On the Firms' Decision to Hire Academic Scientists

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Abstract

We analyse firms' incentives to invest in scientific research as we characterize the optimal contracting of scientists intrinsically motivated to produce basic science. In our setting, firms face a large pool of heterogeneous scientists, with different degrees of scientific ability, and each scientist has reservation utility that is non-decreasing with their ability. Once hired scientists can spend time on their own basic agenda and on the firm's applied agenda, but only the time spent on applied research is of *direct* value to the firm. The time spent on basic research is however indirectly valuable to the firm. We consider different scenarios, as we allow for asymmetric information. The main deterrent to hiring scientists with the highest ability is the opportunity cost, introduced via the type-dependent reservation utility. When the reservation utility is the same for all, top academics are hired. This result is robust to introducing moral hazard and adverse selection. When the reservation utility is positively correlated with the scientist's ability, we show that the impact of moral hazard depends on whether scientists can be made residual claimants. Under adverse selection, firms must allow scientists to dedicate time to their own agenda in increasing proportion to their ability to ensure incentive compatibility. In equilibrium adverse selection triggers an excessive workload which puts pressure on the wage and leads firms to reduce their investment in science.

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"It was out of practical concerns that Bell Labs decided to employ Arno Penzias and Robert Wilson. Penzias and Wilson would undoubtedly have been indignant if anyone had suggested that they were doing anything other than basic research. They appropriately shared a Nobel Prize for their findings at Bell, now taking as a confirmation of the Big Bang." (Rosenberg 1983)

1. INTRODUCTION

Advances in biotechnology, information technologies and nanotechnology have had a significant impact on our everyday life and will shape future innovations. By pushing the boundaries of creativity, these technologies have attracted contributors in both, the public and the private sector. Pisano (2006) explains how they even led all participants to revise their priorities and objectives: "*Before the emergence of biotech, science and business largely operated in separate spheres. […] The biotech sector fused these two domains […]. For-profit enterprises now often carry out basic scientific research themselves, and universities have become active participants in the business of science*."

A large literature analyses how investment decisions in a*pplied (or proprietary)* research can generate rents by providing a competitive advantage to innovating firms (e.g. Gilbert and Newbery 1982; Grossman and Shapiro 1987; Aghion et al 2005). Less is understood however in relation to firms investing in *basic (or open)* science whose returns are more uncertain and difficult to appropriate (Dasgupta and David 1994), but could nevertheless *"provide valuable guidance to the directions in which there is a high probability of payoffs to more applied research"* (Rosenberg 1990). This paper focuses at this latter specific issue.

Investments in basic science can take many forms. Here, we capture such an investment as the decision to hire a scientist with a stronger or lesser intrinsic motivation for basic science measured by the quality of her basic research outputs (e.g. publications). We then analyse the factors that influence the firms' hiring decisions as well as the terms of the contract. In particular we shed light on the firms' incentives to allow contracted scientists to spend time on their own agenda and pursue basic research alongside more applied research following the firm's agenda.[1] The main contribution of our paper, in relation to the literature, is the consideration of the intensity of the firm's investment in science as an endogenous variable modelled as the decision to hire a scientist with a lesser or greater motivation to pursue basic research.[2] While we agree that one's motivation is not observable, we argue that the quality of their research (such publications) can serve as a proxy for their dedication.

The presence of intrinsic motivation obviously impacts the profitability of a contractual relationship. Bénabou and Tirole (2003) show that contractors need to fine tune the interaction between intrinsic and extrinsic motivation to properly incentivize an agent. When it comes to investment in science, Stern (2004) brings to light the private benefits of hiring researchers with a "taste for science". Aside from the *productivity effect* (which measures the impact that their research can have on a firm's future returns) he shows that scientists may require lower salaries when a *preference effect* is more salient, i.e. when the firm offers them the possibility to pursue their own research agenda. Hence the conclusion he reaches is that "scientists pay to be scientists".[3] Sauermann and Roach (2014) nuance these findings by noting that not all scientists are equal. Scientists who believe themselves to be of high ability and who train at top tier institutions are more expensive to hire, even if publishing is allowed, because they have a higher 'price of publishing'. The analysis provided here builds on Stern (2004) and brings further theoretical understanding of the non-obvious relationship between wages and academic ability.

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[1] There is growing evidence that some firms explicitly encourage their employees to carry out curiosity driven research projects, alongside the more focused industrial projects dictated by top management. See, for instance, Rosenberg (1990) and more recently Penin (2007) and Simeth and Raffo (2013).

[2] Alternatively one may observe the decision for the firm to invest in a more academic research environment within the firm research department.

[3] Whether such a result is affected by the fact that scientists choosing to work for firms may possibly have a weaker taste for science than scientists choosing to work in academic institutions, is also a subject of research. Roach and Sauermann (2010) find that those who prefer industrial employment show a weaker 'taste for science', a greater concern for salary and access to resources and a stronger interest in downstream work compared to PhD students who prefer an academic career. Along this lines, Agarwal and Ohyama (2013) use matching theory to examine the sorting pattern of heterogeneous scientists into different career trajectories and find sorting by higher taste for nonmonetary returns into academia over industry.

Our study assumes that the aims of basic and applied research differ and thus, so do their endeavours. Subject to dedicating time to her own personal academic research agenda the scientist produces an academic outcome that has no direct value for the firm. Subject to dedicating time to the firm's research agenda, the scientist produces an outcome that has applications valuable to the firm via a *productivity effect*. Both outcomes are positively correlated with our endogenous variable: the quality of the scientist's basic research.

Even though scientists are characterized by their motivation to pursue basic research, we consider that they also take into consideration and respond to monetary incentives. Thus, using a contract theory approach, we show that the firms' can incentivise researchers to undertake applied research activities by sharing the financial rewards of the more applied research.

The agency issues described above are addressed in Banal-Estañol and Macho-Stadler (2010) who focus on the effects of commercial incentives in public and private R&D. They find that the introduction of commercial incentives not only induces researchers to spend more time in 'development' than in 'research', but also affects the choice of projects whereby researchers tend to choose riskier, more basic, research projects. Aghion et al (2008) argue that the fundamental trade-off between academia and the private sector lies on control rights as they state that in academia *"scientists retain the decision rights over what specific projects to take on, and what methods to use in tackling these projects".* As a result, they claim that scientists would have to be paid a wage premium in order to give up creative control, which is in line with the empirical findings previously cited. [4]

In a paper closer to ours, Lacetera and Zirulia (2012) analyse the optimal contracting of scientists by competing firms. They also acknowledge that scientists perform distinct research activities (basic and applied) and that they respond to monetary and non-monetary incentives. The optimal contract is based on variables that reflect the distinct research outcomes and depends on the intensity of competition on the market as well as the spillovers generated by basic research.

[4] Aghion et al (2008) link this argument to previous work by Aghion and Tirole (1997) and, more generally to the property rights literature (Grossman and Hart 1986; Hart and Moore 1990; Hart 1995).

Contrary to Lacetera and Zirulia (2012), we consider that the time spent on academic research is of no direct benefit to the firm. However, we consider that the research activities may exhibit some complementarity. At the researcher level, seeing the applicability of her research can lead a scientist to enjoy more her time spent doing more basic research. Similarly, progress in her basic research can benefit her more applied research. This allows us to consider a *complementarity effect*. Another important feature of our model, not present in the aforementioned paper is that we consider that the scientists' outside option grants them a reservation utility which is positively correlated with their ability. This generates an *opportunity cost* effect which captures and explains some results in Sauermann and Roach (2014).

Finally, we also cater for potential externalities between the firm's hiring decisions and assume these could be either negative or positive. A positive externality reflects a situation where allowing scientists to interact is beneficial to the firms. A negative externality could reflect a situation where firms lose their competitive hedge when their scientists openly share their research outcomes. As we shall see, *the externality effect* (partially) determines whether hiring decisions are strategic substitutes or complements.

The more realistic model generates several results. We fully characterize the optimal hiring decision and optimal contracts assuming that the effort dedicated to each research activity may or may not be contractible (moral hazard) and that the scientist's ability may or may not be verifiable (adverse selection).

