordinal comparisons among alternatives, we have looked at a situation where rewards can be made contingent on whether the technology of the RU is better than that of the PU (but not on the absolute value difference). As this alternative assumption yields qualitatively similar results, we will not discuss it further.[11]

Monetary incentives to the PU and to the RU play a very similar role in the analysis. We introduce therefore only monetary incentives to the RU, and maintain the assumption that the PU exerts effort to avoid the cost of change. The contract offered to the RU specifies the bonus B if the new technology is adopted. For simplicity, it is assumed that the RU receives no non-pecuniary rewards. The contract to the PU specifies the fixed wage for production activities w plus a possible wage supplement Δw to ensure participation.

Participation Constraints So far we have assumed that the employees of both units stay with the firm even if internal competition is tough. This represents, e.g., a situation where the employees have undertaken firm-specific investments in human capital, so quitting the job is not an attractive option. We generalize the previous analysis by introducing explicit participation constraints. The two units have a reservation utility of zero. The RU can always ensure its reservation utility by choosing $e_R = 0$. Hence we do not need to consider the participation

[10] If the contract is implicit, our analysis corresponds to the case of high discount rates where the firm does not renege on the promise of a bonus (Baker et al., 1994).

[11] Details are available upon request.

constraint of the RU in the analysis. The PU earns rents from its production activity, but it has to bear the possible cost of a change in technology F as well as the cost of improving the existing technology to resist change. We assume that the production activity and the associated compensation result in a non-negative net utility of $\widetilde{u}$. Since $\widetilde{u} < F$, this net utility is not always sufficient to compensate for the cost of change. The result is that the participation constraint of the production unit may bind in equilibrium.

Timing and Other Details The MU offers the contracts to the two units and then they accept or reject the offer. All players observe the offers made. If the contracts are accepted, the RU and the PU develop the technologies. Then, the MU chooses the most profitable one, taking into account the payment of the monetary bonus. At the end of the game, wages are paid and all payoffs are realized.

The effort of the RU translates as before into an innovation of value γe_R, but we allow the effort of the PU to be more productive than in the basic model by assuming that e_P produces an innovation of value βe_P. We focus on the case where the effort of the RU is more productive than that of the PU, $\gamma \geq \beta \geq 1$.

4.3.2 Analysis

We solve the game by backwards induction and look first at the MU's choice between the two technologies. Here, differently from the basic model, the MU takes B into account since it is a monetary reward that it has to pay. The new technology is more profitable than the existing technology if $\beta e_P < \gamma e_R - B$ as B is only paid if the new technology is adopted. The PU dominates the RU in the contest of technologies if and only if $\beta F > (\gamma - 1)B$.

From our previous analysis it should be clear that the MU would never make equilibrium offers such that the RU dominates, $\gamma(B-1) > \beta F$. If so, the MU could reduce B by some small amount, which not only would reduce the expected wage bill but would also increase the expected effort of the two units due to tougher competition. We can therefore restrict attention to contracts such that $\gamma(B-1) \leq \beta F$.

Solving the game as above, we obtain the following result:

Lemma 5 *Let $\gamma(B-1) \leq \beta F$ and suppose that the PU and the RU accept the proposed contracts. The expected payoffs for the PU, the RU, and the firm are respectively: $U_P = \Delta w + \widetilde{u} - (\gamma-1)B/\beta$, $U_R = 0$, and $\Pi = \frac{B(\gamma-1)^2}{\gamma}\frac{3F\beta + B(2+\gamma)}{6F\beta} - w - \Delta w$.*

Proof: The expected payoffs are calculated using the equilibrium strategies found in the Appendix. ■

At the first stage of the game, the MU solves the following program in order to find the optimal contract:

$$Max_{\{B,\Delta w)}\left\{\frac{B(\gamma-1)^2}{\gamma}\frac{3F\beta+B(2+\gamma)}{6F\beta}-w-\Delta w\right\}$$

$$st.\ \Delta w+\widetilde{u}-(\gamma-1)B/\beta\geq 0 \text{ (Participation constraint PU).}$$

