Innovation and Competition with Asymmetric Information*

(PRELIMINARY AND INCOMPLETE DRAFT)

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Abstract

We investigate the relationship between R&D incentives and product market competition in a model where neither competitors nor contractual parties (e.g., suppliers) are able to observe the exact value of a firm's innovation. The intensity of R&D activity thus affects the rival's perception of the firm's strength, as well as its contractual relationship with third parties. We show that the latter "contractual" effect neutralizes any strategic value of R&D, implying that more intense competition invariably stifles innovation incentives in asymmetric information environments. We also compare the firm and the supplier's attitude towards innovation and find that dissonant preferences over R&D intensity arise when R&D generates positive spillovers on rivals and product market competition is intense. Our results raise the issue of how governance factors (monitoring, control of R&D) interact with product market competition in shaping innovation incentives.

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1 Introduction

A major challenge in economic research is to understand what are the determinants of firms' incentives to innovate. Many theoretical and empirical papers have addressed the question of how such incentives are affected by product market competition. Other papers have studied how corporate governance mechanisms affect innovation, emphasizing that R&D decisions are often made by managers who have superior information with respect to firm owners and who may not be maximizing firm value. Yet, previous theoretical work has failed to recognize that contractual problems may interact with product market considerations in affecting firms' incentives to innovate. Indeed, one peculiar feature of innovation is that the outcome of the R&D process (e.g., a demand shock following product innovation) is likely to be private information of the innovating firm vis-à-vis its contractual parties as well as its product market rivals. Hence, by affecting the distribution of firms' types, observable R&D investments shape both the firm's contractual relationships *and* competition in the product market.[1] This suggests that the link between innovation and product market competition cannot be properly understood unless the relationship between firms and their contractual parties is modelled explicitly.

To make a step in that direction, we study a model where oligopolistic product market competitors and contractual parties (e.g., suppliers, financiers) are unable to observe the exact value of the firm's R&D output, and form their expectations of the innovation value (i.e., of product demand) after observing the firm's ex-ante investment in research and development. More intensive R&D is more likely to lead to innovation, thus generating better demand states for the firm. Within this framework, we address two related questions. How does R&D impact the contractual relationship between a firm and its suppliers? How does this in turn affect the firm's behavior in the imperfectly competitive product market? A central finding of the paper is that besides a standard strategic benefit à la Brander and Spencer (1983), whereby rivals scale back their outputs when facing a more innovative firm, R&D also brings a strategic cost whenever its outcome is not observed by the firm's suppliers. Indeed, due to a standard rent extraction-efficiency trade-off, the input supplied to an unsuccessful innovator and thus its product market output are distorted downwards when successful innovations are more likely (i.e., when the firm has engaged in more R&D). Through this contractual channel, investments in R&D make an unsuccessful innovator a less aggressive competitor. As a result, incomplete information vis-à-vis contractual parties destroys the strategic appeal of R&D.

[1] A few papers have emphasized the fact that a firm's actions may simultaneously affect its relationship with financiers as well as product market rivals (see e.g., Gertner, Gibbons and Scharfstein, 1988). Yet, to our knowledge, ours is the first paper to study a principal-agent model with product market competition where the distribution of firm types is endogenously affected by R&D investments.

This result has two important implications. First, in environments where contractual parties are unable to monitor the R&D process and observe the exact value of innovations, as is the case in arm's length relationships, incentives to engage in R&D are reduced with respect to monitoring-intensive contractual relationships. This provides an additional explanation to the highly innovative attitude of firms funded by specialized investors (e.g., venture capitalists), besides the standard argument that knowledgeable investors alleviate R&D financing constraints. The second implication is that the relationship between innovation incentives and product market competition changes dramatically when the innovator's R&D outcome is not observed by contractual parties: due to its lack of strategic value, R&D is inevitably stifled by increased competitive pressure. By contrast, in environments where innovation value is observed by contracting parties, the strategic value of R&D grows with the degree of product market competition: this makes the relationship between competition and innovation more complex, combining both Arrowian and Schumpeterian effects.

Allowing for information asymmetries within the firm-supplier vertical structure also raises the issue of whether firms and their contractual parties have congruent preferences over investments in research and development. Our model suggests that product market competition shapes the contractual parties' innovation incentives in different ways: in the case of positive R&D spillovers we find that dissonant preferences over R&D intensity arise when product market competition is tough. This is because under intense competition R&D investments with spillovers entail a large strategic cost, which leads the supplier (the uninformed principal) to favor low R&D intensities, whereas the firm (the informed agent) would rather engage in highly-intensive R&D so as to maximize its information rent. This implies that when successful innovations are not very promising and competition is tough, a "technology trap" arises whereby a monopolistic supplier would require a cash-constrained firm *not* to engage in R&D. This result is in line with existing evidence by Aghion et al. (2006) that new entry in technologically laggard industries reduces incumbents' innovation incentives, whereas entry in technologically advanced industries boosts innovation incentives.

Our paper contributes to the debate on the relationship between product market competition and innovation that dates back to Schumpeter (1939). The Schumpeterian view that competition kills innovation incentives by reducing the rents that reward innovators has been questioned by various papers starting with Arrow (1962). Recent models (see e.g., Aghion et al. 2005) have emphasized that competition affects both post-innovation rents and pre-innovation rents, hence the resulting relationship between competition and innovation incentives may be less straightforward than predicted by Schumpeter. In models of strategic R&D, innovators take a more active stance towards competition, using investments in R&D to gain market shares in their oligopolistic markets (Brander and Spencer, 1983), or to deter entry and preserve their monopoly rents (Etro, 2006), suggesting that increased pressure from (potential) rivals may well spur innovation. Our paper contributes to this strand of literature showing that R&D loses much of its strategic appeal when the firm's contractual parties do not observe the value of its innovations, implying that the basic Schumpeterian effect of competition on innovators' rents prevails in such asymmetric information environments.

