The Growth and Diffusion of Knowledge and the Theory of the Firm

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Abstract

We analyze the implications of a market imperfection related to the inability to establish intellectual property rights, that we label unverifiable communication. Employees are able to collude with external parties selling "knowledge capital" of the firm. The firm organizer engages in strategic interaction simultaneously with employees and competitors, as she introduces endogenous transaction costs in the market for information between those agents. Incentive schemes and communication costs are the key strategic variables used by the firm to induce frictions in collusive markets. Unverifiable communication introduces severe allocative distortions, both at internal product development and at intended sale of information (technology transfer). We derive implications of the model for observable decisions like characteristics of the employment relationship (full employment, incompatibility with other jobs), firms' preferences over cluster characteristics for location decisions, optimal size at entry, in-house development vs sale strategies for innovations and industry evolution.

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> *[...] In this second approach, business is more like a conversation, or a series of conversations which intersect and interact, and the manager's role is more like a host at a cocktail party attempting to control who talks to whom and what they talk about.*
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> Piore et al. (95):
> "Case Studies in the Organization of Product Development: The Cellular Telephone Equipment Industry".

1 Introduction

In this paper we derive the implications of non-patentable intellectual property rights for the organization and optimal size of the firm. We consider the problem of an innovator that pursues a non-patentable project, the value of which is common knowledge. We focus on the following situation. In order to develop her idea the innovator benefits from collaboration with a team of agents. Development is a joint effort that leads to the production of new knowledge (*learning by doing*). Team members become necessarily informed about the outcome of the learning process. Moreover, this new knowledge cannot be protected by patents. The crucial point is that the innovator is unable to perfectly control communication between team members and third parties. Potential entrants to the market in particular are willing to pay for information relating to the ongoing learning process in the team, since collusion with team members at the innovator's firm increases their probability of effectively entering the final market (as competitors). We label this type of situation as *unverifiable communication.*

Unverifiable communication represents an obstacle to appropriating the returns from innovation because it implies that by collaborating to develop the initial project, the innovator creates a (collusive) market for information, where the sellers are her own employees and the buyers are her competitors in the final market. Trade in this market directly hurts the innovator.

We model a setting with a financially unconstrained innovator that has come up with a project of known value. The project leads to a specific business that requires a prior learning phase, the cost of which can be reduced by hiring a team of agents. At the end of the learning phase the employees (and also the innovator) are able to transmit (at a cost) sensible information to third parties concerned about the result of team learning. This is either because the new product is easy to imitate without the risk of patent infringement liability, or because the third party (*the follower* henceforth) does not want to be negatively affected by the innovator's activity. We study the optimal organization of the firm for the innovator to appropriate the returns of the project in this setting of unverifiable communication with outsiders.

Our primary result is that the firm plays a role of preserving the secrecy of innovative activities. In the first place there is a *direct* benefit of forming a firm. The innovator creates her own venture in order to avoid competitors' direct access to her economic activities. The firm acts as a shield that does not let competitors access its knowledge capital [1]. There is also an *indirect* benefit of forming a firm. Team members are necessarily informed about the learning outcome and are able to inform competitors. Being the organizer of the firm, the innovator controls the size of the team and employees' incentive schemes and communication costs (inside and outside the firm). These variables are set up so as to increase the cost of communication between employees and outsiders. One organizational problem is to design *secrecy instruments* so as minimize undesired leakage of knowledge. Compensation systems are used in order to introduce friction in the market for information between the employees and the follower. The size of the firm also has strategic value for the innovator, since under decreasing returns stake is diluted in large firms .

We find that unverifiable communication leads to a suboptimal firm size. In particular, the innovator can always deter spillovers by setting a sufficiently small team. Yet, if development costs are high, the innovator finds it optimal to hire a *large* team of employees and diffusion of information by a subset of team members cannot be avoided. In this case it is optimal to divide employees in two groups that receive different treatment. One of these groups has stake in the firm and does not sell information. The other group holds no equity and communicates with the follower.

Communication costs are minimized inside the firm and are maximized outside the firm. This is achieved by restricting employees to not sign contracts simultaneously with other firms, demanding full-time employment or through firm location decisions. The innovator will optimize over the characteristics of the cluster where she locates the firm, since they affect appropriability conditions.

We find that the innovator's ability to appropriate returns from invention

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[1] See footnote 19 below.

are driven by a single variable that we label the *power* of the innovator. Interestingly, this variable depends not only on characteristics of the firm, but also on the nature of competition in the market (the degree of product differentiation, the importance of sunk costs, etc.). The nature of product market competition determines the internal organization of the firm and the innovator's ability to develop the process in her firm.

We compare the optimal organization of the innovator's firm under unverifiable communication with the benchmark of the innovator's first best: the maximum innovators' profit[2] under *verifiable* communication.

Under unverifiable communication the innovator can follow two distinct strategies in order to maximize profits. The first one, that we have described above, is to minimize communication with the follower. The second strategy is to directly *sell* information to the follower. An additional result that we find is that also under the second strategy (the intended sale of information to the follower) important transaction costs arise.

The relevance of ill-defined intellectual property rights has been widely documented in the literature. Examples and case studies can be found in Anton and Yao (94), Powell (97), Cheung (82), Pooley (87) and von Hippel (82). Moreover, we point out the transaction costs associated with unverifiable communication that apply far beyond the case of disclosure of trade secrets, encompassing all kinds of strategically sensitive information. Consider, for instance, firm A which develops a process innovation that halves the cost of producing a given good, already commercialized by firm B. The specific information "*A will launch its product in the market at time t, at price p*" has positive demand in firm B (knowing it allows B to take action thereupon). Moreover, it is difficult to avoid a subset of employees in firm A being aware of this type of information and to avoid its transmission outside the firm.

To illustrate the relevance of this type of situation we include the following quotation from a Biotechnology SEC company report. Similar statements can be found in the reports of most Biotechnology companies[3].

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[2] We focus on producers' surplus because under verifiable communication there are property rights over information and the innovator can sell information to the competitor.

[3] For case studies and empirical research that document the importance of fragile intellectual property rights, see Griliches (92), Levin et al. (87), Rumelt (84), Teece (86), Nelson (82), Mishina (91), Pisano and Mang (92), Pisano (97), Powell (96), Shan (90) and OTA (84) and (91).

> Much of the Company's Know-how and Technology is not patentable. To protect its rights, the Company requires all employees, consultants, advisors and collaborators to enter into confidentiality agreements with [the Company] . There can be no assurance, however, that these agreements will provide meaningful protection for the company's trade secrets, know-how, or other proprietary information in the event of any unauthorized use or disclosure.

A number of papers by Piore et al (94), (95) and (97) have emphasized the role of authority inside the firm in directing and managing the flow of information in an industry. At early (rather, at the *interpretative*) stage of an industry it becomes necessary to reduce uncertainty and to have agents exchanging information. Yet the flow of information so generated has to be carefully managed if the firm wants to appropriate the value derived from it[4].

Piore et al. report on a number of extensive case-studies some of which explicitly reveal management preoccupation for unintended flows of information to competing firms. In particular Piore et al. (97) describe the concern of two manufacturers -Diesel and Replay- of fashion clothes (jeans) that share the same firm -Martelli- for product finishing. The manufacturing managers state that [5]:

> *Both Diesel and Replay were in fact very uncomfortable about the idea that their competitors might obtain critical information about their collection through Martelli, and as a result Martelli had been forced to agree to separate the management of the Diesel and Replay accounts and to handle them in physically separate facilities.*

The quote reflects the problem of *unverifiable communication*: the freedom of Martelli to diffuse sensitive information (the manufacturers' season collection) to competitors. It also shows an instance of an organizational response in front of this situation.

From the theoretical perspective, the relevance and implications of imperfect verifiability by the court of key economic information has received

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[4] See the quotation at the beginning of the paper.

[5] Piore et al. (97), page 26.

increased attention in the last years. Authors stress the importance of non-contractible profit streams in the allocation of property rights over physical assets and its relevance for the design of corporate financial structure (see Hart (94) for a survey). Stole and Zwiebel (96) explore the consequences for wage outcomes of non-contractibility of employees' permanence in the firm. They find a large number of implications for the organization of the firm.

