Contracting for an Innovation under Bilateral Asymmetric Information *

David Martimort†, Jean-Christophe Poudou,‡ Wilfried Sand-Zantman§

July 3, 2009

Abstract: We analyze the design of contracts between an innovator and a developer in a framework that allows for asymmetric information, production of pre-contractual evidence, moral hazard and imperfect enforcement of intellectual property rights. The innovator is privately informed about the quality of his idea and may produce forgeable evidence of it at the negotiation stage. Upon contracting, the developer exerts some non-verifiable effort which improves the expected return of the innovation. Under asymmetric information, a good innovator signals the quality of his project by keeping some royalties. This has two drawbacks on incentives. First, moral hazard on the developer's side is exacerbated. Second, the attractiveness for the developer of leaving the current relationship to start a new one increases. This trade-off between signaling and moral hazard is sensitive to the nature of the intellectual property rights that prevail, and to the technology for producing pre-contractual evidence. Royalties are more attractive when property rights are easy to enforce while paid-up licences prevail otherwise. Various robustness checks for these findings are also provided.

*We thank for comments on a preliminary version participants to the following meetings and conferences: University of Grenoble (GAEL), 2005 EEA-Amsterdam, 2006 ESEM-Vienna, 2006 EARIE-Amsterdam and Humboldt Universität. We also thank two referees and two Editors for their insightful comments which much improved the paper. The usual disclaimer applies.

†TSE (GREMAQ and IDEI), EHESS.

‡LASER, Université de Montpellier I.

§TSE (GREMAQ and IDEI), Université de Toulouse.

1 Introduction

Although the diffusion of knowledge plays a crucial role in economic growth by introducing increasing returns and positive externalities,[1] little is known about the exact microeconomic process by which information and ideas move along the supply chain in the production of knowledge. This is surprising given that economists, following the seminal work of Arrow (1962), have long been aware of the importance of resource allocation in promoting invention, and should have drawn from those concerns some lessons for the organization of R&D activities. The objective of this paper is to fill that gap. Taking this Arrowian perspective, we open the black-box of the micro-relationship between innovators who have ideas but often lack the commercial and financial expertise to develop them and developers (for instance customers/financiers) who provide such complementary expertise and exert their competencies at later stages of the R&D process.

At first glance, the bilateral relationship between an innovator and a developer might be hindered by three major contractual hazards. Each one is a source of significant transaction costs in the transmission of knowledge. First, since commercial ideas may contain technical aspects often hard to describe contractually but privately known by innovators, contracting is subject to *asymmetric information*. The negotiation process may require the informed party to disclose evidence to reduce this information gap in which case the production of such evidence is an important part of contracting. Second, the effort of the developer during the development stage of the project may be difficult to verify; a *moral hazard* issue. Lastly, knowledge is a public good and, during the negotiation with the innovator, the developer may infer most of the potential market value of the innovator's idea: an issue related to the *protection of property rights*. This paper analyzes how the design of contracts between an informed innovator and a developer depends on these three important ingredients.

Practitioners are well-aware of these contractual hazards and are constantly looking for ways to mitigate them.[2] Broadly speaking, this paper analyzes the direction toward

[1]See the literature on endogenous growth, in particular Aghion and Howitt (1998).

[2]In a survey of contractual problems in the pharmaceutical industry, Binns and Driscoll (1998) reported that *"Many organizations that perform R&D projects, particularly at an early stage in the drug development cycle, may contribute unique skills and expertise to the planning and execution of a project that ultimately leads to a successful product. In many cases, such organizations may be reluctant to hand over the ownership of intellectual property (created by them) without some control over its subsequent use and exploitation, and without any right themselves to use it, even if they have been promised royalties in the event of a successful product. In almost every case, however, there should be no reason why a solution cannot be found that satisfies everyone's concerns by appropriately addressing ownership, access and user rights and the protection, management and exploitation of intellectual property in the R&D contract."*

which optimal contracting for an innovation should be tilted, and in particular how the return of an innovation should be shared. We pay particular attention to the role played by the strength of intellectual property rights (hereafter IPRs) in shaping those contracts.

Main results. Our key finding is that private information on the quality of an idea requires innovators to keep significant royalties in the project as a credible mean of signaling that it is worth undertaking. Moreover, we show that royalties are much more likely to be used in environments with strong IPRs.

A major contribution of this paper is the analysis of the process by which innovators reveal information and the links between this process and the form of incentive contracts between innovators and developers. Our modeling is quite general and allows both for information revelation through direct disclosure of evidence and through contract design. The first step is costly, i.e., at the cost of forging evidence, even a bad innovator can come with "hard evidence" that his idea is good enough. Since there is always the possibility for a bad innovator to forge favorable evidence, a good innovator must signal himself by specifying a particular contract design that would not be attractive to a bad innovator. This creates some kind of substitutability between the two forms of information revelation.[3] The more costly forging evidence is, the easier it is for a good innovator to convince the developer of the quality of his idea through the contract design, in other words, royalties become less attractive. This approach has a broad appeal and makes it easy to trace out the consequences of various technologies which provide evidence on the kind of contractual arrangements that might prevail.

Comparative statics. First, the trade-off between signaling and moral hazard is somewhat relaxed when forging favorable evidence on the quality of the project becomes harder. In other words, leaving royalties to innovators is more likely when direct devices for communicating information at the negotiation stage are less credible. Second, leaving more royalties to innovators also exacerbates the developer's incentives to steal ideas which are "on the table." This is a more attractive strategy when IPRs are weak.

Empirical evidence. To understand the practical relevance of these issues, consider the example of corporate licensing. Corporate licensing between upstream and downstream units features informational and technological transfers which are at the core of our investigation. Those transfers are of course impeded by the contractual hazards we stressed above. Following the empirical work by Anand and Khanna (2000) and the classical study by Rostoker (1984), we may indeed distinguish industries according to the

[3] In this respect, we rely on the important works of Bull and Watson (2001, 2007), Lacker and Weinberg (1989) and Maggi and Roriguez-Clare (1995) who build principal-agent models where contract design depends on the cost of producing evidence. We borrow from them this general idea but apply it in a signaling environment. (For similar insights, see also Kartik, 2008.) To the best of our knowledge, this application is new.

strength of IPRs that prevail.[4] According to this classification, the industries with the weakest property rights are also the industries where reverse engineering is commonly found. Equipped with this classification, the empirical works provide strong support for our theoretical findings: When property rights are strong enough, the authors found that royalties are much more likely to be used. Moving from the mechanical industry where IPRs are weak, to electrical, chemical and biological industries where IPRs are increasingly stronger, royalties increase respectively from 65, 68, 71 to 76% in the cases surveyed in Rostoker (1984).

Literature review. Our paper belongs to a broader literature addressing information transmission in R&D environments. This literature can be roughly organized along two dimensions. First, some authors have tackled this issue in contexts where information transmission occurs between competing firms or between an upstream innovator and an agent (developing or marketing unit) operating in a downstream market. Second, other authors have studied how contracts can be used to signal information on the value of an innovation.

As far as information disclosure towards competitors is concerned, the focus of the literature has been on understanding whether valuable information should be disclosed, either directly by selling patents or indirectly through market behavior. In that line of research, the seminal paper by Bhattacharya and Ritter (1983) examined an important trade-off between the cost of publicly disclosing valuable information which reduces an informational advantage vis-à-vis competing rivals and its benefit in signaling value to the capital market so that outside finance becomes cheaper. Taking instead a mechanism design perspective, Bhattacharya, Glazer and Sappington (1990, 1992) studied optimal licensing mechanisms inducing information sharing and efficient R&D efforts, whereas d'Aspremont, Bhattacharya and Gérard-Varet (2000) addressed knowledge disclosure in the context of an R&D race where a technologically dominant firm can share partially verifiable knowledge with its rival.[5] Anton and Yao (2004) and Bhattacharya and Guriev (2006) focused on the kind of market competition between innovators and imitators that takes place once information has been revealed. All these models rely on the possibility that innovators may only disclose less than what they really know and that it costs nothing to present such evidence. We will depart from this assumption and assume instead that the innovator can forge favorable evidence on his project, maybe at some cost, to fool developers. Forging costly evidence makes it impossible for good innovators to separate

[4] Even if those authors had no precise information on the form of payments, they showed that cross-industry differences in exclusive rights provisions or cross-licensing can be explained by the strength of intellectual property rights.