The paper also adds to the literature on corporate governance and competition extensively illustrated by Allen and Gale (2000).[2] Although it has been explicitly recognized that corporate governance mechanisms may affect innovation, few papers have explored how corporate governance and competition interact in determining R&D incentives.[3] Indeed, under some conditions our principal-agent relationship can be interpreted as one between a monopolistic capital supplier and a firm in need of outside finance. By explicitly studying how R&D investments affect the informational problems between the financier and the firm as well as the product market equilibrium, we are able to analyze how financiers' and firms' attitudes towards innovation change as product market competition becomes more intense. In particular, our results in the R&D spillover case suggest that monopolistic financiers might force firms under strong competitive pressure *not* to engage in research and development.

Finally, our paper also brings a contribution to contract theory, by showing that the information structure (i.e., the distribution of types) has a non obvious effect on the principal's utility in a principal agent model with product market competition. While in a isolated agency relationship, that is in a monopoly setting à la Mussa and Rosen (1978) and Maskin and Riley (1984), both contractual parties would (ex-ante) always prefer to face distributions putting more weight on good types, we provide conditions under which this standard result does not hold anymore whenever information asymmetries and (positive) technological spillovers between competing organizations are simultaneously at play. In fact, in our competitive environment a principal may prefer distributions which are more concentrated around "bad" types if product market competition is sufficiently large and the types' support is not too large. Moreover, the R&D interpretation of the endogenous information structure allows us to unveil a technology trap result that has been overlooked in earlier contract theory work mainly taking such information structure as given. More generally, our results also suggest that in agency problems with competing organizations there may exist a conflict of preferences between principals and agents concerning the optimal R&D intensity that an organization should perform. This result opens an important policy issue concerning the allocation of decision rights on R&D investments within firms when information asymmetries and

[2] See also Buccirossi and Spagnolo (2006) and Cestone (2006) for more recent surveys.

[3] Aghion, Dewatripont and Rey (1998) propose a moral hazard model where firms' external financial needs and product market competition interact in determining managers' R&D efforts.

product market competition shape firms' efficiency frontier.

The remainder of the paper is organized in the following way. Section 2 sets up the model, in Section 3 we develop the analysis in the simplest case with no R&D spillovers, an issue that is instead treated in Section 4. Section 5 develops a series of interesting extensions and provides a discussion on the robustness of the results. Finally Section 6 concludes. All proofs are relegated to an Appendix.

2 The Model

Players and Environment: Consider a simple economy where a risk-neutral entrepreneur (E_1), needs an essential input to start a business venture. Once started, the firm will face competition in the product market, where an incumbent firm E_2 is already active. While E_1 must rely on an external input supplier (L), we will assume for the moment that the rival E_2 is vertically integrated. Firms compete by setting quantities, and inverse market demands are defined by:

$$P_1(\tilde{\theta}, q_1, q_2) = 1 + \tilde{\theta} - q_1 - \rho q_2, \quad \text{for firm 1,}$$

and

$$P_2(\tilde{\theta}, q_1, q_2) = 1 + \sigma\tilde{\theta} - q_2 - \rho q_1, \quad \text{for firm 2,}$$

where $P_i(.)$ and q_i ($i = 1, 2$) denote the price of the good and the quantity sold by firm i, respectively. As standard, ρ denotes the intensity of product differentiation, with $0 \leq \rho \leq 1$, and it will be a measure of competitive pressure (we will discuss later the case $-1 \leq \rho \leq 0$ to allow for competition in strategic complements). $\tilde{\theta}$ is a random shock affecting firm 1's (inverse) demand function. We interpret $\tilde{\theta}$ as being the uncertain outcome of a demand-enhancing R&D activity carried out by E_1 (the innovator): a higher realization of $\tilde{\theta}$ corresponds to a more successful innovation and thus to a higher consumers' willingness to pay.[4] Formally, the random variable $\tilde{\theta}$ belongs to the set $\Theta \equiv \{\underline{\theta}, \overline{\theta}\}$, with $\underline{\theta}$ normalized to zero. Accordingly, the innovation can either be successful ($\overline{\theta}$) or unsuccessful ($\underline{\theta}$) with respective probabilities λ and $1 - \lambda$, where λ represents the intensity of E_1's R&D. This implies that more intensive R&D investments (higher λ) are more likely to generate successful innovations and thus better demand states for firm 1. Finally, the parameter $\sigma \in [0, 1]$ captures positive R&D spillovers that the innovation produced by E_1 generates on E_2's demand.

We assume that while the extent of R&D activities (λ) is publicly observed, their outcome θ

[4] Alternatively, $\tilde{\theta}$ could also be viewed as the outcome of any kind of demand-enhancing activity, such as informative advertising or pre sales services to potential buyers.

is not: only the innovator E_1 has private information on the exact value of his innovation. For simplicity we also assume that demand enhancing R&D activities are costlessly carried out by E_1.[5]

Finally, production requires an essential input which is transformed into a final output exploiting a one-to-one technology. All firms produce at constant marginal costs normalized to zero.

Contracts: Following the previous literature we assume that L (the principal) makes a take-it-or-leave-it offer to E_1 (the agent), and we invoke the *Revelation Principle* in describing the set of incentive feasible allocations.[6] Precisely, we analyze a usual framework where a communication stage within the hierarchy L-E_1 is played before the competition stage occurs. After the intensity λ of the R&D activity is chosen and publicly observed, and uncertainty has resolved, the informed agent delivers to the uninformed principal a message about the realized state of demand. Given this message, an allocation is selected within the menu of contracts, $\mathcal{C} = \left\{(\overline{q}_1, \overline{T}_1); (\underline{q}_1, \underline{T}_1)\right\}$, specifying both an input level, q_1, and a repayment fee, T_1, from E_1 to L which in equilibrium will both depend upon λ.