From the revenue's perspective, the higher the scientist's ability the greater the returns are, even under moral hazard. Scientists with a greater ability spend more time on research, following their own and the firm's agenda.[5] The cost, i.e. the wage, is then the main determinant of the hiring decision. On the one hand, the wage must be such that a scientist gets at least as much as her reservation utility. If the latter increases with the scientist's ability then selecting a candidate with a high ability puts upward pressure on the wage. On the other hand, allowing scientists to spend time on their own research agenda when hired has a positive impact on their utility which is stronger as their academic ability increases. Therefore, by strategically allowing scientists to spend time

[5] In an extension we show that this result still holds when the overall time spent on research is constrained.

on their agenda the firm may still target a high ability candidate who would then be willing to settle for a lower wage (as in Stern (2004)).

With the above in mind we show that when the opportunity cost is nil, reflecting a world where all scientists have the same outside options irrelevantly of their academic prestige, firms always select the scientist of the highest ability. This result is very robust as it remains valid under moral hazard and adverse selection.

When there is an opportunity cost, the hiring decisions are either strategic complements or strategic substitutes. When the hiring decisions are strategic complements the firms may still hire academics of the highest possible ability. This result applies when the interaction among scientists generates some positive externalities. In this case, instead of free-riding on each other's hired scientist, both firms select high ability scientists. When the hiring decisions are strategic substitutes, which is more likely when the externality from interaction is negative, none of the firms hires a top academic.

In relation to the wage, we refine the findings in Stern (2004) and show that indeed, for a given workload (understood as overall cost of efforts), scientists pay to be scientists. But, if we incorporate the fact that a more academically inclined scientist spends more time on her agenda and the firm's, then her wage can increase with her academic talent as it must cover the cost she incurs from greater dedication.

The introduction of moral hazard (non-verifiable efforts) is inconsequential when the firms can make scientists the residual claimant of all the commercial value generated. Otherwise, when the scientists' share of the firms' profits are capped, moral hazard leads the firms to under-invest and select a scientist with a lower scientific ability than when effort levels are contractible.

The consideration of adverse selection (non-verifiable ability) triggers more interesting results. In absence of an opportunity cost there is no distortion as the first best contract is incentive compatible. Indeed, any for given (positive) efforts, the wage decreases as the scientist's taste for basic research increases because the firms take into consideration the increased utility a scientist gets from following her own agenda. Thus, for any given efforts, the wage is lower for a scientist with high ability. Thus a low ability scientist would not be tempted by the efforts and wage that appeals to a high ability scientist.

When the opportunity cost is positive, reflecting a more realistic world where the outside options depend on the quality of one's basic research, a countervailing incentive arises as firms must match a reservation utility which increases with the scientist's academic ability. In such cases, incentive compatibility requires that scientists be allowed to dedicate part of their time to their own personal basic research agenda. The higher the scientist's ability, the higher would be the reservation utility and the more time she should be given to spend on her own basic research projects. Interestingly, under adverse selection, the opportunity cost intervenes through a very different channel compared to the case where the ability is verifiable. Incentive compatibility requires that a scientist spend more time on her personal agenda than what she would choose if that was her own choice. Consequently, the effort dedicated to the firm's agenda also increases. Thus, under positive opportunity costs, adverse selection triggers an excessive cost of efforts which puts pressure on the wage and leads firms to reduce their investment in science.

The paper's structure is as follows. The next section presents evidence of private firms investing in science. It is followed by a description of the model. We then solve for the optimal contract when all variables are contractible in section four. Moral hazard and adverse selection are introduced in section five and six respectively. Section seven addresses some extensions. Finally section eight concludes.

2. EVIDENCE OF FIRMS INVESTING IN SCIENCE.

In-house investment in basic science in private companies is not a recent phenomenon. Documented examples can be traced back to the 1920s. Indeed in her paper Hoddeson (1981) describes how the R&D department in Bell Telephone System (as well as other major US companies) evolved from gathering engineers who focused on practical and technical issues to becoming vibrant research centres with highly qualified scientists dedicated to more theoretical, basic research. *"By the 1920s, some of the largest industrial firms in America had come to regard scientific research as essential* *to their continuing success."* During those years Bell evolved from a company with technicians solving day to day problems to a company where upstream research was encouraged.

More recently, anecdotal evidence suggests that many scientists are leaving top-level academic positions to lead research units at drug companies[6], and the phenomenon is not confined to the pharma sector.

In some cases, scientists who join the private sector are allowed to pursue their own, personal, agenda. Firms such as IBM and 3M allow their scientists to spend time on their own research agenda experimenting with technologies and ideas that can be completely remote from the companies' core business. According to Google's 20% rule employees can spend time on their side projects one day a week. Innovations like Gmail and AdSense were originated thanks to such policies.[7] Many other firms have put similar measures in place in recent years: LinkedIn has InCubator; Apple has Blue Sky, and Microsoft created The Garage. In all these examples, firms allow employees to use the company resources and part of their working time to carry out their own research and innovation projects. All of them also impose a limit to the time employees can dedicate to their own agenda as each firm's priority continues to be its own research agenda. As put by an industry expert, the logic of these programmes is that it is better for these companies to have a talented engineer, even if they have only 80% of their attention.[8] From the point of view of the scientists, firms can provide expensive state of the art research equipment and resources not always at the reach of public research institutions. A tenured computer scientist at Princeton University who spent eight years at AT&T Labs - Research claimed that "*being inside a company that was running an Internet backbone and had a lot of measurement data and access to interesting research, ... I actually was able to work on things that if I had been an academic I would have had a hard time doing*."[9]

[6] https://www.statnews.com/2015/12/15/academic-scientists-drug-industry/

[7] https://www.fastcompany.com/3015963/google-took-its-20-back-but-other-companies-are-making-employee-side-projects-work-for-them; http://www.forbes.com/sites/johnkotter/2013/08/21/googles-best-new-innovation-rules-around-20-time/#5ff3a50268b8

[8] https://www.fastcompany.com/3015963/google-took-its-20-back-but-other-companies-are-making-employee-side-projects-work-for-them

[9] http://www.sciencemag.org/careers/2009/05/academia-or-industry-finding-right-fit

As for the benefits that firms can gather from such contracts, there is evidence showing that when industrial scientists publish with top academic scientists the number and quality of their company's patents tend to increase, which suggests a positive impact on the firm's performance (Zucker et al 2002). Simeth and Cincera (2015) also find a positive impact of scientific publications on a firm's market value beyond the effects of research and development, patent stocks, and patent quality, and document heterogeneity with respect to this impact between different industrial sectors. Jong and Slavova (2014) consider that a firm's involvement in academic communities (e.g. scientific publications) improves its innovative performance in terms of new products and find empirical support on the product innovation performance and R&D activities of UK therapeutic biotechnology firms. Arts and Veugelers (2016) find that industrial scientists and engineers with a strong taste for science (i.e. who co-publish with academic scientists) develop more novel and valuable patents.

Interviews with researchers in pharmaceutical industry reported by Cockburn and Henderson (1998) provide evidence of the fact that firms access upstream research through investments in absorptive capacity in the form of in-house basic research and pro-publication incentives. Based on their analysis, they identified the following three factors as being determinants for a firm to benefit from scientific research: i) hire the best possible people; ii) reward them on the basis of their standing in the public rank hierarchy; iii) encourage them to be connected with the academic community. In turn, Zucker et al (2002) argue that mobility of top academic scientists to industry depends on scientists' quality, moving costs, and reservation wage.

3. THE MODEL

Two firms face a large pool of heterogeneous scientists. Each scientist is characterized by the quality of the scientific research she can produce which we refer to as her *ability* and denote $\phi \in [0, \overline{\phi}]$. This variable may or may not be verifiable. Let ϕ_i refer to the ability of the scientist hired by firm i .

Each scientist is offered a contract and, if she accepts it, she can dedicate effort to her own, academic research agenda and to the firm's research agenda. We denote by $e_P \geq 0$ the effort a scientist dedicates to her own, *personal*, academic research agenda (open, basic research) and by $e_F \geq 0$ the effort directed towards the *firm's* research agenda (proprietary, applied research). A scientist can then generate two distinct outputs. Subject to dedicating time to her own agenda ($e_P > 0$), she produces an output of an academic nature that has direct benefits for her only. Subject to spending time on the firm's agenda ($e_F > 0$) she produces an output of a commercial or industrial nature that benefits the firm (and possibly the scientist through the wage).