One case of imperfect verifiability that is particularly important is the difficulty in establishing intellectual property rights in innovation-oriented environments. The transaction costs associated with appropriating the returns from innovation by an inventor have been well known since Arrow (70). Since Barzel (68), a number of authors have focused on the case where the full returns from innovation are not captured by the inventor of knowledge-based products because advertising and marketing imply imitation. Imitators in other firms free-ride on the effort of the inventor. In particular, Yu (81), Yu (84) and Kobayashi and Yu (93) derive implications of ill-defined property rights of ideas on the organization of the firm and in particular on vertical integration of research activities. Gort and Klepper (80) study diffusion of innovations and industry evolution in this context.

More recently, Anton and Yao (94) derive the optimal contract for a financially constrained inventor that sells an idea to a buyer when the inventor cannot rely on patents to protect intellectual property. The inventor faces a trade-off in showing information to the buyer. Showing it reduces information asymmetries and increases buyer's willingness to pay. On the other hand, showing information also implies obviously that the buyer needs to buy less information. We will refer to this situation as the *crowding out* effect that communication has over trade. It is important to stress that our results are unrelated to the crowding out effect and that they hinge only on what we call unverifiable communication.

Our paper is close to Jovanovic and Rob (89) in that they assume that imitation *by collaborators* cannot be avoided contractually. Their setting is different than ours in several respects: market structure is perfectly competitive, team formation follows a random matching pattern, and there are no imitators in the market (besides the match).

The problem of the internal organization of the firm when intellectual property rights are imperfect has been studied by Rodriguez-Palenzuela (93). Here, the role played by incentive schemes and physical assets in the appropriation of the benefits from innovation is emphasized. In this paper it is optimal to concentrate control rights over physical assets in one member of the firm in order to maximize the cost of collusion between employees and external parties.

Some of the organizational implications of unverifiable communication have also been analyzed in the banking literature, in particular in Bhattacharya and Chiesa (95) and in Ueda (97). These papers focus on an innovator that needs financial inputs and is forced to reveal sensitive information to her creditor. The creditor can expropriate the innovator by selling information to competitors. In this case, the innovator can optimize over the characteristics of the creditor so as to minimize the hold-up problem.

Ronde (96) studies how to alleviate the problem of unverifiable communication by optimally allocating information inside the firm. The innovator can divide the information related to her invention into different "pieces", and give pieces of information to her employees. This way employees are unable to sell all the information to parties external to the firm and they are still productive inside the firm.

The rest of the paper is organized as follows. Section 2 lays out the model. Section 3 shows the optimal contract under verifiable communication. Unverifiable communication is introduced in section 4, where agents' incentive compatibility conditions for revealing information are derived. The equilibrium set of offers by the follower is shown to depend on incentive schemes. The optimal organizational strategy to develop the product is derived in sections 5 and 6. Section 5 shows the optimal incentive scheme to preserve secrecy, given firm size. The optimal size of the firm is derived in section 6. Section 7 contains the optimal contract to sell information to the follower and section 8 compares product development in a new firm with the sale of information. Section 9 closes the paper with concluding remarks.

2 A model of endogenous spillovers

We consider the optimal organization problem of a researcher (the *innovator*) with a project related to an innovation. Developing the project requires a learning effort, the cost of which can be reduced hiring a team of agents. The knowledge resulting from the learning process cannot be perfectly protected through patents. Hence, once the team has gone through the learning process it becomes an issue for the innovator to control the diffusion of the new knowledge produced. In particular, team members are able to diffuse information to a third party outside the firm (the *follower*), increasing the possibility of competition in the final market.

The timing of the game is as follows. At $t = 1$ the innovator has the option to build a team for product development. She hires N risk neutral agents, communicates the innovative idea and offers them an incentive contract. Internal communication costs are $v(i)$, where $i \in [0, N]$, and $v(i) \in [\underline{v}, \overline{v}]$. Incentive schemes are linear [6]: they specify the proportion of the profits agents obtain, $b(i) \geq 0$, $i \in [0, N]$, plus an initial transfer to the innovator ($A_i \in \Re$, $i \in [0, N]$). $b(i)$ satisfies a balanced budget condition: $\int_0^N b(i)di \leq 1$. Agents face no liquidity constraints, are symmetric and, once informed, are able to reduce the cost of developing the innovation, $C(N, \theta)$. The parameter θ indexes agents' cost-reducing efficiency. This function satisfies the following conditions:

$$\begin{aligned} \frac{\partial C(N,\theta)}{\partial N} &< 0 \quad \frac{\partial^2 C(N,\theta)}{\partial N^2} > 0 \\ \frac{\partial C(N,\theta)}{\partial N} &< \frac{\partial C(N,\theta')}{\partial N} \Leftrightarrow \theta > \theta' \end{aligned}$$

At $t = 2$ team members are able to secretly[7] communicate the idea to the follower and get compensation for it. In particular, the follower makes offers to team members in the innovator's firm[8]. Let n be the number of team members that accept those offers and actually trade with the follower. We will refer to n as the number of *diffusers*. If on the other hand no workers are hired ($N = 0$), the innovator can engage in bargaining with the follower in order to exchange the idea. In this case there is Nash bargaining, where the power of the innovator is α.

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[6] See the discussion in footnote 16.

[7] Since communication is secret, it does not affect the contract between team members and the innovator (A_i, b_i).

[8] We are assuming that the competitor cannot make offers at $t = 1$. For the case when the innovator and the follower trade at $t = 1$ see notes in section 7. A possible justification for our assumption goes as follows. At $t = 1$ the innovator knows that developing a technology should have cost reducing advantages, but the project is too immature to know exactly to which product the technology will be applied in the future. It is at the end of the learning phase $t = 2$ when it becomes clear what will be the firm affected by the new product or which one has the highest willingness to pay for the information. The assumption of symmetric information on the project's value responds to a researcher's reputation consideration. In the early eighties a number of scientists realized that genetic engineering could be applied to the manufacturing of pharmaceuticals. At the early stages of the Biotechnology industry innovative firms' activity was to search which products could be cheaply produced through new methods.

Communication with the follower has a direct, agent-specific cost of $\delta(i)$ units. $\delta(i)$ is an endogenous variable chosen by the innovator and it satisfies: $\delta(i) \in [\underline{\delta}, \overline{\delta}]$, with $\overline{\delta} > \underline{\delta} = \underline{v} \geq 0$. Communication costs should be interpreted as the number of hours the agent is not required to spend working in the team[9] or the expected loss of being caught by the court at unauthorized communication. Team members' decisions to accept or reject offers are taken simultaneously and non-cooperatively. We assume there is ex post bargaining with the follower for the idea. Since either none or many agents communicate with the follower (agents are "atoms"), we assume the follower has all the bargaining power[10]. The role of communication is to increase the probability of entry, $\lambda(n)$, by the follower at $t = 3$. We have $\lambda' > 0$ and $\lambda'' < 0$.

Finally at $t = 3$ products are sold in the market. Either the innovator's firm faces no competition (with probability $1 - \lambda(n)$) and obtains ex post revenues of R_m^o; or entry and competition take place (with probability $\lambda(n)$) and the innovator and the follower firms obtain R_d^o and R_d^1, respectively. We assume that $R_m^o > R_d^o$.

3 Contractible communication

Consider in the first place the optimal number of team members, N^*, and diffusers, n^*, when communication is contractible. Communication costs inside ($\underline{v}N$) and outside the firm ($\underline{\delta}n$) should be kept at minimum levels, since they are purely inefficient.

Proposition 1 *The optimal firm size N^* and communication n^* are depend on the term: $R_d^o + R_d^1 - R_m^o$. There are two cases to consider:*

$$\begin{aligned} \text{Tough competition} &: \quad R_m^o \geq R_d^o + R_d^1 \\ n^* &= 0 \quad \text{and} \quad N^* = N_o^* : -\frac{\partial C(N_o^*, \theta)}{\partial N} \equiv \underline{v} \\ \text{Efficient follower} &: \quad R_m^o < R_d^o + R_d^1 \\ n^* &> 0 \quad \text{and} \quad N^* \geq N_o^* \end{aligned} \tag{1}$$

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[9] This decreases i's time available to, say, find the follower and collude with him.

[10] We make this assumption for simplicity. The model could be generalized to arbitrary division of bargaining power without changing substantially the results.

Proof: in the Appendix.

We find that when competition is tough ($R_m^o \geq R_d^o + R_d^1$) diffusion of knowledge between firms should be avoided ($n^* = 0$).