The rationale for studying this game will be that of investigating how R&D activities simultaneously affect product market outcomes and the contractual relationship between L and E_1.

Timing, Strategies and Solution Concept: A four-stage game, thereafter $\mathcal{G}$, is played as follows:

T=0. R&D investment: The R&D intensity λ is chosen within the hierarchy $L - E_1$. This is publicly observed.

T=1. Contracting: The lender L offers secretly a menu of contracts $\mathcal{C} = \left\{(\overline{q}_1, \overline{T}_1); (\underline{q}_1, \underline{T}_1)\right\}$ to E_1.

T=2. R&D outcome: the demand shock $\tilde{\theta}$ realizes and only E_1 observes it.

T=3. If the contract has been accepted, E_1 reports a message to L about the realized demand state and receives the corresponding allocation, i.e., units of input (loan) and repayment. Product market competition takes place in a standard fashion and, finally, the monetary transfer T_1 is paid out by the entrepreneur to the supplier. If the offer is turned down, E_1 and L enjoy their outside options which are normalized to zero, whereas E_2 acts as a monopolist.

In this simple four-stage game strategies are defined as allocation proposals by L at stage 1, actions by entrepreneurs at stage 3, including messages on the realized nature state, and an acceptance rule by E_1. Our solution concept will be *Bayes Nash Equilibrium.* The choice of the R&D

[5] This assumption is made only for simplicity, all the results that will be presented in the paper remain qualitatively true once we assume that the R&D cost is $C(\lambda)$ with $C'(\lambda) \geq 0$ and $C''(\lambda) > 0$.

[6] Myerson (1982), Laffont and Martimort (2002, Ch. 2) among many others.

intensity will be then derived by using a simple backward argument. Sometimes, when necessary, in deriving our result we shall use second-order Taylor approximations which are appropriate since $(\rho, \lambda) \in [0,1]^2$.

Remark on the R&D Investment Stage: The R&D investment stage is the main innovation of our model and it deserves a discussion. Specifically, we shall compare three alternative *governance* regimes. The first regime characterizes an efficiency benchmark where the coalition $L - E_1$ chooses the R&D intensity cooperatively by maximizing the coalition joint-profit. One may actually think of several justifications for adopting joint-profit maximization as the relevant criterion to make R&D choices. Though there is no reason to think that the same allocation of bargaining powers between the innovator and the supplier prevails ex ante and ex post,[7] it is reasonable to assume that ex ante, i.e., before demand realizes, the innovator keeps a more equal bargaining power with the supplier and joint-profit maximization becomes the relevant criterion. Once the ex ante R&D choice is made, the supplier and the innovator can share ex ante joint-profit through a lump-sum fixed-fee which yields a (non type-dependent) reservation value to the retailer. Second, one should not expect vertical structures which do not maximize ex ante joint-profit to survive in the long-run if we were modelling explicitly entry on both sides of the market.

In the second regime we shall consider cases where the innovator chooses the R&D noncooperatively so as to maximize his own information rent, whereas in the third regime we will assume that the supplier has full control rights on every aspect of the trade terms offered to the innovator, that is the R&D intensity is chosen so as to maximize the (expected) virtual surplus.

Performing this comparative statics exercise will allow us to shed new light on the potential discrepancy of preferences between innovators and their contractual parties in setting the venture's R&D choices in a framework where the value of the innovation is private information. Moving in this direction we will also provide testable implications on how this conflict is shaped by the degree of product market competition and by the extent of R&D spillovers.

[7] Actually, this shift in bargaining powers is rather standard in the incomplete contract literature which assumes that parties have both equal bargaining powers ex post, once some non-verifiable variables become publicly observable, but ex ante investment choices are made according to an efficiency criterion. See Laffont and Martimort (2002, Chapter 6) for some remarks on this. The same perspective can be taken here but in an asymmetric information framework.

3 R&D without Spillovers

3.1 Complete information in firm 1's contractual relationship

We consider initially the benchmark case where firm 1's supplier observes the realized R&D output whereas firm 2 does not. In this environment, the intensity of the (observable) R&D investment affects firm 2's expectation about firm 1's strength - thus generating a strategic effect in the product market - but does not affect the contractual relationship between firm 1's entrepreneur and the supplier. It is straightforward to show that the incentives to innovate depend on the direct impact of R&D on firm 1's expected demand as well as the strategic impact of R&D on equilibrium quantities. Let us assume that at date 0 the entrepreneur-supplier coalition chooses the level of R&D investment λ which maximizes its expected joint profits:

$$\Pi^c = \lambda \left(P_1(\overline{\theta}, \overline{q}_1^*(\lambda), q_2^*(\lambda))\overline{q}_1^*(\lambda) \right) + (1-\lambda) \left(P_1(\underline{\theta}, \underline{q}_1^*(\lambda), q_2^*(\lambda))\underline{q}_1^*(\lambda) \right),$$

anticipating the impact of R&D on the product market outcome.

Formally, at date 1 for any given realization of $\tilde{\theta} \in \{\underline{\theta}, \overline{\theta}\}$ the supplier's problem is to choose a contract $\mathcal{C}^* = \left\{(\underline{T}_1, \underline{q}_1), (\overline{T}_1, \overline{q}_1)\right\}$ so as to maximize the repayment received from E_1 in each demand state subject to its participation constraints:

$$(\underline{PC}) \quad \underline{U}_1 = P_1(\underline{\theta}, \underline{q}_1, q_2)\underline{q}_1 - \underline{T}_1 \geq 0,$$

and,

$$(\overline{PC}) \quad \overline{U}_1 = P_1(\overline{\theta}, \overline{q}_1, q_2)\overline{q}_1 - \overline{T}_1 \geq 0.$$