[5] In a related vein, Bhattacharya and Chiesa (1995) and Yosha (1995) studied the role of financiers in facilitating information sharing among potential competitors and endogenized how much information might be shared in multilateral financial contracting.

themselves from bad ones by only releasing pre-contractual evidence. There is ample room for more credible information revelation by keeping an equity stake in the project.

This point is clearly related to the idea of using contracts to convey some information to the seller and more particularly in our context to the seminal paper by Gallini and Wright (1990). These authors explained how licensing contracts should be designed under asymmetric information. Contrary to our research, information on the quality of an innovation becomes known ex post by competitors. The tension between communicating the licensor's information about the quality of his innovation and avoiding being imitated by competing licensees explains the use of output-based payments and rationalizes the licensors' rents. Macho-Stadler and Perez-Castrillo (1991) and Beggs (1992) also followed that signaling line of research. They analyzed the role played by menus of licensing contracts with different levels of royalties when the information on the quality of the innovation is asymmetric. In the absence of any device to credibly disclose information, contract design is the only remaining tool to communicate information. Accordingly, contracts are distorted to relax the informed innovator's incentive constraint. We take stock of the lessons of those papers but differ from them along several lines. First, we stress the important trade-off between signaling and downstream moral hazard which has so far been overlooked.[6] Second, we link our results to the strength of IPRs showing an important correlation between the developer's incentives within and outside the relationship. Third, we fully develop the process of information communication. More specifically, we append to the standard signaling game a pre-contractual stage where evidence can be produced. Although, at equilibrium, different types of innovators might separate themselves by producing costly evidence on how good is their project, there remains ample room for more credible signaling through contract design. More recently, Anton and Yao (2002) analyzed the mechanism by which ideas can be sold in a world where IPRs are weak. They derive a mechanism with partial disclosure in addition to a signaling device to reveal the true quality of the idea and foster competition between potential sellers while limiting the risk of expropriation. In our context, the seller can both understate or overstate (at a cost) the quality of his idea. Moreover, this value can never be directly observed by the buyers. In short, the types of innovations we are considering are ideas or new technologies the value of which can hardly be assessed by the seller.[7] This makes signaling through contract design a necessary step.

Lastly, our focus on double-edged incentives between an innovator and a developer has some connections with the work of Aghion and Tirole (1994a, 1994b). Taking an incomplete contracts perspective, they considered that property rights are the only tools to provide incentives for both developers and innovators. They side-stepped the informa-

[6] For other models of this trade-off in labor economics, general principal-agent models and regulation see Beaudry (1991), Inderst (2001) and Martimort and Sand-Zantman (2006).

[7] This is reminiscent of Rockett (1990)'s analysis of new versus old technology licensing.

tional asymmetries between developers and innovators which was then the key focus of the literature.[8]

Outline. Section 2 develops a numerical example showing the simple economics behind the trade-off between signaling and moral hazard. Section 3 presents the more general model and a benchmark corresponding to the case where the quality of the innovator's idea is known to both parties. Section 4 describes the set of incentive contracts that induce information revelation on the innovator's side and effort on the developer's side. Section 5 characterizes the equilibrium contract, explains the trade-off between adverse selection and moral hazard, and provides some comparative statics. Section 6 discusses some possible extensions of our basic model and provides some robustness checks. Section 7 concludes. Proofs are relegated to an Appendix.

2 The Trade-Off Between Signaling and Moral Hazard: A Bare-Bone Example

In this section, we develop a bare-bone numerical example illustrating the simple economics behind the contracting arrangements we will consider in later sections.

Consider an innovator (the principal) who knows how good his idea is and who contracts with a developer, downstream unit or customer (the agent), who has the expertise or financial capability to develop this idea. Both parties are risk-neutral and have unlimited liability. Both the principal and the agent are needed to complete the project but each intervenes at different stages throughout the innovation process.

Whether the project will succeed or not is uncertain. The probability of success depends not only on the innate quality of the innovator's idea but also on the developer's effort in providing further expertise, bringing in outside finance, or improving marketing. Suppose that the innovator's idea is good or bad. A good project gives a payoff of 10 dollars with a probability of 0.4 even if the developer contributes little expertise. A bad project may also have a payoff of 10 dollars but only with a probability of 0.1. By exerting an effort that costs 1 dollar, the developer increases the probability of success by 0.2 regardless of the quality of the innovator's idea.

Assume that the innovator has all the bargaining power in designing a contract. Such a contract should stipulate how the returns on the project are shared. This is done by using royalties left to the innovator and through a fixed fee that the developer pays upfront to access the innovator's idea. If the effort and the quality of the idea are verifiable, then

[8] Choi (2001) took instead a complete contracting approach and solved for the optimal royalties which balance incentives on both sides, solving thereby a moral-hazard in teams problem.

a simple contract stipulating that the developer should exert effort and be compensated only with a fixed payment of 1 for his cost yields the first-best expected payoffs to the innovator, respectively $10 \times (0.4 + 0.2) - 1 = 5$ for a good idea and $10 \times (0.1 + 0.2) - 1 = 2$ for a bad one.

Can this outcome still be achieved if the developer's effort is non-verifiable? The answer is yes. Provided that the developer enjoys all returns on the project, 10, in case of success and pays back a fee equal to 5 or 2 depending on whether the idea is good or bad. Indeed, when enjoying 10 in case of success, the developer has incentives to provide effort since the incremental expected gain of doing so exceeds its cost, namely $10 \times 0.2 - 1 = 1 > 0$. Royalties are not needed in this context.

Of course, this solution is no longer feasible when the quality of the innovator's idea is private information. A bad innovator may simply ask also for a fee worth 5. But of course, the developer may be unable to pay out 5 when the project is a bad one. The contract must now simultaneously induce innovators to release information on their ideas, and give the developer a share of the project's return which is sufficiently large to provide incentives as well as secure IPRs and avoids the stealing of ideas. The contract design results from a trade-off between signaling the quality of ideas and providing incentives to developers to exert effort.

How can this trade-off be mitigated? First, the innovator can provide pre-contractual evidence on the quality of his idea. A good innovator will certainly provide such favorable evidence, such as a blue-print or a project outline, at no cost. However, such evidence can also be forged by a bad innovator at a cost.[9] In the most extreme case, that cost is infinite and a good innovator can always provide enough pre-contractual evidence to distinguish himself from a bad one. The licensing contract has to induce the developer's effort and making the developer residual claimant is enough to achieve this outcome.

At a lower cost of forging evidence, for example say it costs 1 to forge favorable evidence, a bad innovator can mimic a good one at the pre-contractual stage and again ask for 5. What can deter this bad innovator from following such a strategy? The answer depends of course on the cost of forging evidence *but also* on the contract proposed by the good innovator. Suppose that the good innovator keeps 6 for himself as royalties when the project succeeds. This is certainly not enough to induce the developer's effort since the expected gain of effort is less than its cost, $(10 - 6) \times 0.2 - 1 < 0$. Accordingly, the good innovator will ask only for a fee worth $(10 - 6) \times 0.4 = 1.6$. This contract is certainly

[9] One can think here that the process of building evidence takes time and that it may not be so easy for a good innovator to provide all evidence on it in a given pre-contractual time period. It is often harder from a 20 minute seminar to distinguish between a good and a bad paper if the presenter devotes enough effort to hide the weak part of his analysis whereas a longer 1 hour and a half seminar will leave little doubt.

unattractive for a bad innovator. Forging favorable evidence at the pre-contractual stage and offering the same contract as a good innovator yields $6 \times 0.1 + 1.6 - 1 = 1.2$. Instead, not forging any favorable evidence and offering the full information contract corresponding to a bad innovator yields a greater payoff of 2. Therefore, to signal himself as having a good idea, the good innovator asks for more royalties which dampens the developer's incentives.