When the follower is "efficient" (or competition is "soft") ($R_m^o < R_d^o + R_d^1$) the innovator hires agents with two purposes. The first one is to reduce her own product development cost $\left(-\frac{\partial C(N^*,\theta)}{\partial N}\right)$, as in the previous case. The second purpose of hiring is to sell information to the follower (technology transfer). In this case there are gains from transferring information to the follower since competition is not too destructive of profits. A positive mass of agents communicates with the follower in order to increase the probability of entry, since the innovator faces no transaction costs to sell knowledge to the follower.

Under verifiable communication the optimal incentives' scheme is not defined, since there is not an agency problem in the usual sense.

4 Non-contractible communication

In order to find the perfect equilibrium consider the game at $t = 2$. Given $(b(i), i \in [0, N])$, team members get offers from the follower and they decide whether to communicate and trade. Call $p(i,n), i \in [0,N]$ the set of offers made to the agents when n agents are communicating. For a team member i to accept an offer $p(i,n)$, when she believes that n agents are communicating, it should be that her utility from keeping the information inside the firm is smaller than from selling it. Consider the division of the interval $[0,N]$ in $\frac{N}{\varepsilon}$ segments of size ε. ε is the "size" of each of the employees.

Proposition 2 *The condition for agent i to prefer communication with the follower is:*

$$\int_i^{i+\varepsilon} b(s)\,ds\left[\lambda(n)R_d^o + (1-\lambda(n))R_m^o - C(N)\right] \tag{2}$$

$$\leq \; [p(i) - \delta(i)]\varepsilon + \int_i^{i+\varepsilon} b(s)\,ds\left[\lambda(n+\varepsilon)R_d^o + (1-\lambda(n+\varepsilon))R_m^o - C(N)\right]$$

In the limit as $\varepsilon \to 0$, the condition (2) is:

$$p(i,n) \geq \delta(i) + b(i)\left[\lambda'(n)\left(R_m^o - R_d^o\right)\right] \equiv k(i,n) \tag{3}$$

Proof: in the Appendix.

$k(i,n)$ is the total communication cost for an agent entitled to a "fraction" $b(i)$ of the profits, when n agents are communicating. It is also the reservation price for the agent. $k(i,n)$ increases with the extent of the stake that the agent has in the innovator's firm, $b(i)$, and with the cost of communication, $\delta(i)$, making it more expensive for the follower to obtain information. $k(i,n)$ decreases with the number of agents that trade with the follower, since communication worsens the profitability of the innovator's firm.

Since agents have no bargaining power, they obtain a negligible share of the surplus: $p(i,n) = k(i,n)$. That expression (3) is the condition for agent i to communicate hinges on the fact that team members in the innovator's firm are unable to coordinate their actions and each agent takes others' decisions to accept offers as given. Competition among them is such that all the gains from trade go to the follower[11].

We have imposed few restrictions on the incentives mapping $b(i)$. Since agents' identity does not matter, we can redefine $b(i)$ without loss of generality in the following way:

Definition 3 *Let* $x(i)$ *be an index in* $[0,N]$ *such that* $b(x) \geq b(x') \Leftrightarrow x \geq x'$ *and call* $\mathbf{b}(\mathbf{x})$ *the resulting incentives' mapping.*

The incentives mapping $\mathbf{b}(\mathbf{x})$ is possibly discontinuous and, by definition, non-decreasing.

4.1 The optimal follower's reaction to $\mathbf{b}(\mathbf{x})$

We now derive the optimal collusive offers made by the follower to team members, given communication costs, incentive schemes and the size of the innovator's firm. Since bargaining is efficient, trade between agents and the follower takes place as long as the joint surplus of the follower and the *marginal* agent is larger when they trade than when they do not trade. The follower makes offers: $p(x,n) = k(x,n)$, $x \in (0,n)$ to n agents, that are

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[11] An important role is played by the assumption that the follower has all the bargaining power before agents. This is just a simplifying assumption. Other divisions of bargaining power would alleviate the transaction cost due to unverifiable communication, but would not make it disappear.

accepted in equilibrium. n is chosen so as to maximize his profit:

$$\begin{aligned}
&\max_{n\leq N} \lambda(n)R_d^1 - \int_0^n k(x,n)dx && (4)\\
=\ & \lambda(n\left(N,\mathbf{b}\left(\mathbf{x}\right)\right))R_d^1 - \lambda'(n\left(N,\mathbf{b}\left(\mathbf{x}\right)\right))\Delta R^o \int_o^{n(N,\mathbf{b}(\mathbf{x}))} b(x)dx - \delta n
\end{aligned}$$

where $\Delta R^o \equiv \left(R_m^o - R_d^o\right)$.

Expression (4) results since $b(x)$ is non-decreasing. The follower will bribe first the agents with lowest stake in the firm (they are homogeneous in other respects). Notice from (4) that agents that decide to communicate exert negative externalities among them, that also affect negatively the agents that are not communicating outside the firm. This negative externality is captured in the first place in the term $\lambda'(n)R_d^1$, that is decreasing in n. Diffusers are able to sell a smaller value to the follower when more agents are communicating, due to decreasing returns in the probability of entry, $\lambda\left(n\right)$.

The second negative externality is captured in the term:

$$-\lambda'\left(n\right)\Delta R^o \int_0^n b\left(x\right)dx$$

in equation (4) and it is the consequence of the fact that communicating with outsiders lowers the expected profits of the innovator's firm, decreasing the returns from retaining the information inside the firm. Program (4) implies in particular that the follower has two motives to buy information. The first one is a *productivity effect*, that increases the probability of entry as long as $\lambda'(n) \geq \delta\left(x\right)$. The second is an *strategic effect* related to the reduction in the cost of buying information when more agents communicate. Indeed, having contact with more team members decreases the profits of the innovator's firm, reducing the opportunity cost of communication for all agents that trade (since $-\lambda'' > 0$) and hence the buyer's price.

We can now state the local necessary condition for optimality of the number of agents that communicate with the follower.

Lemma 4 *Given* $\mathbf{b}\left(\mathbf{x}\right)$ *and* N*, if* n *is the number of agents that communicate with the follower at* $t=2$*, then*[12]*:*

$$\lambda'(n)R_d^1 - \lambda''(n)\Delta R^o \int_0^n b\left(x\right)dx - \delta - b\left(x\right)\left[\lambda'(n)\Delta R^o\right] \quad > \quad 0 \quad x\in[0,n)$$

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[12] We assume that if an agent is indifferent between selling or not information to the entrant, he follows the preferences of the principal.

$$\lambda'(n)R_d^1 - \lambda''(n)\Delta R^o \int_0^n b(x)\,dx - \delta - b(x)\left[\lambda'(n)\Delta R^o\right] \quad \leq \quad 0 \quad x \in [n, N] \tag{5}$$

The first inequality in (5) is an incentive compatibility condition such that the n agents with $b(x) \leq b(n)$ prefer to trade with the follower. The second incentive compatibility condition in (5) implies that the $(N-n)$ agents with $b(x) \geq b(n)$ strictly prefer not to communicate[13].

Proposition 2 implies in particular that team member x's payoff at the continuation equilibrium, given that agents have no bargaining power is:

$$b(x)\left\{\lambda\left[n\left(\mathbf{b}\left(\mathbf{x}\right)\right)\right]R_d^o + \left(1 - \lambda\left[n\left(\mathbf{b}\left(\mathbf{x}\right)\right)\right]\right)R_m^o\right\}$$

and the joint revenues of team members are:

$$\lambda\left[n\left(\mathbf{b}\left(\mathbf{x}\right)\right)\right]R_d^o + \left(1 - \lambda\left[n\left(\mathbf{b}\left(\mathbf{x}\right)\right)\right]\right)R_m^o$$

(as long as $\int_0^{n(\mathbf{b}(\mathbf{x}))} b(x)dx = 1$). This is also the joint gross surplus to be maximized at $t = 1$, since agents face no liquidity constraints.

The inequalities in (5) are necessary conditions for $n\left(\mathbf{b}\left(\mathbf{x}\right)\right)$ to be the follower's optimal response to the existing contract in the innovator's firm. They are not sufficient conditions since there could be in principle more than one solution[14] to (4) for an arbitrary incentives scheme $\mathbf{b}\left(\mathbf{x}\right)$ [15].

5 The optimal incentive contract

In order to solve for the optimal organization and size of the firm we first consider the problem of giving optimal linear incentive schemes[16] for any

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[13] The partition between $[0, n)$ and $[n, N]$ is clear from the definition of $\mathbf{b}\left(\mathbf{x}\right)$ as non-decreasing.