The first order conditions for such program are:

$$1 + \theta - 2q_1 - \rho q_2 = 0, \quad \text{for } \theta \in \{\underline{\theta}, \overline{\theta}\},$$

furthermore, since E_2 does not observe firm 1's R&D output, he will choose the quantity q_2 which solves the following program:

$$\max_{q_2 \in \mathbb{R}_+} \left\{ \left(\lambda P_2(\overline{q}_1, q_2) + (1-\lambda) P_2(\underline{q}_1, q_2) \right) q_2 \right\},$$

This defines firm 2's best response to the innovator's expected quantity $\hat{q}_1$:

$$q_2 = \frac{1}{2} - \frac{\rho}{2}\hat{q}_1.$$

It follows immediately that the Bayes-Nash equilibrium outputs are as follows:

$$q_2^* = \frac{2-\rho(1+\lambda\overline{\theta})}{4-\rho^2}$$

$$\overline{q}_1^*(\lambda) = \frac{1+\overline{\theta}}{2} - \frac{\rho(2-\rho(1+\lambda\overline{\theta}))}{2(4-\rho^2)}$$

$$\underline{q}_1^*(\lambda) = \frac{1}{2} - \frac{\rho(2-\rho(1+\lambda\overline{\theta}))}{2(4-\rho^2)}.$$

Note that firm 2 scales back its own quantity when firm 1 is more likely to be a successful innovator (i.e., when λ is larger). Conversely, for both firm 1's types, a more intense R&D activity implies a larger equilibrium quantity. This has the implication that R&D investment has both a *direct, demand-enhancing effect* on the coalition's expected profits as well as a desirable *strategic effect* due to strategic substitutability in our incomplete information product market game. Indeed, relying on the Envelope Theorem one can show that:

$$\frac{\partial \Pi^c}{\partial \lambda} = \underbrace{(\overline{q}_1^*(\lambda))^2 - \left(\underline{q}_1^*(\lambda)\right)^2}_{\textbf{Direct effect }(+)} \underbrace{- \rho\frac{\partial q_2^*(\lambda)}{\partial \lambda}\left(\lambda\overline{q}_1^*(\lambda) + (1-\lambda)\underline{q}_1^*(\lambda)\right)}_{\textbf{Strategic effect }(+)}. \tag{1}$$

The strategic value of R&D emphasized here is similar in spirit to the one originally unveiled by Brander and Spencer (1983): even without considering entry deterrence, firms are tempted to increase their expenditures on research and development in order to achieve a strategic advantage in the imperfectly competitive product market, and thus increase their market shares.

We now turn to investigating the relationship between product market competition and R&D incentives. The following proposition shows that the intensity of competition in the product market (ρ) has a non-linear effect on date-0 incentives for innovation, at least when complete information exists within the entrepreneur-supplier chain.

Proposition 1 *In technologically advanced industries there exists a U-shaped relationship between competition and R&D incentives. Conversely, in laggard industries competition invariably stifles R&D incentives.*

The intuition for this result is simple: an increase in product market competition has two contrasting effects on R&D incentives (i.e., on $\partial\Pi^c/\partial\lambda$). On the one hand, more competition may reduce the direct benefits of R&D by reducing the output sold at equilibrium, even by a successful innovator. On the other hand, competition makes the strategic benefit of R&D more desirable for firm 1. For firms who can rely on a small "potential for innovation" with respect to their rivals (i.e., for $\lambda\overline{\theta} < 1/4$) the former effect always prevails, entailing that competition has a Schumpeterian effect on R&D. When firms have a large "potential for innovation" (i.e., $\lambda\overline{\theta} \geq 1/4$) a similar Schumpeterian result holds only provided the initial degree of competition is soft. However, at high levels of competition any additional competitive pressure makes the strategic effect very desirable, thus boosting firm 1's incentives to innovate: an Arrow result.

3.2 Incomplete information in firm 1's contractual relationship

We now turn to the case where firm 1's supplier does not observe the realized R&D output. In this case, the intensity of R&D affects both firm 2's expectation about firm 1's strength *and* the internal contractual relationship between firm 1 and its supplier. This has important implications for innovation incentives and their relationship to product market competition. As in the previous section, we proceed backward and study the contracting game between firm 1 and its supplier and the product market game for a given level of R&D intensity λ. The supplier's program at date 1 ($\mathcal{P}_1$) consists in designing a menu of contracts $\mathcal{C} = \left\{(\underline{T}_1, \underline{q}_1), (\overline{T}_1, \overline{q}_1)\right\}$ so as to maximize his expected repayments subject to usual participation and incentive compatibility constraints (needed for types' separation). Hence,

$$\mathcal{P}_1 \ : \begin{cases} \max_{\left\{(\underline{T}_1,\underline{q}_1),(\overline{T}_1,\overline{q}_1)\right\}} \left\{\lambda\overline{T}_1 + (1-\lambda)\underline{T}_1\right\}, \\ \text{subject to} \\ \underline{U}_1 \geq 0 \ , \ \overline{U}_1 \geq \underline{U}_1 + \overline{\theta}\underline{q}_1, \ (\underline{q}_1, \overline{q}_1) \in \Re^2_+. \end{cases}$$

In the optimum one gets $\underline{U}_1 = 0$ and $\overline{U}_1 = \overline{\theta}\underline{q}_1$, then a standard change of variables allows to rewrite $\mathcal{P}_1$ as:

$$\max_{\overline{q}_1 \geq 0, \underline{q}_1 \geq 0} \left\{\lambda\left(P_1(\overline{\theta}, \overline{q}_1, q_2)\overline{q}_1 - \overline{\theta}\underline{q}_1\right) + (1-\lambda)\left(P_1(\underline{\theta}, \underline{q}_1, q_2)\underline{q}_1\right)\right\},$$

whose first-order conditions entail:

(2) $$1 + \overline{\theta} - 2\overline{q}_1 - \rho q_2 = 0,$$

(3) $$1 - 2\underline{q}_1 - \rho q_2 - \frac{\lambda}{1-\lambda}\overline{\theta} = 0.$$