This contract with more royalties can nevertheless be affected by the risk of having the developer steal the idea and run his own business. Suppose that, once the contract has been negotiated and the quality of the idea is known, the developer bypasses the innovator, starts his own business with the idea he has just stolen and makes a net gain of 1. This possibility reduces the incentives for a bad innovator to overstate his idea. More precisely, an innovator with a good idea can induce effort from the developer without triggering any imitation by proposing to the developer a bonus of 6 and a fixed fee of 1.6. Weaker property rights lead to reduced royalties and increased fixed fees.

This example shows that royalties have a signaling value and that there exists a trade-off between signaling and downstream incentives in this environment. It also stresses the substitutability between better technology for producing evidence and the use of royalties. Our analysis formalizes that trade-off.

3 The Model

Let us now present more formally the basic ingredients of our modeling of the developer-innovator relationship we will study.

• **Information and evidence production.** The quality of the innovator's idea, θ, can be either good $\bar{\theta}$ or bad $\underline{\theta}$ with respective probabilities ν and $1 - \nu$. Denote $\Theta = \{\underline{\theta}, \bar{\theta}\}$ and let $\Delta\theta = \bar{\theta} - \underline{\theta}$ be the spread of uncertainty on the quality of the innovator's idea. Finally, $E(\cdot)$ denotes the expectation operator.

The innovator has private information on θ. The degree of privacy of that information and how easily it can be conveyed to potential trading partners is an important feature in our modeling. Indeed, contracts cannot be agreed upon by both parties without being relatively specific on the idea brought by the innovator. Designing a blue-print, running intermediary projects of smaller scale to familiarize the developer with the technology, building the developer's human capital to learn and master this technology are various ways of conveying information. This certification process takes time and is surely costly. When negotiating with a partner, the innovator can release documents, blueprints, and other pieces of evidence that can serve as testimonies of the idea quality.[10] We follow the general insights of the contracting literature with costly falsification.[11] Indeed, we assume that an innovator with idea θ can always provide enough evidence that his idea is in fact $\hat{\theta} \neq \theta$ if he incurs a "falsification cost"[12] worth $\varphi(\hat{\theta} - \theta)$. In other words for each true state of nature θ, there exists a piece of evidence "θ" that can be produced, perhaps at some cost, to make the developer and third-parties, such as Courts of Law, believe that state θ has been realized. More precisely, we assume that $\varphi(x) > 0$ if and only if $x > 0$ and $\varphi(x) = 0$ otherwise, and the right-derivative $\varphi'(0^+)$ exists and is zero. This assumption captures the idea that although one can provide evidence at no cost that the innovator's idea is bad when it really is, the reverse is costly. The cost of forging evidence is more likely to be high when the innovator is supposed to provide more detailed blue-prints and earlier sketches of his projects.

• **Effort.** The developer brings his expertise, effort in managing rough ideas, or his capacity to find outside financing as key inputs to the innovation process. Exerting effort e has a non-monetary cost $\psi(e) = \frac{e^2}{2}$ for the developer. Downstream moral hazard is captured by assuming that e is non-verifiable.[13]

Both the quality of the idea and the developer's expertise are complements at the extrinsic margin. However, ideas and expertise are substitutes at the intrinsic margin, i.e., they enter additively in the probability $p(\theta, e) = \theta + \lambda e$ that an innovation worth π is realized.[14] Here λ parameterizes how important the developer's effort is for the project. Under full information, the probability of innovation would be given by $\theta + \lambda^2\pi$ so we need to assume that $\bar{\theta} + \lambda^2\pi < 1$.

Our contracting environment thus entails bilateral asymmetric information with both adverse selection and moral hazard.

• **Contracts.** Without loss of generality, a contract between the innovator and the developer consists first of an upfront payment a paid by the developer to get access to the innovator's idea and second of a bonus w left to the developer when the innovation succeeds. The royalties $\pi - w$ are left to the innovator. Of course, $w \in [0, \pi]$, i.e., the bonus

[10] We refer to Bull and Watson (2001, 2007) for some previous works explicitly incorporating the production of verifiable knowledge into a mechanism design framework.

[11] See Lacker and Weinberg (1989) and Maggi and Rodriguez-Clare (1995) for instance.

[12] This cost is assumed to be unobservable but, as we will see, not borne at the equilibrium anyway.

[13] The choice of a quadratic disutility of effort is just made for tractability. Our results are robust to the choice of other functional forms as long as $\psi(e)$ remains increasing and convex.

[14] The assumption that the value of the innovation π is fixed is standard in the literature. See Aghion and Tirole (1994a) for instance. Alternatively, this is just a matter of relabeling variables to view the developer's effort as affecting the overall value of the projet which is now a random variable given by $\tilde{\pi} = \theta + \lambda e + \tilde{\epsilon}$ where $\tilde{\epsilon}$ is a random variable with zero mean. A contract will now share that profit between the innovator and the developer for each realization of $\tilde{\epsilon}$. Taking expectations over $\tilde{\epsilon}$ would lead to the same analysis as developed below.

is non-negative and cannot exceed the value of the innovation π. For further reference, we will denote $\mathcal{C} = (a, w)$ for such a contract.

A contract with maximal bonus (or no royalties) $\pi = w$ and a positive up-front payment $a > 0$ makes the developer residual claimant for developing projects. The innovator is then selling his idea to the developer for a fee. A contract such that $\pi > w$ corresponds to the case where the innovator is at least partially rewarded through royalties. In this article, we will be particularly interested in the amount of royalties kept by the innovator under various circumstances.

Under asymmetric information, contracting may reveal information through two different channels. First, the innovator may release pieces of evidence which directly convince the developer, even if the latter knows that evidence may have been forged. Second, the innovator may signal information simply through contract design. We will be particularly concerned with the interaction between this signaling device and the falsification technology. By choosing different fixed fees and bonuses, the innovator may reveal to the developer how valuable his idea is. This will typically be the case in the separating perfect Bayesian equilibrium we consider later, in which different innovators choose different levels of royalties. In other words, even though a bad innovator may have provided favorable evidence at the pre-contractual stage, a good innovator may still find it attractive to distinguish himself through an adequate contract design that is not found attractive by a bad innovator. Of course, the design of this contract depends on how easy it is to falsify evidence.

• **Enforcement.** Once the quality of the idea has been learned through contracting, the developer may find it valuable to leave the contractual relationship and run his own business. Doing so may require duplicating infrastructures, investments in human capital, losing marketable reputation for keeping trade secrets, paying fines for breach of contract and other direct and indirect costs. All the extra costs of setting up a new business can be modeled by assuming that the developer incurs a fixed cost I once he reneges. Alternatively, that fixed cost can be viewed as a measure of how difficult it is to enforce IPRs as in Gallini (1992). In that respect, having I large (resp. small) means that IPRs are easily (resp. hardly) enforceable.[15]

The probability of having a successful project when the developer steals the idea and runs his own business without the innovator is strictly less than its value inside the relationship. We write it as $\gamma(\theta + \lambda e)\pi$ where $\gamma \in [0, 1[$. This assumption captures two essential features. First, the innovator's human capital might also be a key input of

[15]A word of caution is necessary here. Reneging on a contract has also payoff consequences for the innovator which may pocket part of I under the form of patents, copyrights, trade secrecy and confidentiality agreements. Our modeling focuses thus on the part of these fixed costs of leaving the relationship and starting a new business which is not recovered by the innovator.

the development process and this capital disappears when the developer dispenses with the innovator.[16] Another interpretation is that a developer who steals an idea exposes himself to the threat of the innovator releasing this idea to other potential downstream competitors as in Anton and Yao (1994). Downstream competition erodes profits and expected gains and this effect is captured by an exogenous factor γ less than one.