Solving this program leads to the following proposition:

Proposition 2 *If $\beta \geq \widehat{\beta} \equiv \frac{6\gamma}{5\gamma+1}$ and $F \leq \widehat{F} \equiv \frac{\widetilde{u}\beta(2+\gamma)}{\beta+6\gamma-4\beta\gamma}$, then the MU chooses $B^* = \frac{F\beta}{\gamma-1}$ and $\Delta w^* = F - \widetilde{u}$ such that the two units compete neck-to-neck. Otherwise, the MU chooses $B^* = \frac{\widetilde{u}\beta}{\gamma-1}$ and $\Delta w^* = 0$ such that all rents that the PU earns from the production activity are taken away.*

Proof: Notice that the expected profits are increasing in B for $B < \widetilde{u}\beta/(\gamma-1)$ where the participation constraint does not bind. Thus $F\beta/(\gamma-1) \geq B^* \geq \widetilde{u}\beta/(\gamma-1)$ and the participation constraint must bind in the solution. After substituting Δw for $\widetilde{u}-(\gamma-1)B/\beta$, the expected profits are convex in B. The optimal bonus is therefore either $\widetilde{u}\beta/(\gamma-1)$ or $F\beta/(\gamma-1)$. Comparing these two candidate solutions gives the result reported in the proposition. ■

Proposition 2 shows that the main finding of the basic model is confirmed as long as the participation constraints do not bind. More intensive competition leads to higher expected efforts by the two units. Because the PU's participation constraint does not bind, only the RU is compensated for the additional effort, and only if the new technology is better than the improved version of the existing one. Thus, increasing B has a positive net effect on profits.

The situation is somewhat different when B is set so high that the participation constraint of the PU binds. Here, a higher bonus B not only increases the expected wage of the RU, but it forces also the MU to offer a higher fixed wage to the PU in order to ensure its participation. In this case it is more expensive to induce higher efforts by intensifying internal competition. The proposition shows that increasing B beyond the point where the participation constraint binds is optimal only if the following two conditions are met: i) The additional effort exerted by the PU is sufficiently productive ($\beta \geq \widehat{\beta}$), and ii) the PU is not too strong ($F \leq \widehat{F}$). The intuition behind the second necessary condition is that $\partial^2 E(e_R)/\partial B \partial F < 0$; i.e., a higher bonus has a smaller positive effect on the expected effort of the RU when the PU is strong (F does not affect the marginal effect of B on $E(e_P)$). This result illustrates another mechanism through which strong inertial forces inside the firm might reduce innovation. The MU of a firm with low values of F offers a high bonus to the RU and induces the toughest possible internal competition. In turn, this results in a high rate of innovation. Inducing tough competition is not, however, profitable in a firm characterized by high values of F, and the MU offers a low bonus to the RU thereby resulting in a low rate of innovation.

5 The Skunk Works Model of Innovation

The outcome of the innovation process not only depends on the intensity of the creative effort, but also on the locus of search. Often researchers have the freedom to choose among an array of research trajectories that encompass different levels of uncertainty, different types of potential innovations, different knowledge bases, different technological competences, among other features. Most importantly, while some of these research trajectories, if successful, might lead to important adaptation costs for the PU (large F), others might instead come at small or no adaptation costs ($F \simeq 0$). Indeed, some research trajectories are more probable to deliver "radical innovations", while other trajectories are more likely to lead to "incremental innovations". Radical innovations are based on a new set of routines and expertise. Incremental innovations are based on existing routines and expertise (Henderson, 1993).[12]

Not surprisingly, a research trajectory which might lead to radical innovations (henceforth, a radical trajectory) is likely to meet stronger resistance from the PU (Ginn and Rubenstein, 1986). To avoid a costly internal contest, the RU might thus turn to a research trajectory that produces incremental innovations (henceforth, an incremental trajectory). Hence, although in our basic model the competition between the PU and the RU always acts as an incentive mechanism, when the choice of the research trajectory is endogenized it might produce a distortion towards incremental trajectories that could potentially lower expected firm profits.