More specifically, let $\pi_i(\phi_i, \phi_i\phi_j)$ denotes the value gathered by firm i it hires a scientist with ability ϕ_i while its competitor hires a scientist of ability ϕ_j. The function $\pi_i(\phi_i, \phi_i\phi_j)$ measures the commercial value of academic expertise. It depends on the intrinsic academic quality of the scientist hired but it is also impacted by gains or losses generated when allowing the hired scientists to interact and/or to disseminate their academic results. These costs or benefits are captured by the effect of $\phi_i\phi_j$ on π_i.

Assumption 1: The function $\pi_i(\phi_i, \phi_i\phi_j)$ is increasing and concave in ϕ_i.

Assumption 2: A firm cannot free-ride on the other firm's hired scientist unless it invests in basic research itself: $\pi_i(\phi_i, \phi_i\phi_j) = 0$ when $\phi_i = 0$.

This second assumption captures the fact that a firm must hire someone who, at the very least, understands basic science to benefit from it.

To reach closed form solutions we consider the following specific form

$$\pi_i(\phi_i, \phi_j) = \rho\sqrt{\phi_i} + \varepsilon\sqrt{\phi_i\phi_j}. \qquad (1)$$

The parameter $\rho > 0$ measures the *productivity* effect (terminology introduced in Stern (2004)). The parameter ε measures the *externality* from the scientists' interaction. A positive ε reflects that gains could be made from the likes of absorptive capacities. A negative ε reflects potential losses from allowing scientists to interact and/or publish.

To ensure that the profit function is increasing in ϕ_i for all possible values of the parameters, we require that $\overline{\phi} > 1$, $\sqrt{\overline{\phi}} < \rho$ and $\varepsilon \in [-1,1]$. To guarantee the existence of an interior solution we must also have $\rho < \overline{\phi}$.

Finally firm *i*'s overall profits are given by

$$\Pi_i = e_F \pi_i - w_i, \quad (2)$$

where w_i is the wage that it pays the scientist.

We consider that the firm is able to commit to sharing part of the economic outcome with the scientist so that the wage comprises a fixed fee and a percentage of the profits as in Lacetera and Zirulia (2012) and Stern (2004):

$$w_i = t_i + e_F s_i \pi_i, \quad (3)$$

where $t_i \geq 0$ is the fixed fee and $s_i \in [0,1]$ is the percentage of profits paid to the scientist.

We now specify the objective functions for the scientists. We consider that scientists are risk neutral with respect to income so that the objective function of a scientist of ability ϕ_i is linear with respect to the wage and we have

$$U(\phi_i; e_F, e_P) = t_i + u(\phi_i; e_F, e_P), \quad (4)$$

where

$$u(\phi_i; e_F, e_P) = e_F s_i \pi_i + e_P \phi_i - \left[\frac{1}{2}(e_F^2 + e_P^2) - \gamma e_F e_P\right]. \quad (5)$$

The parameter $0 \leq \gamma < 1$ measures the extent to which research activities may be complementary. The higher γ is, the stronger the degree of *complementarity*. We assume that it is the same in both firms and for all scientists, as the size of this variable is more likely to be field dependent.

All scientists have the possibility to work in a university or research centre which gives them a reservation utility $\underline{U}(\phi)$. One potential advantage of working in a university or research centre is the presence of co-workers with similar ambitions and similar research agendas who can make contributions towards the scientist basic research. Specifically, we assume that the reservation utility is expressed as

$$\underline{U}(\phi; e_U) = \underline{w} - \frac{1}{2}e_U^2 + \sigma e_U \phi, \quad (6)$$

where $\underline{w} > 0$ is the wage paid in the university or research centre and σ measures the relative importance given to academic achievements in a more academic environment and e_U is the effort exerted by the scientist in the more academic environment. Clearly, it is optimal for the scientist to exert $e_U = \sigma\phi$ leading to

$$\underline{U}(\phi) = \underline{w} + \frac{1}{2}(\sigma\phi)^2. \tag{7}$$

It is worth emphasizing which variables shape the optimal contracts.:

- The *productivity effect* (as labelled in Stern (2004)) is embedded in $\pi(\phi_i, \phi_i\phi_j)$. The exogenous variable ρ determines the relevance of the productivity effect.
- The *externality effect* also embedded in $\pi(\phi_i, \phi_i\phi_j)$. The exogenous variable ε determines the relevance of the productivity effect.
- The *opportunity cost effect* is measured by $\frac{1}{2}(\sigma\phi_i)^2$ which gives the cost to the firm of deterring a scientist from joining a purely academic environment. The exogenous variable σ captures the importance of this effect.
- The *complementarity effect is* captured by $\gamma e_F e_P$. The exogenous variable γ captures the importance of this effect.

In Stern (2004) there is also a mention of the *preference effect* captured by $e_P\phi_i$ which symbolizes the fact that, by allowing the scientist to pursue her own research agenda, the scientist is willing to accept a lower wage. In Stern (2004) the variable ϕ_i is treated as exogenous and thus measures the impact of this effect. In our analysis this effect is endogenously determined. Thus it does not shape the contract per se.

4. OPTIMAL CONTRACTS WITH CONTRACTIBLE EFFORTS AND ABILITIES.

In this part we assume that each firm has the ability to verify how much effort the scientist dedicates to her own personal research agenda and the firm's research agenda. Moreover it can perfectly verify the scientists' abilities. In this case, the contract specifies the wage w_i, and effort levels (e_P^i, e_F^i) for each possible scientist's ability that it hires.

Firm i solves

$$\max_{w_i, \phi_i, (e_P^i, e_F^i),} \Pi_i = e_F^i \pi_i - w_i \tag{8}$$

subject to a participation constraint:

$$U(\phi_i; e_F^i, e_P^i) \geq \underline{U}(\phi_i) \tag{9}$$

where $\underline{U}(.)$ is given above, and the feasibility constraint:

$$\phi_i \leq \overline{\phi}. \tag{10}$$

Clearly, the fixed fee is set such that (9) holds with equality. It follows that the optimal effort levels must maximize

$$\Pi_i = (1 - s_i)e_F^i \pi_i + u(\phi_i; e_F, e_P) - \frac{1}{2}(\sigma\phi_i)^2 - \underline{w}. \tag{11}$$

Corollary 1: *When all variables are contractible, the share of the profits that the firm gives to the scientist (s_i) is irrelevant. For any $s_i \in [0,1]$ the firm adjusts the fixed fee so as to extract all surplus. The firm's overall profit remains unchanged.*

Lemma 1: *When contractible, the optimal effort levels are increasing with a scientist's ability as they are given by*

$$e_F^i = \frac{\pi_i + \gamma\phi_i}{1 - \gamma^2} \text{ and } e_P^i = \frac{\phi_i + \gamma\pi_i}{1 - \gamma^2}.$$

Proof: The solution is found by differentiating expression (11) above with respect to e_P^i and e_F^i and setting these equal to zero. For any $\gamma > 0$ the values above are always non-negative. It is straightforward to show that the Hessian matrix is negative definite provided $(1 - \gamma^2) > 0$ which holds for all $0 \leq \gamma < 1$ □

Proposition 1: Optimal hiring decisions.

Let $\hat{\sigma} = \sigma^2(1 - \gamma^2) - 1$ and $T^* = 2\,\hat{\sigma} - 3\gamma\varepsilon - \varepsilon^2$.

- *When $\sigma = 0$ and/or $T^* \leq 0$ investment in scientific research is maximized as both firms hire top academics: $\phi^* = \overline{\phi}$.*
- *When $T^* > 0$ the symmetric solution is $\phi^F = \min\{\phi^*, \bar{\phi}\}$ where*

$$\phi^* = \frac{\rho^2}{4}\left[\frac{3\gamma + 2\varepsilon + \sqrt{9\gamma^2 + 8\hat{\sigma}}}{2\hat{\sigma} - \varepsilon(\varepsilon + 3\gamma)}\right]^2. \tag{12}$$

Proof: See Appendix for details.

The first order condition with respect to the scientist's ability can be written as

$$\frac{\partial \Pi_i}{\partial \phi_i} = e_F^i \frac{\partial \pi_i}{\partial \phi_i} + e_P^i - \sigma^2\phi_i = 0, \tag{13}$$

where e_P^i and e_F^i are the efforts level are given in Lemma 1.