The lower return on effort outside the relationship ensures that the innovator and the developer may find some benefits from contracting together. In doing so, the developer can guarantee himself a state-dependent reservation utility $u(\theta)$ which corresponds to his payoff when stealing the idea and running his own business:

$$u(\theta) = \max\left\{0, \max_e (\theta + \lambda e)\gamma\pi - \frac{e^2}{2} - I\right\} = \max\left\{0, \theta\gamma\pi + \frac{\lambda^2\gamma^2\pi^2}{2} - I\right\}.$$

Three cases of interests will be analyzed depending on I.

- **Large imitation costs:** $u(\bar{\theta}) = u(\underline{\theta}) = 0$. In this case, IPRs are easily enforced. The developer never finds it worthwhile to start a new business after having stolen the innovator's idea because the fixed cost of doing so is too large.
- **Low imitation costs:** $u(\bar{\theta}) > u(\underline{\theta}) > 0$. This case corresponds to the situation where IPRs are hard to enforce. The developer finds it easy to renege and to leave the relationship to start a valuable business with the stolen idea.
- **Intermediate imitation costs:** $u(\bar{\theta}) > 0 = u(\underline{\theta})$. In this last case, only good ideas are worth being stolen by the developer.

It turns out that, beyond the particular analysis of all these cases, only the difference $u(\bar{\theta}) - u(\underline{\theta})$ matters in determining contractual distortions as we will see below.[17]

• **Timing.** The contractual relationship between the innovator and the developer unfolds as follows:

- First, the innovator discovers θ.
- Second, the innovator provides evidence "$\hat{\theta}$" on the quality of his idea and, simultaneously offers the contract $\mathcal{C} = (a, w)$ to the developer.[18]

[16]The assumption $\gamma < 1$ ensures that the second-best distortion of the bonus that we will derive later on is always positive. On the contrary, assume that $\gamma = 1$ and I small enough, then the innovator cannot distort the bonus for signaling reasons without inducing expropriation.

[17]Our model could easily account for I being dependent on θ. This might arise for instance when fixed-costs for setting a new business after having stolen a good idea are smaller than when the stolen idea turns out to be bad.

[18]Whether releasing evidence and designing contract terms occur simultaneously or sequentially has no consequence on the outcome of the game. It might sometimes be relevant for references to real-world practices to see the evidence production stage as pre-contractual.

- Third, the developer uses the information he has learned from observing the choice of the contract $\mathcal{C}$ and the evidence "$\hat{\theta}$". He updates accordingly his beliefs about the quality of the innovator's idea. The developer assesses the benefits from stealing the idea and walking away from the relationship with these updated beliefs. If he leaves, the game ends with payoff $E(u(\theta)|\mathcal{C}, \text{“}\hat{\theta}\text{”})$ to the developer and 0 to the innovator.

- Fourth, the developer pays an up-front payment a to the principal if he has not opted out. He then exerts a non-verifiable effort e.

- Fifth, the innovation may either succeed or fail and some royalties of $\pi - w$ are paid to the innovator in the case of success.

Our equilibrium concept is perfect Bayesian equilibrium. In what follows, we will focus on the least-costly separating equilibrium[19] since it is the only equilibrium which survives standard equilibrium refinements like Cho and Kreps (1987).[20] In such outcomes, the different types of innovators separate from one another in their strategy of providing evidence and designing contract terms. Finding this least-costly separating allocation is made easier by the fact that, on the equilibrium path, the developer has correct point mass beliefs on the innovator's idea. Off the equilibrium path, we assume that any unexpected contractual offer[21] is followed with pessimistic beliefs, with the developer assuming that the innovator has the worst possible idea.[22] [23]

Because $u(\theta) \geq 0$ for all θ in Θ, the binding participation constraint is obtained when the developer is prevented from reneging on the contract. In this situation, only the enforcement constraint matters.

• **Complete information on θ.** To provide some preliminary intuition underlying our analysis, suppose first that the quality of the innovator's idea θ is common knowledge. There is no need to produce evidence to convince the developer. The only contractual

[19]This corresponds to the Riley outcome, see Riley (1979).

[20]Pooling equilibria also arise but they are ruled out by that refinement. As most of the literature, we will thus focus on this refined separating equilibrium.

[21]Because we focus on a separating allocation, both kinds of evidence "$\bar{\theta}$" and "$\underline{\theta}$" are produced at equilibrium. Out of equilibrium moves come thus only from modifying bonuses and royalties.

[22]For a justification of these out-of-equilibrium beliefs, see Mailath (1987).

[23]The game form above is an informed principal problem in a common values environment with moral hazard on the developer's side, i.e., the innovator's private information about his idea affects directly the developer's payoff from contracting as well as his payoff from reneging through the probability of success. Contrary to Maskin and Tirole (1992)'s analysis of the informed principal's problem, we do not allow the innovator to offer an "option contract", i.e., a menu of contracts $(c(\underline{\theta}), c(\bar{\theta}))$ from which the innovator chooses after the developer has accepted or not the offer. The main motivation for our focus on simple contracts is both simplicity and realism. However, if we were considering this larger strategy space, our conclusions would be unchanged. Maskin and Tirole (1992) have indeed shown that the set of perfect Bayesian equilibria of that game corresponds to allocations that Pareto-dominate the Riley outcome which again survives Cho-Kreps refinement. Moreover, that outcome is essentially unique when it is interim efficient, i.e., for ν small enough (proof available upon request).

issue stems then from the non-verifiability of the developer's effort. It is well-known that this moral hazard problem can easily be solved by making the risk-neutral agent residual claimant for the overall profit of the project.

Consider thus the simple "sell-out" contract $\mathcal{C}^*(\theta) = (w^*(\theta), a^*(\theta))$ such that

$$w^*(\theta) = \pi \text{ and } a^*(\theta) = \theta\pi + \frac{\lambda^2\pi^2}{2} - u(\theta).$$

Since he enjoys the full marginal gain from increasing the probability of an innovation, the developer exerts the first-best level of effort $e^*(\theta) = \lambda\pi$. The innovator can extract the developer's gains from trade by asking for an upfront payment that makes him just indifferent between walking away or not. Moral hazard on the developer's side is not an issue when the quality of the idea θ is common knowledge and the complete information outcome can easily be achieved.

When θ is common knowledge, the innovator's payoff can be written as:

$$V^*(\theta) = a^*(\theta) = \theta\pi + \frac{\lambda^2\pi^2}{2} - u(\theta). \tag{1}$$

Since the marginal value of an idea is greater inside than outside the relationship, namely $\gamma < 1$, $V^*(\theta)$ is non-negative and a better idea necessarily increases the innovator's payoff and the developer's up-front payment.

It is worth noting that the developer's reservation payoff is always less steep than the aggregate expected surplus $V^*(\theta) + u(\theta)$ of the project:

$$V^*(\bar{\theta}) + u(\bar{\theta}) - (V^*(\underline{\theta}) + u(\underline{\theta})) = \Delta\theta\pi \geq u(\bar{\theta}) - u(\underline{\theta}).$$

This condition simply expresses that the relative gains of having greater ideas are higher within the contract than outside. It plays a role in showing that bonuses are distorted under asymmetric information.

4 Equilibrium Contracts

The case where θ is common knowledge already pointed out the difficulty in writing efficient contracts under asymmetric information. Clearly, the innovator would exaggerate the value of his idea if the scheme $\mathcal{C}^*(\theta)$ were still offered under asymmetric information. We now turn to the design of contracts in this case and show how it differs from the complete information benchmark.