[14] In particular (5) is not necessarily concave, since $\lambda(.)$ is concave. Moreover, $\mathbf{b}\left(\mathbf{x}\right)$ only satisfies a weak monotonicity condition.

[15] See the proof of proposition 5.

[16] See Appendix B at the end of the paper, where the optimal non-linear balanced-budget scheme is derived. The results do not change qualitatively under optimal non-linear schemes, as long as they are "balanced budget" (BB) schemes, $\int_0^N b\left(i, \widetilde{R}\right) di \leq 1$ where $\widetilde{R}$ is the firm's (random) revenue outcome, although it is shown that non-linear schemes alleviate the appropriation problem. Linear schemes should be interpreted as equity held by employees.

initial team size N. As in the standard moral hazard problem, we need to solve a program where the restriction is itself an optimization program. We adopt a first-order condition approach. We solve for the maximization of innovator's profits, subject to the necessary optimality condition of the follower's reaction (5). We then check the second order condition of the follower at the candidate solution. The program is such that it can be shown that the second order condition is always satisfied.

The following remark states that the existence of competition inside the firm to sell the knowledge capital to the follower implies that the follower retains all the surplus from trade. This implies that the innovator's program is conveniently simplified:

Remark 1 *If* $N > 0$, *under unverifiable communication none of the gains from trade with the follower:* $[\lambda(n) - \lambda(0)] R_d^1 \quad \forall n \in [0.N]$ *are internalized by the innovator's team. This implies that:*
The innovator always follows an entry deterring strategy: $\mathbf{b}(\mathbf{x})$ *is a solution to the innovator's problem,*

$$\left\{ \max_{\mathbf{b}(\mathbf{x})} \; (1 - \lambda(n)) R_m^o + \lambda(n) R_d^o \textit{ subject to (5)} \right\} \tag{6}$$

if and only if $\mathbf{b}(\mathbf{x})$ *is a solution to:*

$$\left\{ \min_{\mathbf{b}(\mathbf{x})} [n(\mathbf{b}(\mathbf{x}))] \textit{ subject to (5)} \right\}^{17}$$

Notice in particular that the innovator prefers to minimize diffusion even when the first best is to have as much communication as possible (the "efficient follower" case: $R_m^o < R_d^o + R_d^1$ with $n^* = N^* > 0$). This is due to the fact that with a mass N of agents that potentially sell information, the market is competitive in the supply side and no rent is internalized by the team.

The employees and the innovator are unable to sustain the first best outcome in proposition 1 because they cannot avoid competing ex post for the sale of information to the follower. This is the transaction cost implied by non-contractible communication.

We can now derive the optimal innovator's contract at $t = 1$. Consider in the first place how to set up the optimal incentives' scheme given that N agents have been hired:

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[17] This is clear since -$\lambda'(n)\Delta R^o < 0$ and $b(x)$ only enters in the constraint.

Proposition 5 *The solution to program (6) satisfies:*
Communication costs are minimized inside the firm and maximized outside the firm:

$$\begin{aligned} \delta(x) &= \overline{\delta} \quad x \in [0, N] \\ v(x) &= \underline{v} \quad x \in [0, N] \end{aligned}$$

The incentives scheme follows the following step function:

$$\begin{aligned} b(x) &= 0 \qquad x > n(N, \mathbf{b}(\mathbf{x})) \\ b(x) &= \overline{b} \qquad x \leq n(N, \mathbf{b}(\mathbf{x})) \\ \overline{b} &= \left(\frac{1}{N - n(N, \mathbf{b}(\mathbf{x}))} \right) \end{aligned}$$

If $\lambda'(0)\left[R_d - \frac{1}{N}\Delta R^o\right] > \overline{\delta}$*, then* $n(N, \mathbf{b}(\mathbf{x}))$ *is the solution to*

$$\lambda'(n(N, \mathbf{b}(\mathbf{x})))R_d^1 - \delta - \lambda'(n(N, \mathbf{b}(\mathbf{x})))\Delta R^o \left(\frac{1}{N - n(N, \mathbf{b}(\mathbf{x}))} \right) = 0$$

Otherwise if $\lambda'(0)\left[R_d - \frac{1}{N}\Delta R^o\right] \leq \overline{\delta} \Rightarrow n(N, \mathbf{b}(\mathbf{x})) = 0.$

The proof is left for the appendix.

Communication costs are set as differently as possible inside and outside the firm. Inside the firm communication is productive for the innovator and its costs are minimized ($v = \underline{v}$). Communication with outsiders is purely destructive for profits, since agents compete and entry reduces revenue in the final market ($R_d^o < R_m^o$). Communication costs outside the firm are maximized, $\left(\delta = \overline{\delta}\right)$.

Moreover, it is implicit but clear that starting a firm allows the innovator to keep competitors out of the team, so that they cannot participate at the learning effort and expropriate knowledge. Competitors in this setting are agents with very low (zero!) communication costs with "outsiders" (themselves): they have $\delta(i) = 0$. Clearly, competitors are never chosen as team members, unless the sale of information is intended (see section 7).

Proposition 5 implies that for any number N of agents hired at $t = 1$ the innovator is able to limit to $n(N)$ (but not below) the number of agents that communicate outside the firm. The incentive scheme needed to do this splits the team in two groups, according to whether they are given stake in the innovator's firm. The first group, $[n, N]$, is given as much stake as possible, so that $\overline{b}(N-n) = \int_n^N b(x)dx = 1$. This builds a hard core of (*insider*) agents aligned with the innovator's interests, that are hard to bribe. The second (*outsider*) group, $[0, n)$, is not given a stake. This plays the role of destroying the follower's strategic motive[18] to communicate with team members: trade with a marginal agent reduces the price the follower has to pay to all the other agents.

Notice that segmentation is extreme: team members are given ex post asymmetric treatment, even they are identical ex ante. Opposite behavior is induced between the two groups: insiders keep information within the firm whereas outsiders diffuse information.

The following definition will be useful, since the "power" of the innovator drives most of the results that follow.

Definition 6 *Call N^p the maximum team size such that there is no communication with the follower. We will refer to N^p as the* power *of the innovator.*

Corollary 7 *Given N the number of agents that communicate, $n(N)$, when the innovator sets up the optimal scheme, satisfies:*

$$\begin{aligned} N &\leq N^p \Rightarrow n(N) = 0 \\ N &> N^p \Rightarrow n(N) > 0 \text{ and } n'(N) > 0 \end{aligned}$$

where the power of the innovator, N^p is:

$$N^p \equiv \frac{\lambda'(0)\Delta R^o}{\lambda'(0)R_d^1 - \delta}$$

The last result defines the diffusion constraint that the innovator faces when choosing the optimal firm size. Transaction costs of unverifiable communication correspond to the fact that the diffusion constraint is binding.

The power measures the innovator's ability to form a team of agents without risking the leakage of strategic knowledge outside of the firm. The factors that increase power are the costs of communication δ, and the value of the innovator's project under monopoly, R_m^o; Factors that decrease the power are the value of entry, R_d^1, and the value of the project under duopoly, R_d^o. Power correlates with total cost of colluding with the follower for an agent with positive stake in the initial firm.

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[18] See comments on (4) above.

6 Creating a firm: open vs secret development

We can now derive the optimal size of the firm. Given the lack of agents' liquidity constraints at $t = 1$, transfers can be arranged so as to maximize the joint surplus of the innovator and the team members. The relevant program of the innovator is to choose the number of agents N[19] so as to maximize their joint surplus, subject to the endogenous spillover constraint $n = n(N)$. The constraint is the cost implied by non-contractible communication[20] under the optimal incentives' scheme. Recall that $n(N)$ was found to be non-differentiable at $N = N^p$. There are two types of possible solutions:

- *Secret development* $\left(n\left(\widehat{N}\right) = 0\right)$: corner solutions that destroy the incentives to communicate with the follower. Formally, the innovator follows a secret development strategy whenever:

$$\begin{aligned} \pi^s &\equiv \pi\left(N^p, 0\right) = \lambda\left(0\right) R_d^o + \left(1 - \lambda\left(0\right)\right) R_m^o - \underline{v} N^p - C\left(N^p, \theta\right) \quad (7) \\ &> \pi\left(N, n\left(N\right)\right) \quad N \neq N^p \end{aligned}$$

- *Open development* $\left(n\left(\widehat{N}\right) > 0\right)$: interior solutions allow for a mass of agents diffusing information in equilibrium. This is preferred to secret development if:

$$\pi^o \equiv \max_N \ \pi\left(N, n\left(N\right)\right) > \pi^s$$

We find below the conditions under which the innovator follows a strategy of openness or a strategy of secrecy. We can show that independently of the optimal development strategy the innovator always "underinvests" in team formation: the size of the innovator team in equilibrium is smaller than its size under contractible communication.