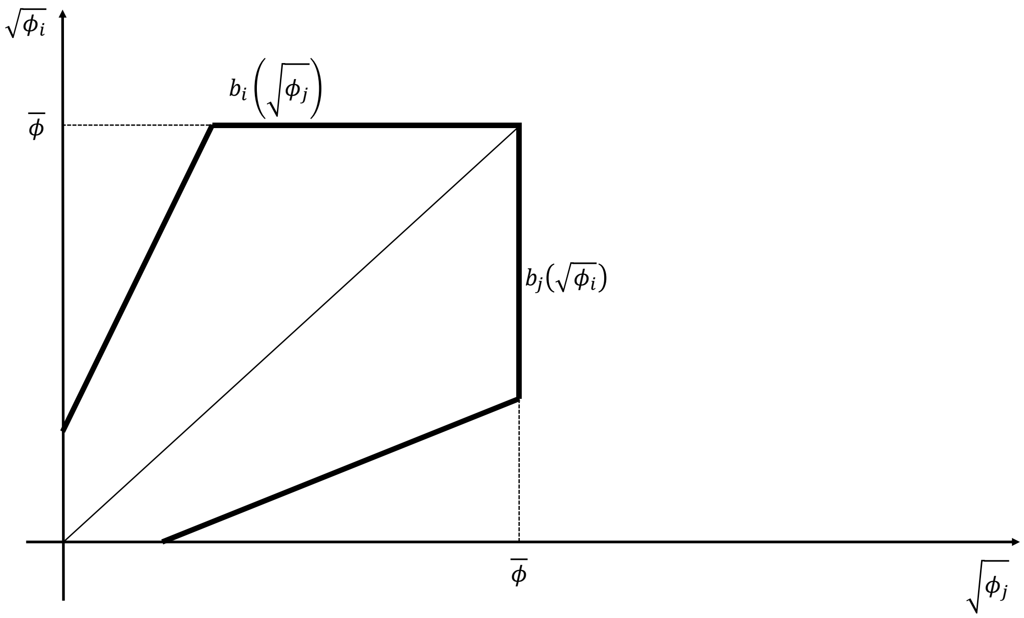
Clearly, when $\sigma = 0$ (no opportunity cost), each firm's dominant strategy consists in hiring a top academic, i.e. the scientist of the highest possible ability since $\frac{\partial \Pi_i}{\partial \phi_i} > 0$.

When the opportunity cost is not zero, the best reply function $\phi_i(\phi_j)$ is such that

$$\sqrt{\phi_i} = \frac{\left(\rho + \varepsilon\sqrt{\phi_j}\right)}{4\hat{\sigma}}\left[3\gamma + \sqrt{9\gamma^2 + 8\hat{\sigma}}\right] \tag{14}$$

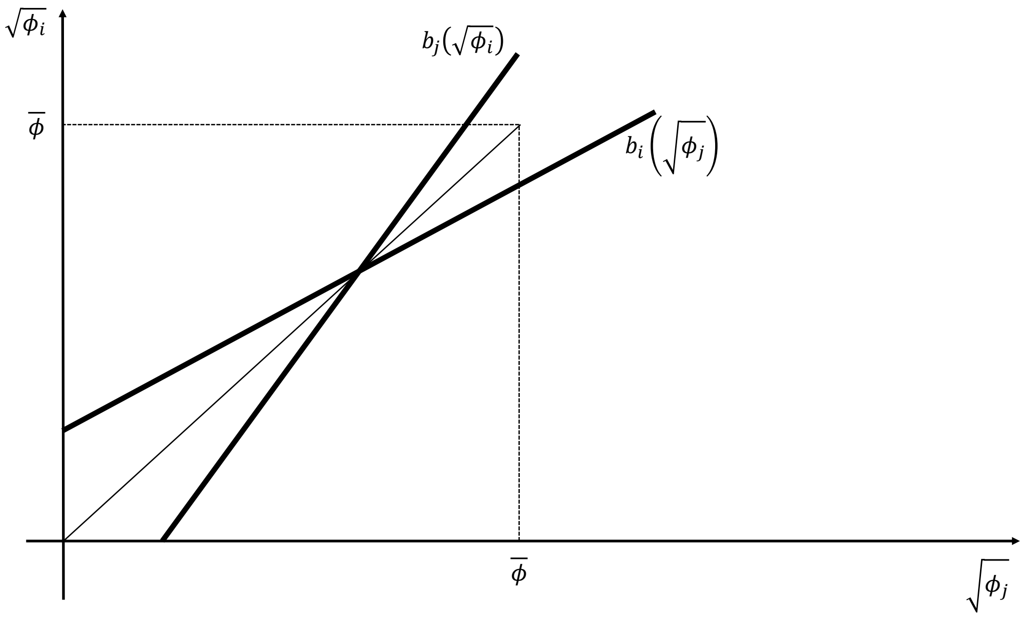
Whether hiring decisions are strategic substitutes or complements depends on ε and $\hat{\sigma}$. When $\sigma^2(1-\gamma^2)$ is large enough so that $\hat{\sigma} > 0$ then the externality determines whether they are strategic substitutes ($\varepsilon < 0$) or complements ($\varepsilon > 0$). They are independent when $\varepsilon = 0$.

When the hiring decisions are strategic complements, there may not always exist a symmetric interior solution. Indeed, if the slope of the reaction function is steeper than 1, then the best reply functions do not intersect. The graphs below illustrate the two possible outcomes that can occur in this case. In the situation below $T^* \leq 0$, firm *i*'s best reply function, $b_i\left(\sqrt{\phi_j}\right)$, has a slope greater than 1 and the equilibrium is for both to select the highest possible only because each firm's decision is eventually constrained so that the solution is determined by the feasibility condition.



Graph 1: Best reply functions when $T^* \leq 0$ (with positive externalities)

In the situation below, $T^* > 0$ and the two reaction functions intersect. The two firms may still hire the highest ability (if the intersection occurs where $\phi_i = \phi_j > \overline{\phi}$). But when T^* is large enough, we have an interior solution as depicted.



Graph 2: Best reply functions when $T^* > 0$ (with positive externalities).

When the hiring decisions are strategic substitutes, letting $\rho < \overline{\phi}$ guarantees that there exists a symmetric solution and it is given by (12). Note that, using the best reply function, we can also write ϕ^* as

$$\phi^* = \rho^2 \left[\frac{3\gamma + \sqrt{9\gamma^2 + 8\hat{\sigma}}}{4\hat{\sigma} - \varepsilon\left(3\gamma + \sqrt{9\gamma^2 + 8\hat{\sigma}}\right)} \right]^2. \qquad (15)$$

We can now perform some comparative statics to identify the factors that affect the firms' hiring decision.

- The *externality effect:* The firms will reduce their investment in academic science in the presence of a negative externality whereby the publications or any other academic work achieved can be used, detrimentally, by the rival firm. Under a positive externality, the firms have an incentive to invest more in academic research which suggests that the potential temptation for firms to free-ride on each other's hire does not apply here.

- The *complementarity effect* has a positive impact on the hiring decision. Greater values of γ are associated with a lower T^* and the equilibrium is more likely to be such that firms select $\overline{\phi}$. If we reach an interior solution, notice that ϕ^F is increasing in γ.
- The *productivity effect* has no impact on T^* but notice that the interior solution ϕ^F is increasing in ρ. The reason for this finding is straightforward. The case where $\rho = 0$ leads to a more complex analysis. On the one hand, it does not affect the outcome when $\sigma = 0$ meaning that the opportunity cost effect weights more than the productivity effect. On the other hand, notice that in the presence of negative externalities, the only equilibrium is $\phi^* = 0$. With positive externality, this equilibrium is dominated by hiring the scientist with the highest possible ability.
- Finally, the *opportunity cost effect* clearly leads to lower investment in science. The greater σ, the more likely it is that we have $T^* > 0$ and the interior solution ϕ^F is decreasing in σ.

We conclude from the analysis above that it is in the firms' interest to hire the scientist with the greatest academic ability unless the opportunity cost is sufficiently large.

Lemma 2 below examines the correlation between the wage and the scientist's ability. Since the participation constraint binds we have

$$w(\phi) = \underline{w} + C(e_F, e_P) - e_P\phi,$$

where $C(e_F, e_P) = \frac{1}{2}(e_F^2 + e_P^2) - \gamma e_F e_P$. Thus the wage increases with the efforts that are to be expended but decreases as the firms allow scientist to work on their agenda. The greater the scientist's ability the more efforts she is to exert but the more satisfaction they get from e_P so the greater the reduction in the wage. Hence the relationship between the wage and the ability is not straightforward.