• **Incentive compatibility.** Let us now describe the incentive feasible contracts $\mathcal{C}(\hat{\theta}) = \{w(\hat{\theta}), a(\hat{\theta})\}_{\hat{\theta}\in\Theta}$ which are offered in a separating perfect Bayesian equilibrium where the innovator is privately informed on θ. For any $\theta \in \Theta$, we denote by $\tilde{V}(\theta, \hat{\theta})$ the type θ innovator's expected payoff when he provides evidence "$\hat{\theta}$" and proposes a contract $\mathcal{C}(\hat{\theta})$ and by $V(\theta) = \tilde{V}(\theta, \theta)$ his payoff when following a truthtelling strategy, i.e., when proposing the equilibrium contract corresponding to his type. We have:

$$\tilde{V}(\theta, \hat{\theta}) = (\theta + \lambda e(\hat{\theta}))(\pi - w(\hat{\theta})) + a(\hat{\theta}) - \varphi(\hat{\theta} - \theta) \tag{2}$$

where $e(\hat{\theta})$ is the agent's effort when the contract $\mathcal{C}(\hat{\theta})$ has been chosen by the principal and the developer has put mass beliefs on the innovator's type being $\hat{\theta}$. This effort maximizes the developer's expected payoff:

$$e(\hat{\theta}) = \arg\max_{e} \left\{ (\hat{\theta} + \lambda e) w(\hat{\theta}) - \frac{e^2}{2} - a(\hat{\theta}) \right\} = \lambda w(\hat{\theta}). \tag{3}$$

At a separating equilibrium, the innovator with idea θ prefers to offer $(a(\theta), w(\theta))$ and provide costlessly evidence "θ". This yields a greater payoff than offering any other contract and providing any other pieces of evidence. Let us first focus on the incentive compatibility constraints that prevent an innovator with type θ to offer the contract and provide evidence for being another type $\hat{\theta}$.[24] These constraints can be written as

$$V(\theta) = \max_{\hat{\theta} \in \Theta} \tilde{V}(\theta, \hat{\theta}) \tag{4}$$

or equivalently as

$$(\theta + \lambda^2 w(\theta))(\pi - w(\theta)) + a(\theta) \geq (\theta + \lambda^2 w(\hat{\theta}))(\pi - w(\hat{\theta})) + a(\hat{\theta}) - \varphi(\hat{\theta} - \theta) \quad \forall (\theta, \hat{\theta}) \in \Theta^2. \tag{5}$$

Taking into account the fact that the cost of providing evidence is zero for type $\bar{\theta}$ and $\varphi(\Delta\theta)$ for type $\underline{\theta}$ if he lies upward, standard revealed preferences obtained by summing the incentive constraints (5) for types $\underline{\theta}$ and $\bar{\theta}$ immediately yield:

$$\Delta\theta(w(\underline{\theta}) - w(\bar{\theta})) + \varphi(\Delta\theta) \geq 0. \tag{6}$$

Intuitively, a good innovator can only credibly convince the developer that he is good by keeping enough royalties. To send a credible signal on the quality of his idea, the good innovator reduces the marginal incentives of the developer. In other words, an immediate prediction of asymmetric information is that royalties are more attractive for innovators having good rather than bad ideas.

Finally, given the out-of equilibrium pessimistic beliefs sustaining our separating allocation, the best strategy for a bad innovator consists in providing evidence "$\underline{\theta}$" and offering the full information contract $\mathcal{C}^*(\underline{\theta}) = (\pi, a^*(\underline{\theta}))$. Such an innovator gets thereby

[24] We study in the Appendix the incentive constraints stipulating that this innovator with type θ does not want to make any unexpected offer.

a payoff $V^*(\underline{\theta})$ given by (1). The upward incentive constraint that prevents an innovator with a bad idea from mimicking an innovator with a better one can be written as:

$$V^*(\underline{\theta}) \geq V(\bar{\theta}) - \Delta\theta(\pi - w(\bar{\theta})) - \varphi(\Delta\theta). \tag{7}$$

This incentive constraint is binding for the least-costly separating allocation. In such an allocation, the good innovator wants to credibly convince the developer that he is so and does this by separating himself from the bad innovator. It is clear from this inequality that using royalties when the idea is good reduces the developer's bonus and relaxes the incentive constraint.

This incentive constraint also shows the significant role of the technology for producing evidence. When $\varphi(\Delta\theta) = 0$, information is completely soft and no evidence whatsoever can be understood as a meaningful signal of the innovator's idea. The incentive constraint can then only be relaxed by increasing the innovator's royalties. When $\varphi(\Delta\theta)$ is instead positive, i.e., a bad innovator finds it harder to provide favorable evidence, royalties can be reduced while still maintaining incentive compatibility. This points to the important substitutability between pre-contractual production of evidence and royalties.

Given that $\mathcal{C}^*(\underline{\theta}) = (\pi, a^*(\underline{\theta}))$ for a separating equilibrium, we may rewrite (6) as:

$$\Delta\theta(\pi - w(\bar{\theta})) + \varphi(\Delta\theta) \geq 0$$

which automatically holds when the bonus $w(\bar{\theta})$ cannot exceed the value of the project π.

• **Enforcement constraint.** A separating contract is feasible if it prevents the developer from leaving the relationship upon inferring θ from the choice of the contract $\mathcal{C}(\theta)$. The following enforcement constraint must thus be satisfied:

$$\theta w(\theta) + \frac{\lambda^2 w^2(\theta)}{2} - a(\theta) \geq u(\theta), \quad \forall \theta \in \Theta. \tag{8}$$

The corresponding enforcement constraint for a developer who learns that the innovator's idea is a good one is important to characterize the least-costly separating allocation. This constraint can also be written as:

$$\bar{\theta}\pi + \lambda^2 w(\bar{\theta}) \left(\pi - \frac{w(\bar{\theta})}{2}\right) - u(\bar{\theta}) \geq V(\bar{\theta}). \tag{9}$$

This condition expresses the fact that the good innovator can at most get the whole surplus of the relationship net of the developer's reservation payoff.

• **Least-costly separating allocation.** We are now ready to state the good innovator's problem who tries to separate himself from a bad innovator:

$$(\mathcal{R}) : \quad \max_{V(\bar{\theta}), w(\bar{\theta}) \in [0,\pi]} V(\bar{\theta}) \quad \text{subject to (7) and (9).}$$

Finally, one should note that when the falsification cost is high enough, the first-best solution is also implementable in an asymmetric information environment, i.e., it solves $(\mathcal{R})$ and (7) is slack. To avoid this less interesting solution, we assume that this cost is not too high. Therefore, we will use throughout the rest of the paper the following assumption:

Assumption 1 $\varphi(\Delta\theta) < \Delta\theta\pi - (u(\bar{\theta}) - u(\underline{\theta}))$.

5 Trading Off Adverse Selection and Moral Hazard

5.1 Characterization of Equilibrium Contracts

Solving problem $(\mathcal{R})$, the least-costly separating contract (indexed with the superscript R) has the following feature

Proposition 1 *Assume that $\Delta\theta$ is small enough, i.e.,*[25]

$$\pi - \frac{\varphi(\Delta\theta) + u(\bar{\theta}) - u(\underline{\theta})}{\Delta\theta} > \frac{5}{8\lambda^2}\Delta\theta. \tag{10}$$

Then the least-costly separating contract entails:

- ⋆ *Both the incentive constraint (7) and the enforcement constraint (9) are binding.*
- ⋆ *A downward distortion of the developer's bonus and effort below their first-best values when contracting with a good innovator:*

$$0 \leq w^R(\bar{\theta}) < w^R(\underline{\theta}) = \pi \text{ and } 0 \leq e^R(\bar{\theta}) < e^R(\underline{\theta}) = \lambda\pi$$

  with

$$w^R(\bar{\theta}) = \pi - \frac{1}{\lambda^2}\left(\sqrt{\Delta\theta^2 + 2\lambda^2(\Delta\theta\pi - (\varphi(\Delta\theta) + u(\bar{\theta}) - u(\underline{\theta})))} - \Delta\theta\right); \tag{11}$$

- ⋆ *The fee $a^R(\bar{\theta})$ is lower than under complete information on θ:*

$$a^R(\bar{\theta}) = \theta w^R(\bar{\theta}) + \frac{\lambda^2}{2}(w^R(\bar{\theta}))^2 - u(\bar{\theta}) < a^*(\bar{\theta}). \tag{12}$$

[25] This restriction is sufficient to ensure that out-of-equilibrium offers are never profitable for any type. See the Appendix for details.