One possible solution to this problem, known as the "skunk works model" of innovation, is to isolate the research team from the influence of the rest of the organization.[13] This, so the argument goes, confers the autonomy, independence and freedom to researchers that are key to pursue radical innovations. The skunk works model was the organizational design followed by IBM to nurture the by then revolutionary PC (Roberts, 2004). Skunks work models are actually

[12] In the organization literature these two kinds of innovations are often referred to as competence destroying and competence enhancing innovations (Tushman and Anderson, 1986).

[13] A windowless facility built by Lockheed at the airport of Burbank, California, during the Cold War was known as the "skunk works". There, secret military projects were developed.

employed by many large innovative firms, such as Intel, HP and Apple, to develop potential breakthroughs. For instance, Texas Instruments is said to have established a sort of "skunk works culture" that has helped it to boost its continued ability to innovate (Electronic Business, 2005). Although the skunk works model has received quite a lot of attention in the popular business press, especially following the hearted support from strategy guru Tom Peters, we know of no formal analysis trying to pin down the advantage of this organizational form. Below we shall therefore adapt our basic framework to analyze the skunk works model of innovation.

Let us assume that there are two possible research trajectories, an incremental trajectory and a radical trajectory. The RU chooses the research trajectory before the game analyzed in section 3 starts.

Assumption 1'. *The characteristics of the two R&D trajectories are:*

Incremental trajectory: $F_I = 0, p_I = 1, \gamma_I = 1, B_I = B > 0$,

Radical trajectory: $F_R = F > 0, p_R = p < 1, \gamma_R = \gamma > 1, B_R = \rho B$ *with* $\rho > 1$.

The incremental trajectory leads to innovation with certainty. The innovation builds on the current competences and expertise, so it does not result in adaptation costs for the PU. Nevertheless, for the RU it is not a particularly "exciting" trajectory, and the reward from having the new technology implemented is low. Instead the radical trajectory is riskier, but implies a higher potential return both for the firm and for the RU ($\gamma_R = \gamma > 1$ and $B_R = \rho B > B$). However, a radical innovation imposes adaptation costs upon the PU whereas an incremental innovation does not. Without further loss of insight let us also normalize π_1 and π_2 to 0.

These assumptions on the parameters generate two important implications:

Implication 1. *The RU dominates the contest of technologies when the incremental trajectory is chosen.*

Implication 2. *Firm expected profits are greater if the radical trajectory is chosen.*

The first implication comes from $F_I = 0$. Hence, in an equilibrium where the incremental trajectory is chosen, the RU exerts zero effort and wins the contest. In this case, the firm's profit is $-w$. If the radical trajectory is chosen, then the game analyzed in the previous section unfolds. The expected profits are therefore higher than $-w$, see Lemma 2 and 3. Hence, as stated in implication 2, the firm prefers the radical trajectory.

Finally, to make the problem interesting, we assume that if the PU observes the choice of the trajectory and can react to it, the RU chooses the incremental trajectory rather than the radical one to avoid a costly internal contest with the PU. From Lemma 2 and 3 it follows that this is the case if the following condition holds:

Assumption 2'. $B > Max\left\{0, p(\rho B - \frac{F}{\gamma})\right\}$.

Below we shall investigate whether the firm can improve its expected profits by isolating the RU and creating a skunk works model of innovation. The crucial difference between having the RU integrated in the firm and the skunk works model is the amount of information that the PU receives about the RU's actions. In particular, we assume that the PU observes the choice of trajectory if the RU is integrated in the firm but not if it is isolated. From a game theoretic point of view the difference between an integrated innovation model and a skunk works model boils down to the timing of the game. In the integrated model, analyzed so far, the research trajectory is chosen (and observed) before defensive and creative efforts are exerted. In the skunk works model the choices of the research trajectory and efforts are all simultaneous. For simplicity, we focus on pure strategies in the choice of the research trajectory.