Proposition 8 *Let $\widehat{N}$ be the solution to:*

$$\begin{aligned} \max_N \pi\left(N, n\right) &\equiv \lambda\left(n\right) R_d^1 - \left(1 - \lambda\left(n\right)\right) R_m^o - \underline{\delta} N^p - C\left(N\right) \\ \textit{subject to} &: \quad n \geq n\left(N\right) \qquad (8) \end{aligned}$$

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[19] The innovator controls N to start with because she can avoid that agent j not designed by her, access the information that she distrbutes inside the firm. It is because the innovator has control rights over physical assets that she can grant that $j \notin \{N\}$.

[20] See corollary 7.

then $\widehat{N} \leq N^*$. *Moreover, if* $\frac{\partial C'(N^p,\theta)}{\partial N} < 0$ *then the innovator strictly employs too little:* $\widehat{N} < N^*$.

The proof is in the Appendix.

Proposition (8) shows that the lack of contractibility of communication between team members and outsiders leads to a transaction cost that reduces the optimal team size. This is the case even when the open development strategy is chosen and communication between a subset of agents and the follower is taking place.

A crucial role in this result is played by competition among team members in the sale of information to the follower. If instead team members were monopolists, each over a proprietary market, there would be no negative externalities among them and no transaction costs. In that implausible case the first-best firm size would be achieved. Supply-side competition makes cooperation with the follower unprofitable. The innovator maximizes only her own profits subject to an endogenous hiring cost: the threat of collusion between agents and the follower. This cost leads to underinvestment in hiring employees .

The result would not follow if the budget constraint could be "broken" $\left(\int_0^N b(x)dx > 1\right)$. In particular, setting:

$$b(i) \geq \left(\lambda'(0)\, R_d^1 - \delta\right) / \left(\lambda'(0)\, \Delta R^o\right) = N^p$$

the incentive compatibility condition (3) could not be met and N^* agents could be hired. This type of schemes have well known problems of dynamic inconsistency (Holmstrom (82)).

Proposition 8 does not depend on the other hand on the absence of liquidity constraints. Under extreme liquidity constraints the innovator would not be able to sell the right to participate in profits and would never make $\int_0^N b(x)dx$ equal to 1, since she is the residual claimant. This makes her less effective at reducing the leakage of knowledge, what turns the underinvestment problem more severe.

This result is an example of a "puppy dog" strategy of "being soft to deter[21] entry", as in Fudemberg and Tirole (84). The innovator is deterring entry since she is minimizing n. In this case the number of employees plays

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[21] Deterring entry in a statistical sense: the probability of entry is minimized.

an additional role of strategic investment. The relevant effect of N over the follower's profits is the *direct* effect:

$$\frac{\partial \pi^{follower}}{\partial N} = \frac{\partial \lambda \left(n \left(N \right) \right) R_d^1}{\partial N} = \lambda' \left(n \right) \frac{dn}{dN} R_d^1 > 0$$

that is positive: the strategic investment "makes the innovator soft", following again Tirole's (88) terminology.

Additionally, the incentive scheme $\mathbf{b}(\mathbf{x})$ and the communication costs with the follower $\boldsymbol{\delta}(\mathbf{x})$ play the role of strategic investments as well. In this case $\boldsymbol{\delta}(\mathbf{x})$ and $\mathbf{b}(\mathbf{x})$ increase the follower's cost of bribing agents. The policies $\mathbf{b}(\mathbf{x})$ and $\boldsymbol{\delta}(\mathbf{x})$ make the innovator tough. She follows a "top dog" strategy of being tough to deter entry.

It has been argued (Holmstrom (89)) that small firms have certain advantages over large firms at innovating. Proposition 8 points to this possibility as a possible result of two *restrictions*, rather than as an intrinsic advantage in being small: the innovator's need to create a firm to avoid competitors' access to the learning process plus a restriction to grow in the innovating firm.

We have shown that unverifiable communication introduces a number of inefficient decisions. The the innovator is unable to fully develop her idea within her own firm and hires too few employees. Communication can be excessive or too scarce, but generally not optimal. Communication costs will generally be too large. A natural question is to compare this equilibrium with the strategy of selling information to the follower.

7 Selling the idea to the follower

In this section we compare the optimal organization for product development with the option of directly selling the project to the follower.

We have throughout assumed that the idea behind the innovation could indeed be sold. The market failure that leads in our model to the underemployment result in proposition (8) arises from the innovator's inability to restrict other agents' communication with non-members. This is relevant only when more than one agent knows the idea at $t = 2$ and when it cannot be verified that informed agents are keeping secrecy with respect to third parties[22]. We will refer to this situation of lack of contractibility as *un-*

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[22] And moreover the effects of that communication are not contractible.

verifiable communication, and it is in fact different than the transaction cost usually attached to trading information, as in Arrow (1962). In Arrow (1962) communication necessary for trade results in the transfer of the good itself, crowding out trade. We label this type of situation as *communication crowding out.* Notice in particular that, as opposed to *unverifiable communication* third parties are not needed for *communication crowding out* to be relevant. To be precise, we are assuming here that the innovator can indeed charge a price to the agents before communication takes place, since the value of knowing the idea is common knowledge. The inefficiency result in proposition 8 is due only to unverifiable communication and it is clearly unrelated to the communication crowding out problem, which has been assumed away.

As a second benchmark we show the innovator's optimal strategy to sell the productive idea to the follower, given that there is not a communication crowding out problem. We need to introduce an additional assumption related to the contractibility of exit by the innovator. We assume it is not verifiable whether the innovator is active in the sector at $t = 3$ or she exited before[23]. Moreover we assume that the innovator has a positive[24] probability α of making an offer to the follower at the bargaining stage.

Proposition 9 *The optimal strategy for the innovator to sell the idea to the follower is:*
At $t = 1$ *set* $N = 0$
At $t = 2$, *if received offers are* $p = \underline{\delta} + \lambda'(0)\left(R_m^o - R_d^o\right)$ *or better, accept and communicate; if offers are lower than* p, *reject, do not communicate; if the innovator makes offers, these should be:* $q = \max\left(0, \lambda'(0)\, R_d^1 - p\right)$.

The proof is in the Appendix .

Given the lack of bargaining power of team members, competition among them drives the sale price of information down to the cost of selling it. Rents from cooperating with the follower can only be realized if the innovator does not introduce her own competition ($N = 0$). Only then is the supply side monopolized and bargaining is one to one.

Notice in particular that the innovator cannot improve things by making the agents' payoffs contingent on the transfer she gets from the follower. This is because direct trade between the agents and the follower is secret.

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[23] We do this for simplicity. Verifiable exit would basically not change things.

[24] We assume this because bargaining is now one to one, as opposed to the team creation case where bargaining is between a large group of sellers and one buyer.

The innovator with $N = 0$ at $t = 2$ can grant herself:

$$\pi (0, 0) = \lambda(0) R_d^o + (1 - \lambda(0)) R_m^o - C(0) \tag{9}$$

The equilibrium payoff from selling information is:-

$$\begin{aligned} \pi^{sell} &\equiv \alpha \left[\lambda' (0) R_d^1 - \underline{\delta} - \lambda'(0) (R_m^o - R_d^o)\right] + \pi (0, 0) \\ &= \alpha (q - p) + \pi (0, 0) \end{aligned}$$

The first term is a fraction (the bargaining power) of the surplus from trade $(q - p)$. The second term is the outside opportunity of the innovator.

Proposition 9 implies that unverifiable communication distorts technology transfer between the innovator and the follower. The first best result (1) implies that under "soft competition" there is a technology transfer motive to hire employees. Unverifiable communication implies that in order to preempt competition in the supply of knowledge, the innovator has to set instead $N = 0$.

8 Comparative statics

We now find conditions under which the innovator that is developing the product in her own firm follows a strategy of secrecy ($\widehat{n} = 0$) or an open development strategy ($\widehat{n} > 0$). We will be able to summarize the effect on profits, optimal firm size and entry of changes in the main parameters in the model $(\delta, R_d^1, R_m^o, R_d^o)$ through changes in the power of the innovator, N^p. We also analyze the effect of changes in the development cost function $C(N)$.