To understand these results, remember that, with the contract $\mathcal{C}^*(\theta)$ designed in the complete information scenario, a bad innovator pretends to be a good one by asking for a greater fixed fee which will be paid upfront by the developer. To prevent this strategic behavior, the least-costly separating contract increases royalties for the good innovator. Using royalties is then a credible signal that the idea is good. However, the use of royalties also reduces the developer's share of returns on innovation. By the same token, the innovator can no longer ask for as large a fixed fee as under complete information and convincing the developer to stay within the relationship becomes harder.

Relying strongly on royalties can also lead to consequences on the developer's incentives to exert effort. Since the private returns on effort are now lower than their social value, effort is underprovided. This illustrates the important trade-off between adverse selection and moral hazard that arises in our contracting environment with double-edged incentives.

5.2 Comparative Statics

We provide now some comparative statics with respect to the main parameters of our model. These exercises will point out some key determinants of contracting arrangements.

Corollary 1 *The least-costly separating bonus $w^R(\bar{\theta})$ increases with the marginal cost of falsification $\varphi(\Delta\theta)$ and the difference $u(\bar{\theta}) - u(\underline{\theta})$. Moreover the probability of innovation with a good idea is lower than the probability of innovation with a bad idea when:*

$$\pi - \frac{\varphi(\Delta\theta) + u(\bar{\theta}) - u(\underline{\theta})}{\Delta\theta} > \frac{3}{2\lambda^2}\Delta\theta.^{26} \tag{13}$$

Technology for producing evidence: Royalties are more attractive for a good innovator when the direct production of evidence makes it easier for a bad innovator to provide false evidence that he is good. On the contrary, the developer's bonus is closer to its first-best value and the moral hazard problem downstream is less acute when the bad innovator finds it more difficult to forge favorable evidence.

Forging pre-contractual evidence may vary in difficulty, and the cost of falsification certainly depends on the nature of the innovation. In quickly evolving sectors like the bio-tech or the software industries, it might be easier to "fool" uninformed parties on the quality of a new process ($\varphi(\Delta\theta)$ small). In more mature sectors, "fooling" might be harder ($\varphi(\Delta\theta)$ large). Our theory predicts that, in the first case, contracting distortions are more pronounced, while in the second case, relying on more direct production of evidence is preferable to using royalties given their negative impact on downstream incentives.

[26]Note that (13) is more stringent than (10).

Reservation payoffs: There is less downward distortion of the bonus $w^R(\bar{\theta})$ when the developer's reservation payoff is steeper, i.e., when $u(\bar{\theta}) - u(\underline{\theta}) > 0$ gets larger. This will typically be the case when I is not too high, i.e., IPRs are weak enough.

A steeper reservation payoff profile can be obtained when I diminishes in the case of intermediate imitation costs and/or when γ increases. When quitting the relationship becomes attractive for the developer, the innovator can no longer easily convince the developer that he has a good idea by keeping a larger stake of the project. The trade-off between signaling and moral hazard is tilted against signaling. Royalties should then decrease to avoid idea-stealing.

For low imitation costs, the difference $u(\bar{\theta}) - u(\underline{\theta}) = \gamma\Delta\theta\pi$ does not depend on I. A change in the legal environment that would make IPRs easier to enforce has no impact on the developer's incentives. For intermediate levels instead, increasing I reduces the developer's reservation payoff $u(\bar{\theta})$ and increases the use of royalties as a signaling device.

Incentives "in" and incentives "out" are correlated: The discussion above shows that the developer's incentives inside the relationship reflect his incentives outside as well. These incentives are stronger when the developer can easily walk away and benefit more from his own effort in developing an alternative business. More generally, contracting with the innovator always gives the developer greater incentives to exert more effort than what he would exert on his own. Formally, the second-best bonus $w^R(\theta)$ is indeed such that:

$$w^R(\bar{\theta}) > \frac{u(\bar{\theta}) - u(\underline{\theta})}{\Delta\theta} = \begin{cases} \gamma\pi & \text{for small imitation costs} \\ \frac{u(\bar{\theta})}{\Delta\theta} & \text{for intermediate imitation costs.} \end{cases}$$

Innovation slow-down: Signaling requires dampening the developer's incentives when he works on a good project. An important issue is whether this distortion is enough to reduce the overall probability of innovation. When (13) holds, the downward distortion in effort that follows a decrease in the bonus left to a developer working on a good project is so large that it offsets any intrinsic advantage of a better idea. This reversed ranking of the probabilities of innovation is more likely when the developer's reservation payoff profile is rather flat. In the case of low imitation costs, this requires γ low enough which means that the innovator's human capital is really key to the project. Intuitively, when the innovator's human capital is a major input of the innovation process, the developer's reservation payoffs when contracting out are quite small. It becomes easy to distort downward incentives within the contract and this significantly decreases the probability of innovation even with a good idea.

Moreover, the dampening effect on effort is greater when the falsification cost $\varphi(\Delta\theta)$ is smaller. As forging favorable evidence becomes easier, the good innovator finds it more necessary to ask for royalties even if this lowers the developer's equilibrium effort. To the extent that one is ready to think of an increase in those falsification costs as coming from a more detailed and lengthy pre-contractual stage, this finding suggests that the innovation slow-down might be mitigated with more detailed pre-contractual procedures.

6 Extensions and Robustness Checks

6.1 Ex ante Investment

In the previous model, we have taken as given the information structure. More realistically, one may want to model the production of knowledge by the innovator and understand how contracting arrangements influence the process by which good ideas are generated. Let us assume then that the innovator can make some ex ante monetary investment i that increases the probability $\nu(i) \in [0,1]$ of generating good ideas ($\nu(\cdot)$ is increasing, concave and satisfies the Inada conditions $\nu'(0) = +\infty$ and $\nu'(+\infty) = 0$ to keep interior solutions). One may think of such investment as building up new research facilities or hiring more productive and talented researchers in the research unit. Denoting $V(\bar{\theta})$ and $V^*(\underline{\theta})$ the net payoffs of innovators with respectively a good and a bad idea in the continuation separating equilibrium described above, the optimal ex ante investment i^* solves:

$$i^* = \arg\max_i \nu(i)V(\bar{\theta}) + (1-\nu(i))V^*(\underline{\theta}) - i \Leftrightarrow 1 = \nu'(i^*)(V(\bar{\theta}) - V^*(\underline{\theta})).$$

Because $V(\bar{\theta}) < V^*(\bar{\theta})$, the ex ante incentives to invest are lower than under complete information on θ, an effect that may exacerbate the innovation slow-down we stressed above since good ideas become less likely. Moreover, one can show [27] that the differential gains $V(\bar{\theta}) - V^*(\underline{\theta})$ increase with I. Therefore, the stronger the IPRs, the higher the level of ex ante investment and thus the proportion of good ideas in the economy. This points to the role that a greater protection of property rights might play. It facilitates information revelation ex post as well as generating better ideas ex ante.

6.2 Double Moral Hazard

In many R&D projects, innovators might be actively involved not only at the inception of a project but also later on at development stages, as experts or advisers, whose incentives at which point are also at stake. We now analyze how this moral hazard on the innovator's side modifies the fundamental trade-off between adverse selection and moral hazard. To do so, we assume that, although the innovator is not able to carry out the project alone, he

[27] At least for λ not too high.

can exert a non-observable and non-verifiable effort ϵ which also increases the probability of an innovation. This probability becomes $p(\theta, e, \epsilon) = \theta + \lambda e + \alpha\epsilon$ where $\alpha \in]0, 1]$ is a scale parameter capturing the impact of the innovator's effort.