The game tree is illustrated in Figure 1. At t=1 the MU decides how to organize innovation activity by choosing between an integrated model and the skunk works model. At t=2 the RU chooses which research trajectory to focus on: Radical or incremental. At t=3 the two units simultaneously exert effort. Notice that the information set of the PU is different depending on the innovation model chosen by the MU at t=0. Then, in case of the radical trajectory, nature (player N) determines whether the new technology is a success or a failure. At t=4 the MU observes the outcome of the innovation process and decides whether to adopt the new technology. Finally, at t=5 all payoffs are realized.

Proposition 3 *Suppose that the RU would choose the radical trajectory if there were no competition from the PU, i.e.* $p\rho > 1$*. Then, the RU chooses the radical trajectory under the skunk works model of innovation and the incremental trajectory under the integrated model of innovation.*

Proposition 3 shows that by implementing a skunk works model the firm can make the radical trajectory the equilibrium outcome of the game when this trajectory is sufficiently attractive for the RU. By contrast, assumption 2 implies this is never the equilibrium outcome of the game under the integrated innovation model. The intuition behind this finding is the following. Under the integrated innovation model, the PU observes the choice of the trajectory. The

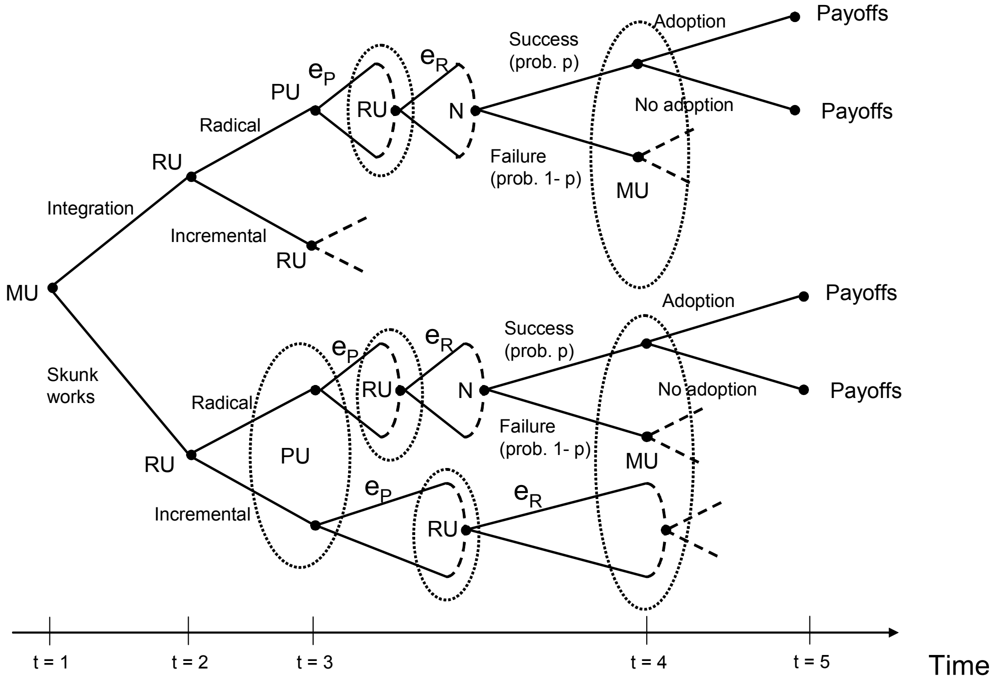

Figure 1: The game tree.

radical trajectory is therefore unattractive for the RU, because it results in strong defensive effort from the PU. Under the skunk works model, on the other hand, the PU does not observe the trajectory chosen. Hence, if the radical trajectory is sufficiently attractive for the RU, the choice of the incremental trajectory cannot be sustained as an equilibrium outcome, because the RU can deviate to the radical trajectory without triggering additional defensive effort by the PU. Isolating the RU from the rest of the organization can therefore induce the choice of the profit maximizing, radical trajectory.