Lemma 2: W*hen $\hat{\sigma} \geq 0$, the optimal wage increases with a scientist's ability. When $\hat{\sigma} < 0$, the wage is increasing with the scientist's ability provided the productivity effect is strong enough so that*

$$\frac{\partial \pi_i}{\partial \phi_i} > \frac{\phi_i}{\pi_i}.$$

Proof: In equilibrium the participation constraint binds and we have

$$w = \underline{w} + \frac{1}{2(1-\gamma^2)}[\hat{\sigma}\phi_i^2 + \pi_i^2].$$

The above is clearly increasing in ϕ_i when $\hat{\sigma} > 0$. But when we have $\sigma = 0$ and therefore $\hat{\sigma} = -1$, the above in increasing provided $[\pi_i^2 - \phi_i^2]$ is increasing.□

Thus, scientists do not always pay to be scientists. We can refine Stern's finding as we conclude that, *for given* efforts or workload, a scientist with a greater academic inclination will accept a lower wage when allowed to spend time on her agenda.

5. OPTIMAL CONTRACTS UNDER MORAL HAZARD

The question we address here is: how does the investment in scientific research when effort levels are not contractible and it is up to each scientist to decide how much effort she will exert for each of the activities.

Lemma 3: *The optimal effort levels are given by*

$$e_F^i = \frac{s_i\pi_i + \gamma\phi_i}{1-\gamma^2} \text{ and } e_P^i = \frac{\phi_i + \gamma s_i \pi_i}{1-\gamma^2}.$$

Proof: The solution is found by differentiating expression (5) above with respect to e_P^i and e_F^i when considering that the wage is given by (3). For any $\gamma > 0$ the values above are always non-negative. It is straightforward to show that the Hessian matrix is negative definite provided $(1-\gamma^2) > 0$ which holds for all $0 \leq \gamma < 1$. □

The firms can set the fixed fee such that the participation constraint holds and select the academic scientist with the degree of scientific ability that maximizes their profits subject to $\phi_i \leq \overline{\phi}$.

Proposition 2: Optimal contract under Moral Hazard

By making each scientist residual claimant of the profits ($s_i = 1$) *the firms can restore the first best and select an academic with the same scientific ability as the one chosen under perfect information.*

If the share of revenues it can share with the scientist is capped so that $s_i \leq \overline{s}$ for both firms, then let $T^{**} = 2\hat{\sigma} - 3\gamma\varepsilon - \overline{s}(2-\overline{s})\varepsilon^2$ where $\hat{\sigma} = \sigma^2(1-\gamma^2) - 1$.

- *When $\sigma = 0$ and/or $T^{**} \leq 0$ investment in scientific research is maximized as both firms hire top academics: $\phi^M = \overline{\phi}$.*
- *When $T^{**} > 0$ the symmetric solution is $\phi^M = \min\{\phi^{**}, \bar{\phi}\}$ where*

$$\phi^{**} = \frac{\rho^2}{4}\left[\frac{3\gamma + 2\overline{s}(2-\overline{s})\varepsilon + \sqrt{9\gamma^2 + 8\overline{s}(2-\overline{s})\hat{\sigma}}}{2\hat{\sigma} - \varepsilon(\overline{s}(2-\overline{s})\varepsilon + 3\gamma)}\right]^2. \tag{16}$$

Proof: See Appendix**.**

The rationale to understand the equilibrium decision is the same as before. When the opportunity cost is not nil the best reply function $\phi_i(\phi_j)$ is such that

$$\sqrt{\phi_i} = \frac{\left(\rho + \varepsilon\sqrt{\phi_j}\right)}{4\hat{\sigma}}\left[3\gamma + \sqrt{9\gamma^2 + 8\overline{s}(2-\overline{s})\hat{\sigma}}\right] \tag{17}$$

Clearly, when $\hat{\sigma} > 0$, the hiring decisions are strategic complements when $\varepsilon > 0$ and strategic substitutes otherwise as before.

Corollary 2: *Moral hazard is inconsequential when the firms can set $s_i = 1$ $(i = 1,2)$. When this is not possible, it leads to under-investment in science.*

Proof: We have $T^{**} \geq T^*$ and the equality hold for $\overline{s} = 1$ only. Therefore the range of variables for which the firms hire ability $\overline{\phi}$ is narrower under moral hazard. In other words, an interior solution is more likely to occur under moral hazard reflecting an under-investment in scientific research. Moreover, one can easily verify that $\phi^{**} \leq \phi^*$ when comparing (12) to (16) and the equality holds only for $\overline{s} = 1$. □

When the solution is interior, the optimal, symmetric, hiring decision is such that

$$e_F \left.\frac{\partial \pi_i}{\partial \phi_i}\right|_{\phi_i=\phi_j=\phi^{**}} + e_p - \sigma^2\phi^{**} + (1-\overline{s})\pi(.)\left.\frac{de_F^i}{d\phi_i}\right|_{\phi_i=\phi_j=\phi^{**}} = 0, \tag{18}$$

where

$$e_F = \frac{\overline{s}\pi^{**} + \gamma\phi^{**}}{1-\gamma^2} \text{ and } e_P = \frac{\phi^{**} + \gamma\overline{s}\pi^{**}}{1-\gamma^2},$$

where $\pi^{**} = \pi(\phi^{**}, \phi^{**}\phi^{**})$.

Interestingly notice that the last term in (18) is non-negative when $\bar{s} < 1$. This last term accounts for benefits of selecting a scientist with a greater ability. Indeed it incorporates the fact that a scientist with a greater ability will exert more effort towards her own research, but also the firm's research agenda.

The conclusion from this short section is that moral hazard has very little impact if any. Importantly, when the opportunity cost is nil, the firms still opt for a scientist with the highest academic ability even when they cannot make them residual claimants.

When the firms are able to make the scientist residual claimant of the entire value she creates, which may be more common in large firms, the symmetric information solution can be implemented. A situation that may arise when the firm is a spin-off created by the firm, or when the scientist is given stock options in start-ups.

Finally, in equilibrium the participation constraint binds and we have

$$w = \underline{w} + \frac{1}{2(1-\gamma^2)}[\hat{\sigma}\phi_i^2 + (\bar{s}\pi_i)^2].$$

Thus, compared to the symmetric information case, scientists are more likely to pay to be scientists under moral hazard when $\bar{s} < 1$.

6. OPTIMAL CONTRACTS UNDER ADVERSE SELECTION

So far we considered that the scientist's ability was verifiable. This can be motivated by the fact that the quality of academic achievements, such as publications, is observable, so that firms can hire academics of higher or lower prestige. However, if we consider that ϕ is more representative of a *taste* for science, this variable is not necessarily observable and certainly more difficult to verify. In this section we assume that scientific ability is not contractible. We do not remove the assumption that there are many scientists of a given scientific ability meaning that the firms can issue a single contract aiming at a particular type of scientist. Finally we assume that efforts are verifiable but consider the case where these are not in an extension.

Let us consider the problem of a firm who wants to contract a scientist of given ability $\hat{\phi}$. It issues a contract which specifies the wage $\hat{w}$, and the effort levels that it wants the scientist to exert $e_k(\hat{\phi})$ with $k = P, F$.

It must ensure that the scientist of ability $\hat{\phi}$ accepts the contract. This is true provided

$$\hat{w} + e_P(\hat{\phi})(\hat{\phi}) - C(\hat{\phi}) \geq \underline{U}(\hat{\phi}), \tag{19}$$

where $C(\hat{\phi}) = \left[\frac{1}{2}\left(\left(e_F(\hat{\phi})\right)^2 + \left(e_P(\hat{\phi})\right)^2\right) - \gamma e_F(\hat{\phi}) e_P(\hat{\phi})\right]$.

It must also ensure that scientists with different tastes of science do not apply:

$$\hat{w} + e_P(\hat{\phi})(\phi') - C(\hat{\phi}) \leq \underline{U}(\phi'), \tag{20}$$

for any other $\phi' \neq \hat{\phi}$. Notice that the cost $C(\hat{\phi})$ is the same as above because it depends not on the scientist's ability but on the level of efforts that are to be exerted.