The innovator's expected quantity, $\hat{q}_1$, can be written as follows:

$$\hat{q}_1 = \frac{1}{2} - \rho\frac{q_2}{2},$$

where, by symmetry it follows $\hat{q}_1 = q_2$ so that:

$$\hat{q}_1^i = q_2^i = \frac{1}{2+\rho}$$

hence from (2) and (3) one gets:

$$\overline{q}_1^i(\lambda) = \frac{1+\overline{\theta}}{2} - \frac{\rho}{2(2+\rho)}$$

and:

$$\underline{q}_1^i(\lambda) = \frac{1}{2} - \frac{\rho}{2(2+\rho)} - \frac{\lambda\overline{\theta}}{2(1-\lambda)}$$

The above results allow to understand how R&D changes the contractual relationship between firm 1 and its supplier, and how this in turn affects the firm's behavior in the product market. By increasing the likelihood that a high-demand state will realize, R&D investment determines the distribution of types faced by firm 1's supplier. Due to a standard rent extraction-efficiency trade-off, the input supplied to an unsuccessful innovator and thus its output ($\underline{q}_1$) is distorted downwards when successful innovations are more likely (i.e., the hazard rate $\lambda/(1-\lambda)$ is large). Through this "contractual" channel, more R&D investments make an unsuccessful innovator a less aggressive competitor in the product market; *an undesirable strategic effect of R&D* that shows up only in an incomplete information environment. To investigate how this modifies innovation incentives, we define the (expected) joint profit of the coalition formed by the innovator and the supplier in the incomplete information case:

$$\Pi^i = \lambda\left(P_1(\overline{\theta}, \overline{q}_1^i(\lambda), q_2^i(\lambda))\overline{q}_1^i(\lambda)\right) + (1-\lambda)\left(P_1(\underline{\theta}, \underline{q}_1^i(\lambda), q_2^i(\lambda))\underline{q}_1^i(\lambda)\right),$$

and using the first-order conditions we show that:

$$\Pi^i = \lambda(\overline{q}_1^i(\lambda))^2 + (1-\lambda)(\underline{q}_1^i(\lambda))^2 + \lambda\underline{q}_1^i(\lambda)\overline{\theta}.$$

Hence:

$$\frac{\partial\Pi^i}{\partial\lambda} = (\overline{q}_1^i(\lambda))^2 - (\underline{q}_1^i(\lambda))^2 + 2(1-\lambda)\underline{q}_1^i(\lambda)\frac{\partial\underline{q}_1^i(\lambda)}{\partial\lambda} - \underline{q}_1^i(\lambda)\frac{\overline{\theta}}{(1-\lambda)^2} - \frac{\lambda\overline{\theta}}{1-\lambda}\frac{\partial\underline{q}_1^i(\lambda)}{\partial\lambda}.$$

Comparing the marginal benefits of R&D with and without complete information we obtain the following result:

Corollary 2 *Incomplete information vis-à-vis suppliers reduces firm 1's R&D incentives.*

As argued above, in an incomplete information environment a strategic cost of R&D adds to the direct effect and the strategic benefit pinned down in equation (1) defining the marginal benefits of R&D activities. Hence, the supplier's inability to observe the outcome of R&D has a negative impact on innovation incentives, even in our simple model where the financing of R&D is not an issue. Our result provides an additional argument to the claim that environments where capital suppliers are able to closely monitor the innovation process (as is the case in venture capital financing) boost the incentives for R&D with respect to arm's length financing. More generally, it is also in line with the empirical evidence that vertically integrated firms do more R&D than their non-integrated counterparts (see Ciliberto, forthcoming).

Incomplete information also affects the link between competition and innovation incentives, as stated in the following proposition:

Proposition 3 *When the supplier does not observe the outcome of R&D, more intense competition stifles R&D incentives.*

Incomplete information vis-à-vis the contractual party destroys firm 1's potential to use R&D in order to build a strategic advantage with respect to its rival. In our model, this entails that more intense competition can only reduce the innovator's benefits from R&D in a standard Schumpeterian fashion. This result suggests that contractual factors may have an important role in shaping the relationship between competition and innovation. In particular, we predict that when a firm's contractual relationships are plagued by asymmetric information, R&D loses much of its strategic appeal, which in turn makes innovation a decreasing function of competitive pressure. By contrast, in environments where firms' quality is more easily observed by their contracting parties (financiers, suppliers) the strategic value of R&D makes the relationship between competition and innovation more complex, combining both Arrowian and Schumpeterian effects.

4 R&D with Perfect Spillovers

As stressed by much of the literature on research and development, a firm's innovation process often gives rise to technological spillovers.[8] It is thus worth investigating whether the main results

[8] The idea that R&D activities might create positive spillovers for competitors dates back to Ruff (1969). The modern theoretical treatment of the topic has however developed after the seminal contributions by Spence (1984)

of section 3 also extend to a somewhat more complex environment where R&D spillovers are at play. As we shall argue below, this case is also worth analyzing in that asymmetric information vis-à-vis contractual parties is not simply responsible for underinvestment in R&D as illustrated in Corollary 1. Indeed, we are able to show that under some conditions, a "technology trap" occurs whereby the firm's contractual party would gain by *bribing* the firm not engage at all in R&D: this raises the issue of how governance of R&D in contractual relationships affects innovation and competition.