Consider in the first place the effect on profits. Clearly, greater power of the innovator implies the possibility of setting a larger team without generating spillovers to other firms. It is less evident that greater power also increases innovator's profits when the solution to (8) is an interior solution. The following proposition shows that greater power also improves appropriability conditions when open development is preferred.

Proposition 10 *If $N^p < N^*$, the value of product development to the innovator strictly increases with the power*[25] *of the innovator $N^p (\delta, R_d^1, R_m^o, R_d^o)$.*

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[25] (see definition 6).

The proof is straightforward. Define the feasible choice set in (8) as

$$F\left(N^{p}\right) \equiv \left\{(N, n) \in \Re^{2} : n \geq n(N)\right\}$$

It can easily be shown that the choice set strictly increases with the power [26]:

$$F\left(N^{p}\right) \subset F\left(N^{p\prime}\right) \Leftrightarrow N^{p} < N^{p\prime}$$

Moreover, the constraint $n \geq n(N)$ was shown in proposition 5 to be always binding. ■

This result has an interesting implication in the choice between creating a firm or trading with the follower.

Corollary 11 *There exists a team size* N_{*}^{p} *such that: If* $N^{p} \geq N_{*}^{p}$ *the innovator creates a firm and hires a team of agents in order to develop the innovation. If* $N^{p} < N_{*}^{p}$ *the innovator sells the idea to the follower and commits not to set up a firm.*

Proof: in the Appendix.

The variable that determines the decision on in-house development is the power of the innovator. This implies in particular that a very efficient follower will be able to preempt innovators' firm formation and force information sale by the latter. The follower's high efficiency (the combination of low cost, market power,and low communication costs) induces "weak discipline" in the innovator's firm as it gives employees incentives for know-how disclosure.

We can derive the effect of changes in the cost reducing technology on the choice of a development strategy. The following proposition shows a positive relationship between the efficiency of the innovator and the likelihood of entry by the follower. This is due to the fact that greater efficiency increases the benefit of a larger team size, making the innovator willing to suffer a greater probability of entry.

Proposition 12 *There is an efficiency level* θ_{*} *in cost development such that "inefficient" technologies* $(\theta < \theta_{*})$ *lead to secret development and efficient technologies* $(\theta \geq \theta_{*})$ *lead to open development. Increases in efficiency beyond*

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[26] Since the boundary of the set F shifts to the right in the (n, N) space, and since N^{p} increases and $\partial\left(\frac{dn}{dN}\right)/\partial N^{p} < 0$.

θ_* increase the optimal team size, the number of agents that communicate with the follower and the probability of entry by the latter:

$$\theta \geq \theta_* \Rightarrow \frac{d\widehat{N}}{d\theta} > 0 \qquad \frac{dn}{d\theta} = \frac{dn}{d\widehat{N}}\frac{d\widehat{N}}{d\theta} > 0 \qquad \frac{d\lambda}{d\theta} = \frac{d\lambda}{dn}\frac{dn}{d\theta} > 0.$$

Proof: in the Appendix.

Interestingly, the result points to a negative relationship between innovator's efficiency and her ability at monopolizing the final market. Relatively inefficient firms have a smaller probability of facing a competitor and a higher probability to remain unchallenged in their niche markets.

Proposition 13 *If power is sufficiently small ($N^p < N^p_*$), secret development is preferred. If power is sufficiently large ($N^p \geq N^p_*$) open development is superior to secret development. Increase in power beyond N^p_* increases the optimal firm size (hence diffusion and entry). Formally:*

$$N^p \leq N^p_* \Rightarrow \widehat{N} = N^p$$

$$N^p > N^p_* \Rightarrow \widehat{N} > N^p \text{ and } \frac{d\widehat{N}}{dN^p} > 0 \qquad \frac{dn}{dN^p} > 0 \qquad \frac{d\lambda}{dN^p} > 0$$

The proof is in the Appendix.

This implies that drastic innovation (characterized by high monopoly profits, R^o_m, and possibly subject to higher communication costs -since it relies in less conventional wisdom) is likely to be developed by new firms that start up as "large" firms, relatively to new firms that introduce less drastic innovation.

Proposition 13 has implications on the value for the innovator of investments in physical assets. Although we have modeled the creation of the firm as a team that does not necessarily use physical assets, these can easily be introduced in the analysis[27]. In particular, the innovator will generally have positive demand for physical assets that increase her power. That is, the innovator will generally invest in physical assets that reduce the profitability of the entrant or that make competition "tougher". In our setting, it is clear that the innovator will invest in physical assets that increase her power at a stage *previous* to team formation. This is because physical assets play a strategic role in the interaction between the innovator and her employees. She must have sunk the cost at a stage previous to "entry" by the employees, where entry refers to the market of information.

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[27] We choose to treat the investment in physical assets separately in a different paper.

8.1 The effect of competition, $R_m^o - R_d^o$

Given R_d^1, increases in $R_m^o - R_d^o$ imply that the innovation introduced is more radical and profitable in absolute terms, but also that competition is relatively more destructive of profits. Clearly the innovator is better off with a greater value of the innovation. Lower competition directly increases profits and moreover it has an effect in the strategic play within the firm that improves appropriability conditions. It reduces transaction cost of non-contractible communication and it allows her to hire a larger team and/or to reduce unwanted diffusion for a given team size. In particular, the previous comparative statics results have the following implications on the effect of competition.

- *Sell minor innovations and keep "blockbuster" innovations in-house.* This is clear from corollary 11. More radical innovations face better appropriability, because they induce larger discipline inside the firm. This is the effect of a larger opportunity cost of selling information when the projects of the firm have high value.
- *As competition increases in the industry, find buyers of ideas instead of developing them on your own.* Competition does not discipline agents with respect of the moral hazard variable we are considering (colluding with rivals). On the contrary, greater competition encourages diffusion since it decreases the agents' opportunity cost of selling information. If an R&D intensive sector is characterize by increasing competition, we expect to see a transition in innovating firms from internal development towards early technology transfer to established firms.

8.2 The effect of follower's efficiency, R_d^1.

Given R_m^o and R_d^o, increases in R_d^1 should be interpreted as increases in factors that make competition softer, together with characteristics that enhance the market power or the cost efficiency of the follower. For instance, the innovator could be introducing a process development that reduces the production cost of a given good. If the follower is already producing that same good through a less efficient technology[28], R_d^1 measures the established consumer base of

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[28] To be clear, the entrant would be entering the new technology, but incumbent with respect to the inefficient technology.

the follower while using the old technology, a fraction of which is loyal to him. There are at least two interesting implications of the previous propositions with respect to the efficiency of the follower.

- *Absence of a dominant firm.* If there is not an industry "champion" with a large consumers' base it becomes easier for the innovator to attempt her own venture. The absence of an existing firm with distribution channels or good reputation increases the power of the innovator and increases the profits from creating a venture. The other side of the coin is the following possibility.

- *Becoming a "magnet" of innovations.* If firm A has a sufficient number of assets and of sufficient quality (like reputation, human capital, consumer base, etc.) -if R_d^1 is large-, firm A will preempt other firms from developing their own innovations. The strength of firm A makes that other firms find appropriablity conditions to be harsh and opt for selling their projects to firm A. Firm A ends up developing projects even if it does not undertake R&D investments.

8.3 The effect of communication costs, δ.

It is clear that the innovator prefers unbounded communication costs between non-firm members. This would assure that the first best (**??**) can be achieved. Higher communication costs increase the power of the innovator, making more attractive the secret development strategy. Some specific implications are as follows:

- *Life-cycle of an industry.* It can be argued that communication costs decrease over the life-cycle of an industry. As the initial breakthroughs look more familiar more researchers are "insiders" and exchanging information is less time-consuming. If this is the case we expect from innovators a transition from strategies of integration (vertical and lateral) at the initial stages towards trade with established firms later on.

- *Full-time job, incompatible with other positions.* The innovator wants to set the employment relationship so as to maximize the communication cost with outsiders. An employee with a part time job would have more hours that are fully out of control of the innovator. Those hours could be used to contact with members of other firms. By the same token, employing an agent that is known to be also working for a different company implies a risk in that the cost of transmitting information across firms could be particularly low for that individual. Clearly, it is the firm with high quality projects the one that follows this principle first.

- *Control turnover.* By a similar argument than the previous remark, the age and history of an agent is relevant for selecting him into the team. Previous appointments of an employee are correlated with the employee having a number of potential contacts in other firms that reduce the cost of transmitting information to those firms.