4.1. No opportunity cost: σ = 0.

When $\sigma = 0$ and all variables are contractible, the firms hire the scientist with the strongest taste for science $\hat{\phi} = \overline{\phi}$.

Lemma 4: *The symmetric information contract is incentive compatible when $\sigma = 0$ and $\phi^* = \bar{\phi}$.*

Proof: Consider that each firm issues a contract such that

$$\overline{e}_F = \frac{\overline{\pi} + \gamma\overline{\phi}}{1-\gamma^2} \text{ and } \overline{e}_P = \frac{\overline{\phi} + \gamma\overline{\pi}}{1-\gamma^2}$$

where $\overline{\pi} = \rho\sqrt{\overline{\phi}} + \varepsilon\overline{\phi}$ and such that the wage $\overline{w}$ is such that

$$\overline{w} + e_P(\bar{\phi})(\bar{\phi}) - C(\bar{\phi}) = \underline{w}. \tag{21}$$

Then clearly, any scientist with a lesser taste for science would get strictly less than $\underline{w}$ should she accept the same contract since we have

$$U(\phi) = \underline{w} - \overline{e}_P(\overline{\phi} - \phi) < \underline{w}.$$

As a result, the top academic is hired and we have no distortion of the surplus.□

The above lemma follows directly from the observation made in Stern (2004) according to which a scientist with a taste for science is willing to accept a lower wage provided she is allowed to publish. Thus, for a given workload, scientists with a high ability are rather tempted to downplay their passion for academic research. Said differently, if the symmetric information contract is issued (described in the proof above), it will only appeal to the highest type as any other type consider the wage to be too low.

More importantly however, the above result reinforces the fact that the opportunity cost, measured via a type dependent utility, is a key variable that affects the firms' hiring decisions.

4.2. Positive opportunity cost: σ > 0.

In this case, even if $\phi^F = \bar{\phi}$, the reason why the first best contract may no longer be optimal is that it is not necessarily incentive compatible as a positive opportunity cost generates a countervailing incentive. Indeed, while a scientist with a lower ability gets a lower utility from the same contract, she also has a lower reservation utility and therefore may apply for the research position in the firm. Hence, we must characterize the condition that guarantees incentive compatibility for all possible targeted types, including $\bar{\phi}$.

Proposition 3: Incentive compatibility.

To ensure that the contract will attract scientists with specific ability $\hat{\phi} \leq \overline{\phi}$ the firm must impose

$$e_P(\hat{\phi}) = \sigma^2(\hat{\phi}). \tag{22}$$

The more academically oriented the scientist, the greater the time the firm has to allow her to spend on her own research agenda.

Proof: The participation constraint (19) can bind due to the fact that there should be no need to leave rents to the scientist in an environment where there are many of them. Then, (20) holds provided

$$e_P(\hat{\phi})(\hat{\phi} - \phi') \geq \frac{1}{2}\sigma^2(\hat{\phi} - \phi')(\hat{\phi} + \phi'). \tag{23}$$

Thus, to deter scientists with a lesser taste for science $(\phi' < \hat{\phi})$ the firm must implement $e_P(\hat{\phi}) \geq \frac{1}{2}\sigma^2(\hat{\phi} + \phi')$. If, in particular, it imposes $e_P(\hat{\phi}) = \sigma^2(\hat{\phi})$ then the inequality is satisfied for any $\phi' < \hat{\phi}$.

To deter scientists with a greater taste for science $(\hat{\phi} < \phi')$ the firm must implement $e_P(\hat{\phi}) \leq \frac{1}{2}\sigma^2(\hat{\phi} + \phi')$. If, in particular, it imposes $e_P(\hat{\phi}) = \sigma^2(\hat{\phi})$ then the inequality is satisfied for any $\phi' > \hat{\phi}$.□

An alternative approach to characterize incentive compatible contracts consists in using the envelope theorem. Let the effort levels required when the scientists reveals to be of ability $\tilde{\phi}$ be given by $\tilde{e}_P \equiv e_P(\tilde{\phi})$ and $\tilde{e}_F \equiv e_F(\tilde{\phi})$ and let the wage be such that $\widetilde{w} \equiv t_i + e_F(\tilde{\phi})s_i\pi_i(\tilde{\phi}, \phi_j)$. Given these, the utility of the scientist becomes effectively a function of the true ability ϕ and the revealed ability $\tilde{\phi}$:

$$U(\phi, \tilde{\phi}) = \widetilde{w} + \tilde{e}_P\phi - C(\tilde{\phi}). \tag{24}$$

where $C(\tilde{\phi}) = \left[\frac{1}{2}((\tilde{e}_F)^2 + (\tilde{e}_P)^2) - \gamma\tilde{e}_F\tilde{e}_P\right]$.

Under incentive compatibility the scientist finds it optimal to reveal her true ability so that $\tilde{\phi} = \phi$ and, by the envelope theorem, we have

$$\frac{dU(\phi, \tilde{\phi})}{d\phi} = \left.\frac{\partial U(\phi, \tilde{\phi})}{\partial \phi}\right|_{\tilde{\phi}=\phi} = \left.\frac{\partial u(\phi, \tilde{\phi})}{\partial \phi}\right|_{\tilde{\phi}=\phi} = e_P(\phi). \tag{25}$$

Moreover, when the participation constraint binds we must have

$$\frac{dU(\phi, \tilde{\phi})}{d\phi} = \frac{d\underline{U}(\phi)}{d\phi}. \tag{26}$$

So that increases in the utility from accepting the job match increases in the reservation utility but not more. Expressions (25) and (26) lead us to (22).

Proposition 3 helps us uderstand the strategy of some working places where scientists with a greater taste for science are explicitly allowed to pursue their own private research agenda.

To characterize the optimal hiring decision, each firm maximizes (11) subject to the additional constraint $e_P(\hat{\phi}) = \sigma^2(\hat{\phi})$. Notice that, in absence of moral hazard, the parameter s_i is irrelevant.

Proposition 4: Optimal hiring decisions under adverse selection (when σ > 0).

Let $\hat{\sigma} = \sigma^2(1-\gamma^2) - 1$ *and* $T^{***} = 2\,\hat{\sigma}\sigma^2 - 3\gamma\sigma^2\varepsilon - \varepsilon^2$*.*

- *When* $\sigma = 0$ *and/or* $T^{***} \leq 0$ *investment in scientific research is maximized as both firms hire top academics:* $\phi^* = \overline{\phi}$*.*
- *When* $T^{***} > 0$ *the symmetric solution* $\phi^A = \min\{\phi^{***}, \bar{\phi}\}$ *where*

$$\phi^{***} = \frac{\rho^2}{4}\left[\frac{3\gamma\sigma^2 + 2\varepsilon + \sqrt{9\gamma^2\sigma^2 + 8\hat{\sigma}}}{2\hat{\sigma}\sigma^2 - \varepsilon(\varepsilon + 3\gamma\sigma^2)}\right]^2. \tag{27}$$

Proof: See Appendix.

When the opportunity cost is not zero, the best reply function $\phi_i(\phi_j)$ is such that

$$\sqrt{\phi_i} = \frac{\left(\rho + \varepsilon\sqrt{\phi_j}\right)}{4\hat{\sigma}\sigma}\left[3\gamma\sigma + \sqrt{9\gamma^2\sigma^2 + 8\hat{\sigma}}\right] \tag{28}$$

Once again the hiring decisions may be strategic complements or strategic substitutes. Note that, using the best reply function, we can also write ϕ^{***} as

$$\phi^{***} = \rho^2\left[\frac{3\gamma\sigma + \sqrt{9\gamma^2 + 8\hat{\sigma}}}{4\hat{\sigma}\sigma - \varepsilon\left(3\gamma\sigma + \sqrt{9\gamma^2 + 8\hat{\sigma}}\right)}\right]^2. \tag{29}$$

Notice that we have $T^{***} = \sigma^2 T^* + (\sigma^2 - 1)\varepsilon^2$. Since we necessarily have $(\sigma^2 - 1) > 0$ for the solution to be interior when all variables are contractible (no moral hazard), we can deduce that: when $\phi^F = \phi^*$ we necessarily have an interior solution under adverse selection.