4.1 Innovation incentives and competition

We assume that firm 1's successful innovations generate a positive technological spillover on firm 2's demand. However, we keep our assumption that only the firm that has engaged in the research and development process observes the exact value of the resulting innovation, whereas the rival firm must base its estimate of the innovation value on the observable R&D investment λ. Moreover, to keep things simple we assume that there is perfect spillover, i.e., $\sigma = 1$.[9] In this setting, the rival maximizes the expected profit function:

$$\max_{q_2 \in \mathbb{R}_+} \left\{ \left(\lambda \left(1 + \overline{\theta} - q_2 - \rho \overline{q}_1 \right) + (1-\lambda)(1 + q_2 - \rho \underline{q}_1) \right) q_2 \right\},$$

entailing the best response function:

$$q_2 = \frac{1 + \lambda \overline{\theta}}{2} - \frac{\rho}{2} \overline{q}_1.$$

Differently from an environment where R&D spillovers can be avoided or are absent for technological reasons, R&D investments now bring about a *negative strategic impact* in that they raise the competitor's demand thus shifting its reaction function upward. This undesirable strategic effect implies that an increase in competitive pressure reduces a firm's incentives for R&D even in the benchmark case where no information asymmetry plagues the supplier-firm relationship. In the incomplete information case where the supplier cannot observe the firm's R&D output, the additional strategic cost of R&D illustrated in section 3.2. shows up, reinforcing such negative effect of competition on innovation incentives. While a more detailed analysis of this case is relegated to the Appendix, these results are summarized in the following proposition:

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and d'Aspremont and Jacquemin (1988).

[9]The results for the imperfect spillover case $\sigma \in (0, 1)$ will follow from a simple continuity argument.

Proposition 4 *Under both complete and incomplete information within the supplier-firm relationship, more intense competition stifles R&D incentives.*

It is worth stressing again the fact that in the positive spillover case three effects shape the firm's incentives for innovation. First, an increase in R&D directly enhances the innovator's expected demand. Second, a higher probability of innovation also increases the competitor's expected demand, thus shifting its reaction function upward: a negative strategic effects due to R&D spillovers. Finally, in the incomplete information case a further negative strategic effect shows up due to the downward distortion of the unsuccessful innovator's output, which drives the rival to increase output *along* its own reaction functions.[10] This suggests that incentives for innovation may be quite weak in the presence of R&D spillovers *and* information asymmetries within the firm-supplier hierarchy, as we argue below.

4.2 Innovation incentives, governance of R&D and technology traps

When the supplier-firm relationship is plagued by asymmetric information on the innovation value, the supplier (the principal) and the firm (the agent) may have dissonant preferences over the intensity of research and development to be performed by the firm. Indeed, the supplier is mainly concerned with minimizing the negative strategic effects of R&D as well as the information rent to be left to the firm; the firm clearly aims at maximizing its rent. Obviously, it would be efficient to engage in research and development to an extent that maximizes the supplier-firm hierarchy's joint profits, as we have assumed so far. Yet, if side transfers between the two contractual parties cannot be agreed upon conditional on the efficient level of R&D, a governance problem arises whereby different allocations of control would lead to very different R&D investments.[11]

In this section we will restrict attention to the case where the type support is small, i.e. the technological innovation is "not too promising", an assumption which is technically meaningful in

[10] To put it in other words, when faced with a better demand distribution (larger λ), the rival becomes more aggressive for two reasons. First, its reaction function is shifted upwards due to a larger expected demand; this generates the basic strategic effect emphasized in the complete information benchmark. Second, the rival expects to face softer competition in that - in the asymmetric information case - firm 1's expected reaction function is shifted downwards, and thus increases its output along its own reaction function.

[11] We can think of two main reasons why side transfers cannot be used to implement the efficient level of R&D intensity. First, if a firm is wealth constrained and the supplier has all the bargaining power ex-ante, the firm may be obliged to undertake the amount of research and development required by the latter at the time the contractual relationship is established. In other environments, however, research and development may mostly consist of non-tangible investments on the firm's side which are unlikely to be verifiable. In this case, we can expect the firm to choose an "R&D effort" which maximizes its ex-post information rent.

that it guarantees an internal solution to the competing firms' production problem:

$$\overline{\theta} < \frac{1}{2}.$$

To begin with, let us study the optimal R&D investment in the efficient governance regime where joint profits are maximized. Denote with $(\overline{q}_1^a(\lambda), \underline{q}_1^a(\lambda))$ firm 1's equilibrium allocation as a function of λ. Straightforward calculations allow to write the supplier-firm's joint profits in the asymmetric information case as a function of λ:

$$\Pi^i = \lambda(\overline{q}_1^a(\lambda))^2 + (1-\lambda)(\underline{q}_1^a(\lambda))^2 + \lambda\underline{q}_1^a(\lambda).$$

The next proposition illustrates the result.

Proposition 5 *The efficient intensity of R&D is defined as $\lambda^*(\rho) = \min\left\{\frac{1}{2} + \frac{(1-\rho)}{\overline{\theta}}, 1\right\}$. R&D intensity $\lambda^*(\rho)$ is decreasing in ρ and achieves its minimum at $\rho = 1$: $\lambda^*(1) = \frac{1}{2}$.*

As we argued in section 4.1., more intense competition always makes R&D less profitable, due to a strengthening of its negative strategic effects. Notice also that the efficient R&D intensity is also decreasing in the types' support $\overline{\theta}$, which we interpreted as a measure of innovation potential. This is because large values of $\overline{\theta}$ (and thus of the expected spillover) magnify the strategic cost of R&D, in contrast with the no-spillover case where large values of $\overline{\theta}$ amplify the strategic benefit of R&D.

Let us now analyze the optimal choice of R&D from the supplier's point of view. In this case, the probability of the high-demand type is chosen so as to take into account also the rents granted to the innovator to elicit truthful information revelation. This additional ingredient plays a crucial role in determining a technology trap that we illustrate in the next proposition.