On top of inducing information revelation, the contract must now induce both the innovator and the developer to exert enough effort. Given the contract chosen by the developer $\mathcal{C}(\hat{\theta}) = (w(\hat{\theta}), a(\hat{\theta}))$, the developer and the innovator choose non-cooperatively their respective efforts.[28] This yields the following moral hazard incentive constraints:

$$\epsilon(\hat{\theta}) = \alpha \left(\pi - w(\hat{\theta})\right) \text{ and } e(\hat{\theta}) = \lambda w(\hat{\theta}). \tag{14}$$

Even when θ is common knowledge, solving the *moral hazard in teams* problem already requires sharing returns between the innovator and the developer.[29] Under asymmetric information on θ, the relevant upwards adverse selection incentive constraint of a bad innovator is still given by (7). The least-costly separating allocation requires again increasing the royalties of the good innovator which then puts a positive impact on his effort. Royalties are more attractive when the innovator's involvement in the project is long-lasting.

6.3 Complementarity Between Ideas and Development

So far, we have assumed that the probability of success was additively separable in the developer's effort and the innovator's idea. This separability ensured that the first-best effort did not depend on the innate quality of the project and allowed us to stress the impact of signaling on dampening incentives downstream.

Suppose now that effort and ideas are complement at the intrinsic margin also. The probability of success can be written as $p(\theta, e) = \lambda\theta e$ with values of those parameters such that this number is always less than one at equilibrium.

The first-best effort $e^*(\theta) = \lambda\theta\pi$ is now type-dependent, with the developer finding it worthwhile to supply more effort when associated with a better innovator. Similarly, when stealing the idea and running his own business, the developer would supply $\gamma e^*(\theta)$ and get a reservation payoff $u(\theta) = \max\{0, (1-\gamma^2)(\lambda\theta)^2\pi - I\}$.

[28] We restrict ourselves to the case where the innovator and the developer cannot commit to "burn money" which would facilitate solving the moral hazard in teams problem they face. With this proviso, fixed fees and royalties upon successful projects define the most general class of contracts.

[29] For completeness, notice that the optimal full information bonus is given by $w^* = \frac{\lambda^2}{\lambda^2+\alpha^2}\pi$. It corresponds to the full information payoff of an innovator given by $V^*(\theta) = \theta\pi + \frac{\pi^2}{2(\lambda^2+\alpha^2)}\left(\lambda^4 + \alpha^4 + \lambda^2\alpha^2\right) - u(\theta)$.

Rewriting the bad innovator's incentive constraint in this context, we obtain:

$$V^*(\underline{\theta}) = \frac{(\lambda\theta\pi)^2}{2} - u(\underline{\theta}) \geq V(\bar{\theta}) - \frac{(\lambda)^2}{2}(\bar{\theta}^2 - \underline{\theta}^2)w(\bar{\theta})(\pi - w(\bar{\theta})) - \varphi(\Delta\theta).$$

As in the additive case, leaving royalties to the innovators, i.e., reducing $w(\bar{\theta})$ below π, certainly relaxes this incentive constraint. However, in this multiplicative model, these dampened incentives come with a consequence. Reducing too much $w(\bar{\theta})$ shifts the probability of success too close to zero and this is not so attractive for a good innovator. Put differently, complementarity between ideas and efforts means that royalties might not be such an attractive option.

6.4 Bargaining Power

Our assumption that the developer has no bargaining power, although legitimate given the innovator's access to privileged information, can be relaxed. Suppose that contracts are negotiated through Nash bargaining. To simplify, let us give equal bargaining power to each contracting partner.

Under full information, the innovator's payoff is now $V_N^*(\theta) = \frac{1}{2}V^*(\theta)$. Under asymmetric information, the bad innovator's incentive constraint in the least-costly separating equilibrium becomes:

$$V_N^*(\underline{\theta}) \geq V_N(\bar{\theta}) - \frac{\Delta\theta}{2}(\pi - w(\bar{\theta})) - \varphi(\Delta\theta).$$

This expression makes it clear that the innovator's gains from playing "truthfully" are now half those he would have received when having all the bargaining power. The gains of offering the same contract as a good innovator are also divided by two. If there was no possibility of producing favorable evidence, the equilibrium policy would be just the same as when the innovator has all the bargaining power. However, notice that the cost of producing wrong evidence is not borne at a separating equilibrium by any type whereas it is borne at full value by a bad innovator when deviating. Overall, everything happens as if the cost of producing evidence had been doubled. In that respect, reducing the innovator's bargaining power makes it easier to satisfy the signaling incentive constraint and tilts the choice of the incentive schemes against royalties. The same trade-off between signaling and dampened incentives as in our previous model does arise but it is of a much lower magnitude.

7 Conclusion

This paper has analyzed contract design between an informed innovator and a developer in a variety of settings. This design is complex because it optimally responds to various contractual hazards. Indeed, a contract must simultaneously induce the innovator to convey information on the value of his idea, while providing incentives to the developer to exert effort and protect the innovator's IPRs.

To prevent bad innovators from exaggerating the quality of their ideas, the best innovators signal themselves by asking for more royalties. This reduces the developers' share of returns on a successful project and dampens his incentives. The magnitude of that distortion depends significantly on both market conditions and the technology of contracting, especially on how easy it is to forge false evidence during the pre-contractual negotiation.

Royalties are attractive under a variety of circumstances, in particular when IPRs can be easily enforced and when the innovator may be involved at later development stages of the project.

More broadly, our analysis points at the fact that the diffusion of knowledge over the whole economy depends significantly on the contracts and the regime of IPRs that prevail. The cost of informational asymmetries, which might come for example in terms of innovation slow-down, and the role that those contractual forms play have certainly been overlooked by the existing endogenous growth literature. This suggests that much work remains in reconciling the micro-perspective of our paper and the more macro-oriented view of the growth literature.

An important extension of our work would be to consider ex ante competition between potential developers. Such competition is likely to relax the enforcement constraint and it has roughly the same features as making IPRs easier to enforce.[30] We thus predict that more competition makes royalties more attractive to innovators.

Finally, we believe that the lessons of our model can also be viewed as a building block for a more thorough analysis of organizational forms (vertical integration between upstream and downstream units, research-joint ventures, etc...) that facilitate innovation. We plan to investigate some of these issues in future research.

[30] In the spirit of Anton and Yao (1994).

References

[1] Aghion, P., and P. Howitt (1998), *Endogenous Growth Theory,* MIT Press: Cambridge.

[2] Aghion, P., and J. Tirole (1994a), "On the Management of Innovation," *Quarterly Journal of Economics*, 109, 1185-1209.

[3] Aghion, P., and J. Tirole (1994b), "Opening the Black-Box of Innovation," *European Economic Review*, Papers and Proceedings, 38, 701-710.

[4] Anand, B., and T. Khanna (2000), "The Structure of Licensing Contracts," *The Journal of Industrial Economics*, 84, 190-209.

[5] Anton, J.J., and D.Yao (1994), "Expropriation and Inventions: Appropriable Rents in the Absence of Property Rights," *American Economic Review*, 84, 190-209.

[6] Anton, J.J., and D.Yao (2002), "The Sale of Ideas: Strategic Disclosure, Property Rights and Contracting," *Review of Economic Studies*, 69, 513-532.

[7] Anton, J.J., and D.Yao (2004), "Little Patents and Big Secrets: Managing Intellectual Property," *RAND Journal of Economics*, 35, 1-22.

[8] Arrow, K. (1962), "Economic Welfare and the Allocation of Resources for Invention,"in Nelson, R. (ed.) *The Rate and Direction of Inventive Activity,* Princeton: Princeton University Press.

[9] Beaudry, P. (1994), "Why an Informed Principal May Leave Rents to an Agent," *International Economic Review*, 35, 821-832.

[10] Beggs, A. 1992, "The Licensing of Patents under Asymmetric Information," *International Journal of Industrial Organization,* 10, 171-191.

[11] Bhattacharya, S., J. Glazer and D. Sappington (1990), "Sharing Productive Knowledge in Internally Financed R and D Contests", *Journal of Industrial Economics,* 39, 187-208.

[12] Bhattacharya, S., J. Glazer and D. Sappington (1992), "Licensing and the Sharing of Knowledge in Research Joint Ventures", *Journal of Economic Theory,* 56, 43-69.

[13] Bhattacharya, S., and J. Ritter, (1983), "Innovation and Communication: Signalling with Partial Disclosure ", *Review of Economic Studies*, 50, 331-46.