What is more interesting is the fact that, under adverse selection, the opportunity cost effect does not impact the decision via the same channel. Indeed, taking into account the fact that the participation constraint binds, firm i selects a scientist with a given ability so as to maximise

$$\Pi_i = e_F^i \pi_i + e_P(\phi_i)\phi_i - C(e_F, \phi_i) - \frac{1}{2}(\sigma\phi_i)^2 - \underline{w}. \tag{30}$$

where $C(e_F, \phi_i) = \left[\frac{1}{2}\left(\left(e_P(\phi_i)\right)^2 + e_F^2\right) - \gamma e_P(\phi_i) e_F\right]$.

The first order condition with respect to the scientist's ability is given by

$$\frac{\partial \Pi_i}{\partial \phi_i} = e_F^i \frac{\partial \pi_i}{\partial \phi_i} + [e_P(\phi_i) - \sigma^2 \phi_i] + \phi_i \frac{d e_P(\phi_i)}{d \phi_i} - \frac{\partial C(e_F, \phi_i)}{\partial \phi_i} = 0. \quad (31)$$

Notice that, under incentive compatibility and voluntary participation, the second term, which is usually negative, vanishes. Therefore the opportunity cost effect which drove the investment decision down no longer influences the hiring decision via a different channel. The greater σ is, the more time the scientists must spend on their own agenda, which, as the corollary below shows, induces a greater loss for the firms.

Corollary 3: *Under adverse selection, any interior solution is supported by the fact that incentive compatibility requires that the firms set* e_P *beyond what the scientist would choose for herself.*

Proof: the first order condition can also be written as

$$\frac{\partial \Pi_i}{\partial \phi_i} = e_F^i \frac{\partial \pi_i}{\partial \phi_i} + [e_P(\phi_i) - \sigma^2 \phi_i] + \frac{\partial u(\phi_i; e_F, e_P)}{\partial e_P} \frac{d e_P(\phi_i)}{d \phi_i} \phi_i = 0. \quad (32)$$

Given that the second term vanishes under incentive compatibility, we can only have an interior solution provided the last term is non-positive so that

$$\left. \frac{\partial u(\phi_i; e_F, e_P)}{\partial e_P} \right|_{e_P = \sigma^2 \phi_i} < 0. \quad (33)$$

The firms request that scientists spend too much time on their own research agenda.□

When we have an interior solution, one can show that $\phi^{***} \leq \phi^*$. The reason firms under-invest is because they each have to implement higher levels of efforts to guarantee that the contract they issue is incentive compatible. Specifically we have (see Appendix)

$$e_F = \pi^{***} + \gamma \sigma^2 \phi^{***} \text{ and } e_P = \sigma^2 \phi^{***},$$

where $\pi^{***} = \pi(\phi^{***}, \phi^{***} \phi^{***})$.

As shown in Appendix the first order condition with respect to e_F is similar to the one reached under symmetric information. However, since the level of effort e_P is increased, so is e_F. To reduce the cost incurred from implementing levels of efforts that are too large, the firms select a scientist with a lower profile.

Finally, we consider the wage paid to the scientists.

Lemma 5: *Under adverse selection the wage is increasing with the scientist's ability*.

Proof: In equilibrium the participation constraint binds and we have

$$w = \underline{w} + \frac{1}{2}[\hat{\sigma}\sigma^2\phi_i^2 + \pi_i^2].$$

The above is clearly increasing in ϕ_i even when $\sigma = 0$.□

The reason the wage is now increasing with the ability has to do with the fact that the higher the type, the more time the scientist must be allowed to spend on her agenda (as well as the firm's agenda) and the greater the compensation she must receive for doing so.

7. EXTENSIONS

7.1 Adverse selection and moral hazard.

When each hiring firm faces both moral hazard and adverse selection, it must decide on the optimal contract anticipating the effort levels and using the incentive compatibility constraint. When the firms seek to hire the scientists with the highest possible ability little distortion is introduced unless the share of the profits they can give the scientist is capped. Indeed, recall from the previous section that incentive compatibility is not an issue for the top academics.

Proposition 6: Optimal hiring decisions under adverse selection and moral hazard.

When the firms face both moral hazard and adverse selection, they systematically over-invest and seek to hire scientists with the highest ability because they face no opportunity cost.

Proof: In such a scenario the firms solve the following problem. Each firm sets the wage and selects a scientist's ability so as to maximise (11) subject to all of the incentive constraints:

$$e_F = \frac{s_i\pi_i + \gamma\phi_i}{1-\gamma^2} \text{ and } e_P = \frac{\phi_i + \gamma s_i\pi_i}{1-\gamma^2}$$
$$\text{and } e_P = \sigma^2\phi_i.$$

The three constraints must hold which implies that all decision variables are dependent on ϕ_i. The optimal transfer is such that the participation constraint binds. The optimal share of profits given to the scientist is such that

$$e_P = \frac{\phi_i + \gamma s_i\pi_i}{1-\gamma^2} = \sigma^2\phi_i. \quad (34)$$

We then have

$$\frac{d\Pi_i}{d\phi_i} = (1-s_i)\pi_i\frac{de_F}{d\phi_i} + e_F(1-s_i)\frac{\partial\pi_i}{\partial\phi_i} - \frac{ds_i}{d\phi_i}e_F\pi_i + \frac{\partial u}{\partial\phi_i} + \frac{\partial u}{\partial s_i}\frac{ds_i}{d\phi_i} - \sigma^2\phi_i. \quad (35)$$

Since $\frac{\partial u}{\partial\phi_i} = e_P = \sigma^2\phi_i$ under incentive compatibility and given further simplifications, we are left with

$$\frac{d\Pi_i}{d\phi_i} = (1-s_i)\pi_i\frac{de_F}{d\phi_i} + e_F(1-s_i)\frac{\partial\pi_i}{\partial\phi_i} > 0. \quad (36)$$

Thus each firm seeks to hire the scientists with the highest profile.

7.2. Effort allocation.

One may suggest that the reason why it is optimal for the firms to select the scientist with the highest possible ability when there is no opportunity cost effect has to do with the fact that total effort is not constrained. If it were, one may argue that hiring a top academic is detrimental for the firms for she will spend too much effort on her own academic research agenda and not enough on the firm's. This reasoning is not always correct as shown below.

Corollary 4: *When all variables are contractible, if we considered that the overall effort was constrained such that* $e_F + e_P = \bar{e}$*, the firms would still hire the scientists of the highest ability when* $\sigma = 0$*. Under moral hazard, whereby the firms lose control of the effort allocation, the same result remains valid when the scientist is made residual claimant of the value she generates.*

Proof: It is straightforward to show that, when all variables are contractible we have

$$\frac{\partial \Pi_i}{\partial \phi_i} = e_F \frac{\partial \pi_i}{\partial \phi_i} + (\overline{e} - e_F) > 0. \tag{40}$$

Under moral hazard, it is true that e_F is potentially decreasing with the scientist's ability since we have

$$e_F = \frac{\pi_i - \phi_i + (1+\gamma)\overline{e}}{2(1+\gamma)}. \tag{41}$$

However, when the scientist is residual claimant of the value she generates we still have

$$\frac{\partial \Pi_i}{\partial \phi_i} = \frac{\partial u(\phi_i; e_F, e_P)}{\partial \phi_i} > 0. \tag{42}$$

Thus we conclude that our finding according to which the opportunity cost effect is a determinant one, is quite robust.

8. CONCLUSIONS

In this paper we investigate the firms' decision to invest in science. This could be understood as a decision to build a more "academic" environment in a context where firms do not directly benefit from the time scientists dedicate to academic research.

The paper allows for type dependent reservation utilities, which reflects the fact that not all scientists have access to the same alternative. Remaining in a more academic environment provides an outside option whose value can be increasing in their ability to publish. As there are many scientists, firms do not really compete for one specific person and instead view their objective as having to deter one of them from remaining in academia.

We show that the relative opportunity cost incurred by the firms which must offer a wage that compensates the scientist from not getting what he would get in academia is tempered by the fact that a higher ability will expect a lower wage provided she can work on her agenda, consistently with the preference effect in Stern (2004). This result can be extrapolated as we argue then that "creating a more academic environment" in industries will go a long way into making the academic sector relatively less attractive which will allow further reduction in the wage for researchers with a taste for science.

The paper then brings to light the factors that impact the decision of the firms' to invest in science. These are not always what may come to mind. And when they are, it may not be for the reasons one has in mind.