Proposition 6 *The level of R&D intensity λ^P that maximizes the supplier's utility is equal to 1 if competition is weak ($\rho < 2\overline{\theta}$) and equal to 0 if competition is tough ($\rho \geq 2\overline{\theta}$). The level of R&D intensity λ^A that maximizes the firm's information rent is equal to 1 for any degree of competition.*

The intuition for this result is the following. The uninformed supplier has a twofold objective: first, he aims at minimizing the negative strategic effect of R&D - the more so the larger is ρ; secondly, he tries to minimize the firm's information rent which is instead concave in λ in the relevant parameter space. When the firm is faced with tough competition, the first objective dominates, inducing the supplier to favor a firm which undertakes no R&D at all, whereas the firm (the informed agent) would rather engage in highly-intensive R&D so as to maximize its information rent. This suggests that in presence of strong competitive pressure a *low technology trap* might force sectors with low R&D knowledge base not to innovate if the non-informed party has the decision right on the R&D activities performed by the informed one.[12] This result provides a rationale to the evidence provided by Aghion et al. (2006) that new entry in technologically laggard industries reduces incumbents' innovation incentives, whereas entry in technologically advanced industries boosts innovation incentives.

The following corollary emphasizes the result that the entrepreneur might have preferences over the intensity of research and development which are not aligned with the firm's supplier:

Corollary 7 *Assume the firm privately observes the value of its innovation. Then, when product market competition is tough, the firm and its contractual party have dissonant preferences over the amount of research and development to be performed by the firm.*

Our result opens issues of corporate governance in the debate on the design of R&D incentives; in particular, the regime of property rights on the R&D effort will play a crucial role in determining the innovative activity of a financially constrained entrepreneur. Notice also that under some conditions our principal-agent relationship can be interpreted as one between a monopolistic capital supplier and a firm in need of outside finance. By explicitly studying how R&D investments affect the informational problems between the financier and the firm as well as the product market equilibrium, we provide predictions on how financiers' and firms' attitudes towards innovation change as product market competition becomes more intense. In particular, the results in Proposition 6 suggest that monopolistic financiers might force firms under strong competitive pressure *not* to engage in research and development.

5 Extensions

[To be completed]

6 Concluding Remarks

This paper makes a first step towards understanding the interplay between contractual problems and product market competition in shaping firms' decisions to engage in R&D activities. We study the contractual relationship, plagued by asymmetric information, between a supplier and a

[12] Of course, this result holds only when this R&D effort is verifiable.

firm facing imperfect competition in the product market, and analyze how the vertical structure's joint profits are affected when the firm invests in research and development activities to generate a product innovation. In our model, neither competitors nor contractual parties (e.g., the supplier) are able to observe the outcome of the R&D process; hence, the intensity of R&D activity affects the rival's perception of the firm's strength, as well as its contractual relationship with third parties. Within this setting, we show that asymmetric information vis-à-vis contractual parties neutralizes any strategic value of R&D, implying that more intense competition invariably stifles innovation incentives. We also compare the firm and the supplier's attitude towards innovation and find that dissonant preferences over R&D intensity arise when R&D generates positive spillovers on rivals and product market competition is intense. Our results raise the issue of how governance factors (monitoring, control of R&D) interact with product market competition in shaping innovation incentives.

7 Appendix

Proof of Proposition 1

In order to prove the result we need to show that $\partial^2\Pi^*/\partial\lambda\partial\rho \leq 0$ for all $\rho \in [0,1]$ if $\lambda\overline{\theta} \leq 1/4$, and that there exists a ρ^* such that $\partial^2\Pi^*/\partial\lambda\partial\rho > 0$ (resp. $\leq$) for $\rho > \rho^*$ (resp. $\leq$) whenever $\lambda\overline{\theta} > 1/4$. So, substituting the complete information allocation $(\overline{q}_1^*(\lambda)^2, \underline{q}_1^*(\lambda))$ into $\partial\Pi^i/\partial\lambda$, and using $\partial q_2^*(\lambda)/\partial\lambda = -\rho\overline{\theta}/(4-\rho^2)$ we have:

$$\frac{\partial\Pi^c(\lambda,\rho)}{\partial\lambda} = \frac{4\overline{\theta}\,(2-\rho)}{(2+\rho)^2\,(2-\rho)^2} - \frac{\overline{\theta}^2\,(8\rho^2\,(1-2\lambda) - \rho^4\,(1-2\lambda) - 16)}{4\,(2+\rho)^2\,(2-\rho)^2}. \tag{4}$$

Differentiating again with respect to ρ we also get:

$$\frac{\partial^2\Pi^c(\lambda,\rho)}{\partial\lambda\partial\rho} = \frac{\overline{\theta}\left(\rho(8\overline{\theta}\lambda - 3\rho) - 4(1-2\rho)\right)}{(2-\rho)^3(2+\rho)^3}. \tag{5}$$

Now by inspecting 5 the result follows immediately. *QED*

Proof of Corollary 2

In order to prove the result we need to show that $\partial^2\Pi^*/\partial\lambda\partial\rho \leq 0$ fro all $(\lambda,\rho) \in [0,1]^2$. So, substituting the allocation $(\overline{q}_1^i(\lambda)^2, \underline{q}_1^i(\lambda))$ into $\partial\Pi^i/\partial\lambda$, we have:

$$\frac{\partial\Pi^i}{\partial\lambda} = \frac{\overline{\theta}\left(4 - 8\lambda + 4\lambda^2\right)}{4\,(1-\lambda)^2\,(2+\rho)} + \frac{\overline{\theta}^2\,(2+\rho-2\lambda\,(2+\rho)\,(2+\lambda))}{4\,(1-\lambda)^2\,(2+\rho)}.$$

Differentiating again one gets:

$$\frac{\partial^2\Pi^i}{\partial\lambda\partial\rho} = -\frac{\overline{\theta}}{(2+\rho)^2} < 0,$$

which proves the result. *QED*

Proof of Proposition 3

Since $(\lambda,\rho) \in [0,1]^2$ in order to prove this result we use a second order Taylor approximation of the joint profits around $(0,0)$ so to have:

$$\Pi^s(\lambda,\rho) \approx \Pi^s(0,0) + \Pi^s_\rho(0,0)\rho + \Pi^i_\lambda(0,0)\lambda + \frac{1}{2}\Pi^s_{\lambda\lambda}(0,0)\lambda^2 + \frac{1}{2}\Pi^s_{\rho\rho}(0,0)\rho^2 + \Pi^s_{\lambda\rho}(0,0)\lambda\rho,$$

for $s = c, i$.