Proposition 3 implies that the firm can benefit from a skunk works model when resistance to change in case of a radical innovation is particularly strong, and would induce researchers to follow more incremental research trajectories under the integrated model. This problem is particularly acute in organizations that show very high adaptation costs in case of radical innovations. This is often the case for large bureaucratic corporations or established market leaders within a given technological paradigm (Tushman and Anderson, 1986; Henderson, 1993). Moreover, our findings show that in order to induce the RU to choose the radical trajectory, the expected reward from making a radical innovation must be sufficiently high ($p\rho$ large). Hence, the firm needs not only to isolate its researchers but also to provide the right incentives in order to stimulate radical innovations. Finally, it is important that researchers are completely isolated from the rest of the organization. If the PU is able to infer the type of project that the RU is working on from financial accounts or internal memos, our analysis suggests that the advantage of the skunk works model is lost.

6 Conclusion

In this paper we have studied the competition that arises between an R&D department and a production department as a consequence of the potential introduction of an innovation that requires important re-adjustment for the production department. We have shown that stronger resistance to change due to larger adjustment costs is not necessarily a problem for a firm. To the contrary, firms with a capable R&D department can leverage such resistance to change to foster more valuable innovations as well as larger improvements of the existing technology.

Our analysis has shown that firms that successfully maintain a balance between the two departments outperform firms where one department largely dominates the other. From this principle, several implications have been derived concerning the selection of talents and the use of monetary incentives. Interestingly, the internal competition analyzed in this paper might also explain why there is a tension between exploiting the current technology and exploring new ones, a topic widely discussed in the management literature.

There are clearly other ways to balance the strengths of the two departments than the measures studied here. One alternative channel is to handicap the stronger department by implementing an "innovation policy" (Lazear and Rosen, 1981). An example of such a policy would be the following: "The R&D department's innovation is chosen if it is x percent better than the existing technology". One problem that the management faces when implementing such a policy is that it requires commitment, because the less profitable technology sometimes has to be chosen. Rotemberg and Saloner (2000) propose to hire managers with an intrinsic preference for certain kinds of projects as a solution to the commitment problem. For example, a "visionary manager" with a preference for new technologies might help to strike a better balance between a strong production department and a weak R&D department.

In the last part of the paper we have analyzed the "skunk works model" of innovation, which consists of isolating the R&D department from the rest of the firm. It has been shown that this organizational model can solve the problem that arises when the R&D department chooses too safe a research trajectory to avoid a costly competition with the production department. This requires, however, that the R&D department is well-motivated and is allowed to work on "exciting" innovations.

7 Appendix

7.1 The Equilibrium Strategies of Lemma 4

When the PU dominates ($F + \pi_0(\alpha) > \gamma B$), the PU randomizes according to $G(e_P) = \frac{\pi_0(\alpha)+e_P}{\gamma B}$ for all $e_P \in [0, \gamma B - \pi_0(\alpha)]$. The RU randomizes on $e_R \in \{0\} \cup \left[\frac{\pi_0(\alpha)}{\gamma}, B\right]$ according to $H(e_R)$ where $H(e_R) = 1 - \frac{\gamma B}{F} + \frac{\pi_0(\alpha)}{\gamma}$ for all $e_R \in \left[0, \frac{\pi_0(\alpha)}{\gamma}\right)$ and $H(e_R) = 1 - \frac{\gamma B}{F} + \frac{\gamma e_R}{F}$ for all $e_R \in \left[\frac{\pi_0(\alpha)}{\gamma}, B\right]$. When the RU dominates ($F + \pi_0(\alpha) < \gamma B$), the PU randomizes according to $G(e_P) = 1 - \frac{F}{\gamma B} + \frac{e_P}{\gamma B}$ for all $e_P \in [0, F]$ and the RU randomizes according to $H(e_R) = \frac{\gamma e_R}{F} - \frac{\pi_0(\alpha)}{F}$ for all $e_R \in \left[\frac{\pi_0(\alpha)}{\gamma}, \frac{\pi_0(\alpha)+F}{\gamma}\right]$. ■