[14] Bhattacharya, S. and G. Chiesa (1995), "Proprietary Information, Financial Intermediation, and Research Incentives", *Journal of Financial Intermediation,* 4, 328-357.

[15] Bhattacharya, S. and S. Guriev (2006), "Knowledge Disclosure, Patents and Optimal Organization of Research and Development", *Journal of European Economic Association,* 4, 1112-1147.

[16] Binns, R. and B. Driscoll (1998), "Intellectual Property Issues in R&D Contracts," *Pharmaceutical Science & Technology Today*, 1, 95-99.

[17] Bull, J. and J. Watson (2001), "Evidence Disclosure and Partial Verifiability," *Journal of Economic Theory*, 118, 1-31.

[18] Bull, J. and J. Watson (2007), "Hard Evidence and Mechanism Design," *Games and Economic Behavior*, 58, 75-93.

[19] Choi, J.P. (2001), "Technology Transfer with Moral Hazard," *International Journal of Industrial Organization*, 19, 249-266.

[20] D'Aspremont, C., S. Bhattacharya and L.-A. Gerard-Varet (2003), "Bargaining and Sharing Innovative Knowledge", *Review of Economic Studies,* 67, 255-271.

[21] Gallini, N. (1992), "Patent Policy and Costly Imitation," *Rand Journal of Economics*, 23, 52-63.

[22] Gallini, N. and B. Wright (1990), "Technology Transfer under Asymmetric Information," *Rand Journal of Economics*, 21, 147-160.

[23] Inderst, R. (2001), "Incentives Scheme as a Signaling Device," *Journal of Economic Behavior and Organization*, 44, 455-465.

[24] Kartik, N (2008), "Strategic Communication with Lying Costs," *Review of Economic Studies*, forthcoming.

[25] Lacker, J. and J. Weinberg (1989), "Optimal Contracts under Costly State Falsification," *Journal of Political Economy*, 97, 1345-63.

[26] Macho-Stadler I., and D. Perez-Castrillo (1991), "Contrats de Licences et Asymétrie d'Information," *Annales d'Economie et de Statistiques*, 24, 189-208.

[27] Maggi, G. and A. Rodriguez-Clare (1995), "Costly Distortion of Information in Agency Problems," *Rand Journal of Economics*, 26: 675-689.

[28] Mailath, G. (1987), "Incentive Compatibility in Signaling Games with a Continuum of Types," *Econometrica*, 55, 1349-1365.

[29] Martimort, D., and W. Sand-Zantman (2006), "Signaling and the Design of Delegated Management for Public Utilities," *RAND Journal of Economics*, 37, 763-782.

[30] Maskin, E., and J. Tirole (1992), "The Principal-Agent Relationship with an Informed Principal, II: Common Values," *Econometrica*, 60, 1-42.

[31] Riley J. (1979), "Informational Equilibrium," *Econometrica*, 47, 331-357.

[32] Rockett K. (1990), "The Quality of Licensed Technology," *International Journal of industrial Organization*, 8, 559-574.

[33] Rostoker M.D. (1984), "A Survey of Corporate Licensing," *IDEA*, 24, 59-92.

[34] Yosha, O. (1995), "Information Disclosure and the Choice of Financing Source", *Journal of Financial Intermediation,* 4, 3-20.

Appendix

• **Proof of Proposition 1 and Corollary 1:** Note first that the monotonicity constraint (6) can be easily checked ex post in the least-costly separating allocation since $w^R(\bar{\theta})$ found below is less than π.

Let us now turn to the solution to problem $(\mathcal{R})$. Observe first that (7) does not hold for the full information solution obtained when only (9) is binding.

Suppose that only (7) is binding. Then, it is optimal to set $w(\bar{\theta}) = 0$ and we would obtain:

$$V(\bar{\theta}) = V^*(\underline{\theta}) + \Delta\theta = V^*(\bar{\theta}) > \bar{\theta}\pi - u(\bar{\theta})$$

which contradicts with our starting assumption that (9) is slack.

Therefore, necessarily both constraints (7) and (9) are binding at the solution to $(\mathcal{R})$. We can now rewrite $(\mathcal{R})$ as:

$$(\mathcal{R}') : \quad \max_{w(\bar{\theta})\in[0,\pi]} \bar{\theta}\pi + \lambda^2 w(\bar{\theta})\left(\pi - \frac{w(\bar{\theta})}{2}\right)$$

subject to

$$\underline{\theta}\pi + \frac{\lambda^2\pi^2}{2} - u(\underline{\theta}) = -\Delta\theta(\pi - w(\bar{\theta})) + \bar{\theta}\pi + \lambda^2 w(\bar{\theta})\left(\pi - \frac{w(\bar{\theta})}{2}\right) - u(\bar{\theta}) - \varphi(\Delta\theta). \quad \text{(A.1)}$$

The optimal $w(\bar{\theta})$ is obtained when solving (A.1) which is a second-order equation in $w(\bar{\theta})$ that can be rewritten as:

$$\frac{\lambda^2}{2}w^2(\bar{\theta}) - (\lambda^2\pi + \Delta\theta)w(\bar{\theta}) + \frac{\lambda^2\pi^2}{2} + \varphi(\Delta\theta) + u(\bar{\theta}) - u(\underline{\theta}) = 0. \quad \text{(A.2)}$$

Keeping the only solution which is less than π yields (11).

Turning now to the fixed fee, the value of $a^R(\bar{\theta})$ immediately follows from (9) being binding.

Finally, we need to check that the incentive constraints of an innovator with a good idea $\bar{\theta}$ is slack. First, this means that this innovator should not be willing to offer the same contract as the innovator with a bad idea. This corresponds to the following incentive constraint:

$$V^R(\bar{\theta}) = \bar{\theta}\pi + \lambda^2 w^R(\bar{\theta})\left(\pi - \frac{w^R(\bar{\theta})}{2}\right) - u(\bar{\theta}) > V^*(\underline{\theta}) + \Delta\theta(\pi - w^R(\underline{\theta})) = V^*(\underline{\theta})$$

which immediately follows from (7) being itself binding.

Also, the equilibrium offer $(w^R(\bar{\theta}), a^R(\bar{\theta}))$ must be preferred by the innovator with idea $\bar{\theta}$ to any out-of-equilibrium contract whose offer is followed by pessimistic beliefs. In that case, of course, there is no point forging favorable evidence. This gives the following incentive constraint:

$$V^R(\bar{\theta}) \geq \max_{\{w\in[0,\pi], a\leq \underline{\theta}w + \frac{\lambda^2}{2}w^2 - u(\underline{\theta})\}} a + (\bar{\theta} + \lambda^2 w)(\pi - w) \tag{A.3}$$

The right-hand side of (A.3) can also be written as:

$$\max_{w\in[0,\pi]} \underline{\theta}\pi + \Delta\theta(\pi - w) + \lambda^2 w\left(\pi - \frac{w}{2}\right) - u(\underline{\theta}) = V^*(\underline{\theta}) + \frac{\Delta\theta^2}{2\lambda^2}.$$

Given that (7) is binding, (A.3) is satisfied when (10) holds. Since $u(\bar{\theta}) - u(\underline{\theta}) < \gamma\pi\Delta\theta$, and that $\varphi'(0^+) = \lim_{\Delta\theta\to 0} \frac{\varphi(\Delta\theta)}{\Delta\theta} = 0$ this property holds when $\Delta\theta$ is small enough.

Concerning Corollary 1, from (11) differentiating $w^R(\bar{\theta})$ with respect to $\varphi(\Delta\theta)$ and $u(\bar{\theta}) - u(\underline{\theta})$ leads to the result. Finally, the probability of an innovation with a bad (resp. good) idea is $\underline{\theta} + \lambda^2\pi$ (resp. $\bar{\theta} + \lambda^2 w^R(\bar{\theta})$). We have $\underline{\theta} + \lambda^2\pi > \bar{\theta} + \lambda^2 w^R(\bar{\theta})$ when condition (13) holds. ■