Then after tedious but simple algebraic manipulations we have:

$$\Pi^i(\lambda,\rho) \approx \frac{1}{4}(1-\rho+\frac{3}{4}\rho^2)+\frac{\overline{\theta}}{2}\lambda(1-\frac{1}{2}\rho)+\lambda\frac{\overline{\theta}^2}{4}(1-\frac{1}{2}\lambda), \tag{6}$$

and,

$$\Pi^c(\lambda,\rho) \approx -\frac{1}{4}\rho(1-\frac{3}{4}\rho)+\frac{\overline{\theta}}{2}(1-\lambda\rho)+\frac{1}{4}\overline{\theta}^2, \tag{7}$$

taking the difference between (6) and (7) it follows:

$$\Pi^i(\lambda,\rho)-\Pi^c(\lambda,\rho) \approx -\frac{1}{4}\lambda\overline{\theta}^2,$$

which yields immediately the result. *QED*

Proof of Proposition 4

Consider first the complete information allocation derived in the case with spillovers. Then using the second one can easily check that:

$$\Pi^c(\lambda,\rho)=\lambda\left(\overline{q}_1^c(\lambda,\rho)\right)^2+(1-\lambda)(\underline{q}_1^c(\lambda,\rho))^2$$

and so:

$$\frac{\partial\Pi^c(\lambda,\rho)}{\partial\lambda}=\frac{2\overline{\theta}}{(2+\rho)^2}+\frac{\overline{\theta}^2\left(4\rho\left(1-2\lambda\right)+\rho^2\left(1-2\lambda\right)+4\right)}{4(2+\rho)^2}.$$

This immediately yields:

$$\frac{\partial^2\Pi^c(\lambda,\rho)}{\partial\lambda\partial\rho}=-\frac{4\overline{\theta}}{(2+\rho)^3}-\frac{4\lambda\overline{\theta}^2}{(2+\rho)^3}<0$$

Now consider the incomplete information setting, using the first-order conditions we have:

$$\Pi^i(\lambda,\rho)=\lambda\left(\overline{q}_1^i(\lambda,\rho)\right)^2+(1-\lambda)(\underline{q}_1^i(\lambda,\rho))^2+\lambda\overline{\theta}\underline{q}_1^i(\lambda,\rho),$$

from which substituting the equilibrium allocation $(\overline{q}_1^i(\lambda,\rho),\underline{q}_1^i(\lambda,\rho))$ one gets easily:

$$\frac{\partial^2\Pi^i(\lambda,\rho)}{\partial\lambda\partial\rho}=\frac{\overline{\theta}\left(32\rho-12\rho^2+\rho^4-32\right)}{(2+\rho)^3\left(2-\rho\right)^3}+\frac{\overline{\theta}^2\lambda\left(-32+16\rho+4\rho^3+2\rho^4\right)}{(2+\rho)^3\left(2-\rho\right)^3},$$

which is clearly negative for all $\rho\in[0,1]$. *QED*

Proof of Proposition 5

In proving this result we shall again use a second order Taylor approximation around the point $(\lambda, \rho) = (0, 0)$ of the function $\Pi(\lambda, \rho)$. Simple manipulations then allow to get:

$$\Pi^i(\lambda, \rho) \approx \frac{1}{4}(1 - \rho + \frac{3}{4}\rho^2) + \lambda\frac{\overline{\theta}}{2}(1 - \rho) + \lambda\frac{\overline{\theta}^2}{4}(1 - \lambda),$$

and so

$$\frac{\partial \Pi^i}{\partial \lambda} \approx -\frac{\overline{\theta}\left(\overline{\theta}(2\lambda - 1) - 2(1 - \rho)\right)}{4},$$

from which the result follows immediately. *QED*

Proof of Proposition 6

Again we use Taylor approximation around $(0, 0)$ to express the supplier's profit, π^i. We then have:

$$\pi^i(\lambda, \rho) \approx \frac{1}{4}(1 - \rho + \frac{3}{4}\rho^2) - \frac{1}{4}\overline{\theta}\lambda\rho + \lambda\frac{\overline{\theta}^2}{4}(1 + \lambda)$$

Differentiating again one has:

$$\frac{\partial \pi^i(\lambda, \rho)}{\partial \lambda} \approx \frac{\overline{\theta}\left(\overline{\theta} - \rho + 2\overline{\theta}\lambda\right)}{4}$$

which yields immediately the result since .$\frac{\partial \pi^i(\lambda, \rho)}{\partial \lambda}$ is increasing in λ and thus $\pi^i(\lambda, \rho)$ is convex in λ with $\pi^i(0, \rho) \geq \pi^i(1, \rho)$ (resp. $<$) if $\rho \geq 2\overline{\theta}$ (resp. $>$). *QED*

Proof of Proposition 6

The result can be immediately proved once we determine the agent's expected information rents $V_1^i = .\lambda\overline{\theta}\underline{q}_1^i$. Substituting the expression for $\underline{q}_1^i$ into V_1^i we have:

$$V_1^i(\lambda, \rho) = \lambda\frac{\overline{\theta}}{2}(1 - \frac{1}{2}\rho) - \frac{1}{2}\overline{\theta}^2\lambda^2,$$

yielding immediately:

$$\frac{\partial V_1^i(\lambda, \rho)}{\partial \lambda} = -\frac{\overline{\theta}\left(\rho + 4\overline{\theta}\lambda - 2\right)}{4}.$$

The result then immediately follows as for $\rho \geq 2\overline{\theta}$ the agent (expected) information rents are maximized at a positive λ while the supplier would choose $\lambda = 0$. *QED*

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