7.2 The Equilibrium Strategies of Lemma 5

The PU randomizes according to $G(e_P) = \frac{B+\beta e_P}{\gamma B}$ for all $e_P \in [0, (\gamma-1)B/\beta]$ and the RU randomizes according to $H(e_R) = 1 - \frac{\gamma B}{\beta F} + \frac{\gamma e_R}{\beta F}$ for all $e_R \in \{0\} \cup [B/\gamma, B]$. ■

7.3 Proof of Proposition 2

Notice that the expected profits are increasing in B for $B < \widetilde{u}\beta/(\gamma-1)$ where the participation constraint does not bind. Thus $F\beta/(\gamma-1) \geq B^* \geq \widetilde{u}\beta/(\gamma-1)$ and the participation constraint must bind in the solution. After substituting Δw for $\widetilde{u} - (\gamma-1)B/\beta$, the expected profits are convex in B. The optimal bonus is therefore either $\widetilde{u}\beta/(\gamma-1)$ or $F\beta/(\gamma-1)$. Comparing these two candidate solutions gives the result reported in the proposition.

7.4 Proof of Proposition 3

First notice that Assumption 2' implies that the RU chooses the incremental trajectory under the integrated model of innovation. Consider now the skunk works model. Here, there cannot exist an equilibrium where the RU chooses the incremental trajectory. Indeed, in such an equilibrium $e_P = 0$, because the PU would not try to resist an incremental innovation that implies zero adaptation costs. Therefore, the RU would have an incentive to deviate to the radical trajectory (and choose e_R close to zero), which would result in an expected utility of $p\rho B > B$. Consider instead an equilibrium where the RU chooses the radical trajectory. From Lemma 3 we know that when $F > \gamma\rho B$ the PU randomizes in equilibrium according to $G(e_P) = \frac{e_P}{p\gamma\rho B}$ for all $e_P \in [0, p\gamma\rho B]$ and $U_R = 0$. Suppose that the RU would deviate to the incremental trajectory. This would produce an expected utility equal to:

$$G(\gamma e_R)(B - e_R) + (1 - G(\gamma e_R))(-e_R) = e_R \left(\frac{1}{p\gamma\rho} - 1 \right),$$

which is non-positive since $\gamma > 1$ and $p\rho > 1$. Therefore, the RU has no incentive to deviate. Similarly, when $F < \gamma\rho B$ the PU randomizes according to $G(e_P) = 1 - \frac{F}{\gamma\rho B} + \frac{e_P}{p\gamma\rho B}$ for all $e_P \in [0, pF]$ and $U_R = p(\rho B - \frac{F}{\gamma})$. Suppose that the RU would deviate to the incremental trajectory. This would produce an expected utility equal to $B - \frac{F}{\gamma\rho} + \frac{e_R}{p\gamma\rho} - e_R$. Since $p\rho\gamma > 1$, the optimal effort when deviating to the incremental trajectory would therefore be $e_R = 0$. This would result in an expected utility of $B - \frac{F}{\rho\gamma}$. It is easy to see that such deviation is not profitable when $p\rho > 1$. Hence, for $p\rho > 1$ only the radical trajectory can be sustained as an equilibrium outcome of the game. ■

References

[1] Baye, M. R., D. Kovenock, C. G. de Vries (1996): "The All-Pay Auction with Complete Information", *Economic Theory*, 8, 291-305.

[2] Bower, J. L. (2005): "Teradyne: The Aurora Project", Harvard Business School, Case Study #9-397-114.

[3] Burgelman, R. A. (1994): "Fading Memories: A Process Theory of Strategic Business Exit in Dynamic Environments", *Administrative Science Quarterly*, 39, 24-56.