- *Control employees publications.* In R&D intensive sectors employees are often contributors to science journals and specialized literature. The innovator wants to contract upon the right to submit publications with her employees. This is a form of increasing communication costs.

- *Locating in a dense or a sparse cluster.* The cost of communication should be linked to the density of similar activities around the firm. The innovator has discretion to choose the location of her firm, affecting communication costs. In particular the highly innovative firm has incentives to locate in relatively low density clusters, or start new ones. The less innovative firm has incentives to locate in dense clusters, to effectively buy information from the other firms.

- *Knowledge hierarchies: allocation of information inside the firm.* Since there is a cost in employees' access to the knowledge capital, it might pay for the innovator to restrict information only to a subset of the employees. This is the route taken by Ronde (96). In our setting, if the development cost depends on the number of *informed* agents, N, that directly participate in the learning process and the number of *uninformed* agents, M, that work under command of informed agents, we have $C = C(N, M)$, with $\frac{\partial C(N,M)}{\partial N} < \frac{\partial C(N,M)}{\partial M} < 0$. It is clear that (if hiring costs are sufficiently low) the innovator hires a positive mass of such uninformed workers, since they reduce development cost and do not affect the diffusion constraint $n(N)$. A hierarchy is established, such that knowledge workers work on incentive schemes and command workers follow orders and get a fixed wage. The latter are hired to alleviate the dilution and relax the diffusion constraint.

9 Conclusions

We have analyzed the implications of a market imperfection related to the inability to establish intellectual property rights that we label *unverifiable communication*. This situation is different from the well known problem inventors face when selling non-patentable ideas (Arrow (70)). Instead, we are concerned with the problem of collusion between the employees of a firm and third parties external to the firm when sensible information relating to the strategy of the firm is hard to describe in contracts or communication is non-contractible. We argue that this setting is relevant for R&D intensive sectors. We find that the characteristics of the firm's strategic interaction in the product market determine the strategic interaction between the innovator and her employees. In particular, the firm-organizer engages herself in strategic interaction simultaneously with firm insiders and outsiders as she tries to distort the market for information between those agents. Incentive schemes and communication costs are the key strategic variables used by the firm to introduce those market frictions.

We spell out some determinants of the innovator's decision between setting up a new firm (and hiring employees) and selling information to the potential follower. Interestingly, we find that unverifiable communication introduces severe distortions in both cases. In the first case firms are created with team sizes that are too small. This is because the key to limit spillovers is the use of incentive schemes and hiring implies dilution of ownership. In the second case where the innovator is better off selling her project to the established firm, we find that unverifiable communication severely distorts technology transfer. Although it would be optimal (under verifiable communication) to hire a team of employees in order to facilitate technology transfer, the optimal transfer strategy is not to hire employees, since this implies that the rents flow to the buyer of information.

We derive implications of the model for observable decisions like characteristics of the employment relationship (full employment, incompatibility with other jobs), firms' preferences over cluster characteristics for location decisions, optimal size at entry, in-house development vs sale strategies for innovations and industry evolution.

The case of unverifiable communication has a large number of further extensions that we sketched in the last section. Potentially important avenues for future work are the implications for the allocation of information inside the firm and extensions where the dynamics of the industry are worked out in a setting where cluster formation is endogenous.

Appendix A:

Proof of Proposition 1

Consider the bargaining problem at $t = 2$. Since bargaining is efficient the number of employees that communicate with the follower is, given N:

$$\max_{n \leq N} \ \left(1 - \lambda\left(n\right)\right) R_m^o + \lambda\left(n\right) R_d^o + \lambda\left(n\right) R_d^1 - \underline{\delta} n \equiv S\left(\widehat{n}\left(N\right)\right)$$

where $\widehat{n}\left(N\right) \equiv \min\left(n_o^*, N\right)$ and $n_o^* : \lambda'\left(n_o^*\right)\left(R_d^o + R_d^1 - R_m^o\right) \equiv \underline{\delta}$

Clearly the condition for $n_o^* > 0$ is $R_d^o + R_d^1 - R_m^o > 0$. If this condition holds, the total payoff for the innovator as of $t = 1$ is:

$$\begin{aligned} &\max_{N} \ \left(1 - \lambda\left(\widehat{n}\left(N\right)\right)\right) R_m^o + \lambda\left(\widehat{n}\left(N\right)\right) R_d^o + \alpha\left[S\left(\widehat{n}\left(N\right)\right) - \lambda\left(0\right) R_d^1\right] \\ &+ \left(1 - \alpha\right)\left[\left(1 - \lambda\left(0\right)\right) R_m^o + \lambda\left(0\right) R_d^o\right] - C\left(N\right) \end{aligned}$$

which has three possible solutions. Define where $N_o^* : -\frac{\partial C\left(N_o^*, \theta\right)}{\partial N} \equiv 0$. Then

$$\text{if} : \quad -\frac{\partial C\left(n_o^*, \theta\right)}{\partial N} > 0 \Rightarrow N = N_o^* > n = n_o^*$$

$$\begin{aligned} \text{if } -\frac{\partial C\left(n_o^*, \theta\right)}{\partial N} &\leq 0 \text{ and} \\ \left(1 + \alpha\right)\lambda'\left(n_o^*\right)\left(R_d^o - R_m^o\right) + \alpha\lambda'\left(n_o^*\right) R_d^1 - \frac{\partial C\left(n_o^*, \theta\right)}{\partial N} &> 0 \end{aligned}$$

then: $\Rightarrow n = n_o^* = N = N_o^*$.

Finally,

$$\begin{aligned} \text{if } -\frac{\partial C\left(n_o^*, \theta\right)}{\partial N} &\leq 0 \text{ and} \\ \left(1 + \alpha\right)\lambda'\left(n^*\right)\left(R_d^o - R_m^o\right) + \alpha\lambda'\left(n^*\right) R_d^1 - \frac{\partial C\left(n_o^*, \theta\right)}{\partial N} &< 0 \end{aligned}$$

then: $\Rightarrow n = N = \widehat{N}^* < n_o^*$

where $\widehat{N}^*$ is given from:

$$\left(1 + \alpha\right)\lambda'\left(\widehat{N}^*\right)\left(R_d^o - R_m^o\right) + \alpha\lambda'\left(\widehat{N}^*\right) R_d^1 - \frac{\partial C\left(\widehat{N}^*, \theta\right)}{\partial N} \equiv 0$$

and it is clear that $\widehat{N}^* > N_o^*$. So the claim is satisfied.

■

Proof of Proposition 2

Expression (2) can be written as:

$$\left(\int_i^{i+\varepsilon} b\left(s\right) ds\right)\left(\frac{\lambda\left(n+\varepsilon\right)-\lambda\left(n\right)}{\varepsilon}\right)\left[R_d^o - R_m^o\right] = \delta\left(i\right) - p\left(i\right)$$

and the limit as $\varepsilon \rightarrow 0$ is as in (3).

■

Proof of Proposition 5

From Remark 1 the relevant program is:

$$\begin{array}{rcl}
 & & \min\limits_{\mathbf{b(x)}} \quad n \qquad\qquad\qquad \text{subject to,} \qquad\qquad\qquad \text{(A1)} \\
\gamma(x) & : & \lambda'(n)R_d^1 - \lambda''(n)\Delta R^o \displaystyle\int_0^n b\left(x\right)dx - \delta - b\left(n\right)\left[\lambda'(n)\Delta R^o\right] \\
 & \geq & 0 \quad x \in [0,n) \\
\widetilde{\gamma}(x) & : & \lambda'(n)R_d^1 - \lambda''(n)\Delta R^o \displaystyle\int_0^n b\left(x\right)dx - \delta - b\left(x\right)\left[\lambda'(n)\Delta R^o\right] \\
 & \leq & 0 \quad x \in [n,N] \\
\mu(x) & : & b(x) \geq 0 \quad x \in [0,n) \\
\beta & : & \displaystyle\int_o^N b(x)dx \leq 1 \\
\omega & : & \delta\left(x\right) \leq \underline{\delta} \quad x \in [0,n)
\end{array}$$