Moral hazard which means that the firm loses control of how the scientists spend their time is not a deterrent per se. It is a deterrent when the firms cannot make scientists residual claimant. So the loss in welfare is due to contracting issues rather than the presence of moral hazard.

Adverse selection is a deterrent but only in the presence of an opportunity cost reflecting the fact that the reservation utility is positively correlated to the type. With no opportunity cost, a scientist has no incentive to claim that she enjoys academic research more than what she actually does as doing so would only decrease her wage since the firm would over-estimate the utility she gathers from spending time on her own research. Thus, in this case, the first best which consists in hiring the academic with the highest ability, can be implemented at no cost. When there is an opportunity cost a countervailing incentive arises that induces the necessity for the firm to address incentive compatibility. By overstating their interest for basic science, the scientists also claim that their outside options are better than what they are and therefore they put upward pressure on the wage. Incentive compatibility is achieved by imposing that scientists spend an amount of time on basic research that is increasing with their academic ability. In fact, scientists have to spend more time on their own research than the amount they would choose in their own interest. Thus, under positive opportunity costs, adverse selection triggers an excessive workload which puts pressure on the wage and leads firms to reduce their investment in science.

APPENDIX

Proof of Proposition 1:

Firm i ($i = 1,2$) selects ability ϕ_i that maximizes (11). The first order condition with respect to the scientist's ability is given by

$$\frac{\partial \Pi_i}{\partial \phi_i} = e_P^i + e_F^i \frac{\partial \pi_i}{\partial \phi_i} - \sigma^2 \phi_i = 0, \tag{A1}$$

where the efforts level are given in Lemma 1.

Clearly, when $\sigma = 0$ we have $\frac{\partial \Pi_i}{\partial \phi_i} > 0$ so that it is optimal for each firm to select the scientist with highest possible ability.

When σ is non-zero, the Hessian matrix associated with the maximization of profits with respect to the effort levels and the parameter ϕ_i is given by

$$H = \begin{bmatrix} -1 & \gamma & \pi_i' \\ \gamma & -1 & 1 \\ \pi_i' & 1 & \Pi_i'' \end{bmatrix} \tag{A2}$$

where $\pi_i' = \frac{\partial \pi_i}{\partial \phi_i}$ and $\Pi_i'' = e_F^i \frac{\partial^2 \pi_i}{\partial \phi_i^2} - \sigma^2$. Clearly, the matrix above is negative definite provided its determinant is non-positive.

Given the fact that $\pi_i = \sqrt{\phi_i}\left(\rho + \varepsilon\sqrt{\phi_j}\right)$ we have

$$\pi_i = -4\phi_i^2 \frac{\partial^2 \pi_i}{\partial \phi_i^2}, \tag{A3}$$

and

$$\frac{\partial \pi_i}{\partial \phi_i} = -2\phi_i \frac{\partial^2 \pi_i}{\partial \phi_i^2}. \tag{A4}$$

Given the above, and the first order condition, one can show that determinant of the matrix H can be written as

$$\det H = \frac{\partial^2 \pi_i}{\partial \phi_i^2} [4\pi_i + 3\gamma \phi_i] < 0 \tag{A5}$$

since $\frac{\partial^2 \pi_i}{\partial \phi_i^2} < 0$. Hence the matrix H is negative definite.

While the objective function is concave, we may not have an interior solution. We give, in the text, the best reply function and explain what condition must be satisfied for a symmetric interior solution to exist. When it does exist we have $\phi_i = \phi_j = \phi^*$ which solves

$$\left(2\,\hat{\sigma} - \varepsilon(\varepsilon + 3\gamma)\right)\phi^* - \rho\sqrt{\phi^*}(3\gamma + 2\varepsilon) - \rho^2 = 0. \tag{A6}$$

Notice that the above equation has no real solution when $T^* = 2\,\hat{\sigma} - \varepsilon(\varepsilon + 3\gamma) < 0.$□

Proof of Proposition 2:

It is straightforward to understand that the first best can be achieved by setting $s_i = s_j = 1$.

When this is not possible, the proof follows the same logic as that of Proposition 1. The first order condition with respect to the scientist's ability is given by

$$\frac{d\Pi_i}{d\phi_i} = e_F^i \frac{\partial \pi_i}{\partial \phi_i} + e_P^i - \sigma^2 \phi_i + (1 - s_i)\pi_i \frac{de_F^i}{d\phi_i} = 0, \tag{A7}$$

where the effort levels are given in Lemma 2.

To satisfy the second order condition we must have

$$\frac{3\gamma}{4\sqrt{\phi_i}}\left(\rho + \varepsilon\sqrt{\phi_j}\right) - \hat{\sigma} < 0. \tag{A8}$$

Using the best reply function we can substitute $\left(\rho + \varepsilon\sqrt{\phi_j}\right)$ in the above which leads to

$$-\frac{\hat{\sigma}\sqrt{9\gamma^2 + 8\bar{s}(2 - \bar{s})\hat{\sigma}}}{3\gamma + \sqrt{9\gamma^2 + 8\bar{s}(2 - \bar{s})\hat{\sigma}}} < 0 \tag{A9}$$

which is always true

Finally, while the objective function is concave, we may not have a symmetric interior solution for the same reason as those given in the explanation of Proposition 1. When it does exist we have $\phi_i = \phi_j = \phi^{**}$ which solves

$$\left(2\,\hat{\sigma} - \varepsilon(\bar{s}(2 - \bar{s})\varepsilon + 3\gamma)\right)\phi^{**} - \rho\sqrt{\phi^{**}}\left(3\gamma + 2\varepsilon\bar{s}(2 - \bar{s})\right) - \bar{s}(2 - \bar{s})\rho^2 = 0. \tag{A10}$$

Notice that the above equation has no real solution when $T^{**} = 2\,\hat{\sigma} - \varepsilon(\bar{s}(2 - \bar{s})\varepsilon + 3\gamma) < 0.$□

Proof of Proposition 4:

Firm i $(i = 1,2)$ selects a scientist of ability ϕ_i who maximizes (11) subjects to the additional constraint $e_P(\phi^*) = \sigma^2(\phi^*)$. As we replace $e_P(.)$, the first order conditions with respect to e_F and ability are given by

$$\frac{\partial \Pi_i}{\partial e_F} = \pi_i - e_F^i + \gamma\sigma^2\phi_i = 0 \tag{A11}$$

and

$$\frac{\partial \Pi_i}{\partial \phi_i} = e_F^i \frac{\partial \pi_i}{\partial \phi_i} + \gamma\sigma^2 e_F^i - \sigma^2(\sigma^2 - 1)\phi_i = 0. \tag{A12}$$

The Hessian matrix associated with the maximization of profits with respect to the effort levels and the parameter ϕ_i is given by

$$H = \begin{bmatrix} -1 & \pi_i' + \gamma\sigma^2 \\ \pi_i' + \gamma\sigma^2 & \Pi_i'' \end{bmatrix} \tag{A13}$$

where $\pi_i' = \frac{\partial \pi_i}{\partial \phi_i}$ and $\Pi_i'' = e_F^i \frac{\partial^2 \pi_i}{\partial \phi_i^2} - \sigma^2(\sigma^2 - 1)$. Clearly, the matrix above is negative definite provided its determinant is non-negative.

Given the first order condition and the fact that $\pi_i = \sqrt{\phi_i}\left(\rho + \varepsilon\sqrt{\phi_j}\right)$ one can show that determinant of the matrix H can be written as

$$\det H = 2(\pi_i')^2 > 0. \tag{A14}$$

Hence the matrix H is negative definite.

Finally, while the objective function is concave, we may not have a symmetric interior solution for the same reason as those given in the explanation of Proposition 1. When it does exist we have $\phi_i = \phi_j = \phi^{***}$ which solves

$$\left(2\,\hat{\sigma}\sigma^2 - \varepsilon(\varepsilon + 3\gamma\sigma^2)\right)\phi^{***} - \rho\sqrt{\phi^{***}}\,(3\gamma\sigma^2 + 2\varepsilon) - \rho^2 = 0. \tag{A15}$$

Notice that the above equation has no real solution when

$$T^{***} = 2\,\hat{\sigma}\sigma^2 - \varepsilon(\varepsilon + 3\gamma\sigma^2) < 0.$$

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