[4] Che, Y.-K. and I. Gale (2003): "Optimal Design of Research Contests", *American Economic Review*, 93, 646-671.

[5] Foster, R. (1986): *Innovation: The Attacker's Advantage*. Summit Books, New York.

[6] Ganuza, J. J. and E. Hauk (2006): "Allocating Ideas. Horizontal Competition in Tournaments", *Journal of Economics and Management Strategy*, forthcoming.

[7] Ginn, M. E. and Rubenstein, A. H. (1986): "The R&D/Production Interface: A Case Study of New Product Commercialization", *Journal of Product Innovation Management*, 3, 158-170.

[8] Hannan, M. T. and Freeman, J. (1984): "Structural Inertia and Organizational Change", *American Sociological Review*, 49, 149-164.

[9] Hart, O (1983): "The Market as an Incentive Mechanism", *Bell Journal of Economics*, 14, 366-382.

[10] Henderson, R. (1993): "Underinvestment and incompetence as responses to radical innovation: Evidence from the semiconductor photolithographic alignment equipment industry", *RAND Journal of Economics*, 24, 248-270.

[11] Hillman, A. L. and J. G. Riley (1989): "Politically Contestable Rents and Transfers", *Economics and Politics*, 1, 17-39.

[12] Lazear, E. P. and S. Rosen (1981): "Rank-Order Tournaments as Optimum Labor Contracts", *Journal of Political Economy*, 89, 841-864.

[13] Levin, J. (2002): "Multilateral Contracting and the Employment Relationship", *Quarterly Journal of Economics*, 117, 1075-1103.

[14] Levinthal, D. and March, J. (1993): "The myopia of learning", *Strategic Management Journal*, 14, 95-112.

[15] March, J. (1991): "Exploration and Exploitation in Organizational Learning", *Organization Science*, 2, 71-87.

[16] Meyer, M., P.R. Milgrom, and J. Roberts (1992): "Organizational Prospects, Influence Costs and Ownership Changes", *Journal of Economics and Management Strategy*, 1, 9-35.

[17] Milgrom, P.R. (1988): "Employment Contracts, Influence Activities and Efficient Organization Design", *Journal of Political Economy*, 96, 42-60.

[18] Milgrom, P.R. and J. Roberts, 1988, "An Economic Approach to Influence Activities in Organizations", *American Journal of Sociology*, 94 suppl., S154-S179.

[19] Morrill, C. (1991): "Conflict Management, Honor, and Organizational Change", *American Journal of Sociology*, 97, 585-621.

[20] Roberts, J. D. (2004): *The modern firm*. Oxford University Press.

[21] Robbins, S.P. (1998): *Organisational Behaviour*. New Jersey: Prentice Hall.

[22] Rotemberg, J. and Saloner, G. (1994): "The Benefits of Narrow Business Strategies", *American Economic Review*, 84, 1330-49.

[23] Rotemberg, J. and G. Saloner (1995): "Overt Interfunctional Conflict and Its Reduction through Business Strategy", *Rand Journal of Economics*, 26, 630-653.

[24] Rotemberg, J. and Saloner, G. (2000): "Visionaries, Managers and Strategic Direction", *RAND Journal of Economics*, 31, 693-716.

[25] Schaefer, S. (1998): "Influence Costs, Structural Inertia, and Organizational Change", *Journal of Economics and Management Strategy*, 237-63.

[26] Schmidt, K. M. (1997): "Managerial Incentives and Product Market Competition", *Review of Economic Studies*, 64, 191-214.

[27] Stern, S. (2004): "Do Scientists Pay to Be Scientists?", *Management Science*, 50, 835-853.

[28] Taylor, C. (1997): "Digging for Golden Carrots: An Analysis of Research Tournaments", *American Economic Review*, 85, 872-890.

[29] Tushman, M. L. and P. Anderson (1986): "Technological Discontinuities and Organizational Requirements", *Administrative Science Quarterly*, 31, 439-65.