The Kuhn-Tucker conditions are:

$$\begin{array}{rcl}
\gamma(x)\left[-\lambda''(n)\Delta R^o\right] - \mu(x) + \beta & = & 0 \\
\widetilde{\gamma}(x)\left[-\lambda'(n)\Delta R^o\right] - \mu(x) + \beta & = & 0 \\
\gamma(x)\left\{\lambda'(n)R_d^1 - \lambda''(n)\Delta R^o \displaystyle\int_0^n b\left(x\right)dx - \delta - b\left(n\right)\left[\lambda'(n)\Delta R^o\right]\right\} & = & 0 \\
\widetilde{\gamma}(x)\left\{\lambda'(n)R_d^1 - \lambda''(n)\Delta R^o \displaystyle\int_0^n b\left(x\right)dx - \delta - b\left(n\right)\left[\lambda'(n)\Delta R^o\right]\right\} & = & 0 \\
\beta\left(\displaystyle\int_0^N b(x)dx - 1\right) & = & 0 \\
-1 + \omega & = & 0
\end{array}$$

and the unique solution satisfies:

$$\begin{aligned}
\mu(x) &= \beta > 0 \Rightarrow b(x) = 0 \quad \forall x \leq n \quad \text{and} \quad \int_o^N b(x)dx = 1 \\
\widetilde{\gamma}(x) &= \beta / \left(\lambda'(n)\Delta R^o\right) > 0 \Rightarrow b(x) = \frac{1}{N-n} \equiv \overline{b} \quad \forall x \geq n \quad \text{and :} \\
0 &= \left\{\lambda'(n)R_d^1 - \delta - \overline{b}\left[\lambda'(n)\Delta R^o\right]\right\} \\
\delta\left(x\right) &= \underline{\delta} \qquad \forall x
\end{aligned}$$

This implies that at the innovator's optimal incentive scheme, the first order condition at the optimal n for the follower is:

$$\lambda'(n)R_d^1 - \delta - \lambda''(n)\int_0^n b(x)dx\Delta R^o - \lambda'(n)b(n)\Delta R^o = \lambda'(n)R_d^1 - \delta \leq 0$$

since $b(x) = 0$ for $x \in [0, n]$.

The second order condition for the follower at the optimal contract is:

$$\begin{aligned}
& \lambda''(n)R_d^1 - \lambda'''(n)\int_0^n b(x)dx\Delta R^o - \lambda''(n)b(n)\Delta R^o \\
& -\lambda'(n)\Delta R^o\left[b(n+\varepsilon) - b(n)\right] - \lambda''(n)b(n)\Delta R^o \\
= \; & \lambda''(n)R_d^1 - \lambda'(n)b(n+\varepsilon)\Delta R^o = \lambda''(n)R_d^1 - \lambda'(n)\Delta R^o\overline{b} < 0
\end{aligned}$$

for $\varepsilon \in (0, N-n)$, since $b(x)$ is not differentiable at $x = n$.

■

Proof of Proposition 8

If $N^p \geq N^*$ the constraint is not binding and the first best in (**??**) can be attained ($\widehat{N} = N^*$). Otherwise if $N^p < N^*$[29], since $n(N)$ in corollary 7 is not differentiable only in $N = N^p$, there are too possible solutions to the program: corner solution at $\widehat{N} = N^p < N^*$ or interior solutions. Interior solutions satisfy the first order condition:

$$-\frac{dn}{dN}\lambda'\left(n(\widehat{N})\right)\Delta R^o - \underline{\delta} = \frac{\partial C(\widehat{N},\theta)}{\partial N} < -\underline{\delta} = -\mu' + \frac{\partial C(N^*,\theta)}{\partial N}$$

The last equality is from (**??**) and since $\mu' > 0$. We have that : $\widehat{N} \leq N^*$

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[29] The condition for this is $-C'(N^p) > 0$.

Proof of Proposition 9

The surplus from trade when no employees are hired is characterized by the possibility of monopolizing the supply side when the innovator has bargaining power. When agents are "of size ε", surplus εS, is given by:

$$\begin{aligned} \varepsilon S &= \left[\lambda(\varepsilon) R_d^1 + \lambda(\varepsilon) R_d^o + (1-\lambda(\varepsilon)) R_m^o - \underline{\delta}\varepsilon\right] \\ &\quad -\lambda(0) R_d^1 - \lambda(0) R_d^o - (1-\lambda(0)) R_m^o \end{aligned}$$

In the limit as $\varepsilon \to 0$:

$$S = \lambda'(0)\left(R_d^1 - R_m^o + R_d^o\right) - \underline{\delta}$$

The innovator has $\pi(0,0)$ as the outside opportunity and has probability α of making offers.

If a positive mass of agents are hired there is perfect competition in the supply of information (no rents) and surplus is: $\lambda'(0)(-R_m^o + R_d^o) - \underline{\delta} < 0$.

■

Proof of Proposition 11

The profitability of creating a firm increases with the power from proposition 10. The profitability of selling information increases with R_d^1 and R_d^o, that are negatively related to power, but it increases with R_m^o. We only need to show that profit from development increases with R_m^o faster than profits from selling, so that if R_m^o is high enough creating a firm is preferred.

The marginal increase in profits from selling, with respect to R_m^o is:

$$\begin{aligned} \frac{\partial \pi^{sell}}{\partial R_m^o} &= (1-\lambda(0)) - \alpha\lambda'(0) < \frac{\partial \pi^{develop}}{\partial R_m^o} \\ &\leq \frac{\partial \pi(N = N^p)}{\partial R_m^o} = (1-\lambda(0)) - \underline{\delta} - C'(N^p)\frac{\partial N^p}{\partial R_m^o} \end{aligned}$$

since the secret development strategy is a lower bound of the firm creation profits.

■

Proof of Proposition 12

The first-order condition for an interior maximum is:

$$-\frac{\frac{\partial \pi}{\partial n}}{\frac{\partial \pi}{\partial N}} = -\frac{\lambda'(n)\Delta R^o}{\underline{\delta} + \frac{\partial C(N,\theta)}{\partial N}} = \frac{dn\left(\widehat{N}\right)}{dN} \tag{A2}$$

We show in the first place that if $\lambda'''(n) < 0$ then $n(N)$ is convex . The first derivative can be expressed as:

$$\frac{dn}{dN} = \frac{\lambda'(n)\,g(n)}{\lambda'(n)\,g(n) - \lambda''(n)\,(N-n)} \in (0,1)$$

where $g(n) \equiv \lambda'(n)\,R_d^1 - \overline{\delta}$. This implies in particular that $\frac{d(N-n)}{dN} = 1 - \frac{dn}{dN} < 1$.

Then, $\frac{d(-\lambda''(n)(N-n))}{dN} = -\lambda'''(n)\,(N-n)\,\frac{dn}{dN} - \lambda''(n)\,\frac{d(N-n)}{dN} > 0$ and necessarily $n(N)$ is convex.

Consider the derivative of the left-hand -side of (10) with respect to θ. This enters through:

$$\frac{\partial\left(\frac{\partial\pi}{\partial N}\right)}{\partial\theta} = \frac{\partial\left(-\delta - \frac{\partial C}{\partial N}\right)}{\partial\theta} = \frac{\partial^2 C}{\partial\theta\partial N} < 0$$

So that the left-hand-side in (10) increases with θ and $\widehat{N}$ has to increase (given convexity of $n(N)$).

■

Proof of Proposition 13

The partial of the slope of the gradient $\nabla\pi$ (the left-hand-side of (10)) with respect to N^p is:

$$-\frac{\lambda'(n)}{-\underline{\delta} - \frac{\partial C}{\partial N}} > 0$$

and the partial of dn/dN with respect to N^p is negative. So clearly $\widehat{N}$ increases with power.

■

Appendix B:

Optimal non-linear schemes.

Define incentives' schemes by: $b(x,R) \geq 0$, where R are revenue outcomes ($R \in \{R_m^o, R_d^o\}$) and x indexes agents, with $b(x,R) > b(x',R)$ iff $x > x'$ and $\int_0^N b(x,R)\,dx \leq 1$. Solving program (10) when $b(x,.)$ takes possibly two values yields: $b(x,R_d^o) = 0 \quad \forall x$ and $b(x,R_m^o)$:

$$\lambda'(n(N,\mathbf{b}(\mathbf{x})))R_d^1 - \delta - \lambda'(n(N,\mathbf{b}(\mathbf{x})))R_m^o\left(\frac{1}{N - n(N,\mathbf{b}(\mathbf{x}))}\right) = 0$$

The power of the innovator is increased up to: $N^{p\prime} = \frac{\lambda'(0)R_m^o}{\lambda'(0)R_d^1 - \overline{\delta}}$

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